LEONARDO DA VINCI · THE ANATOMIST

1452 - 1519

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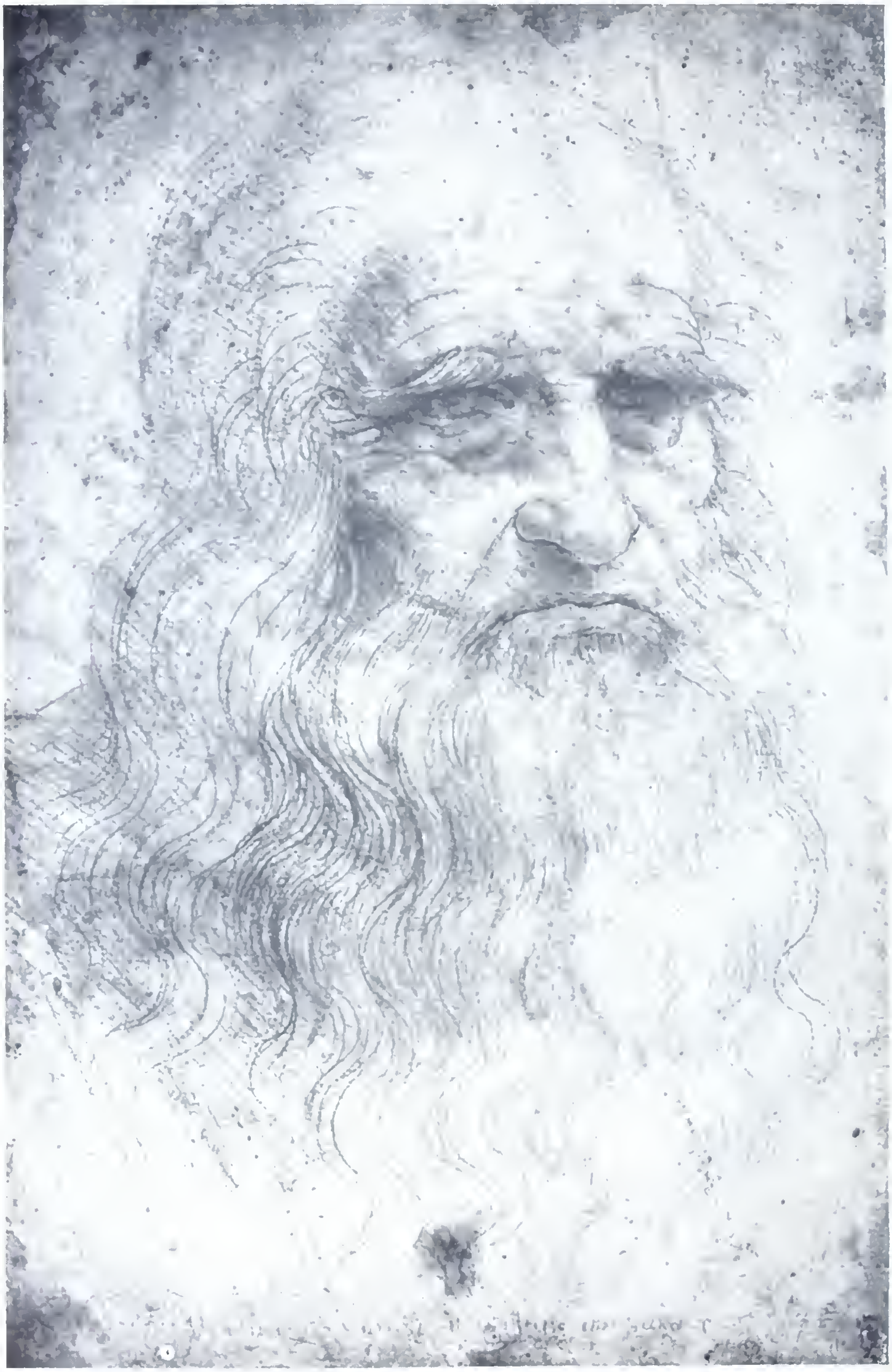
LEONARDO DA VINCI

THE ANATOMIST

BY

J. PLAYFAIR McMURRICH



Portrait of Leonardo da Vinci, probably by himself. Royal Palace, Turin (Anderson).

LEONARDO DA VINCI
THE ANATOMIST
(1452-1519)

BY

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Professor of Anatomy, University of Toronto

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AUTHOR'S PREFACE

In attempting to evaluate even one only of the activities of so many-minded a man as Leonardo da Vinci, one is, perforce, led far afield beyond the topics that are of immediate concern, in order that one may endeavor to see these in their proper environment and perspective. The friends who have aided me in these extra-territorial studies have been many, too many to mention individually, but to one, Dr. George Sarton, I am especially indebted. It was at his suggestion that I undertook the study, of which what follows is the result, and throughout its progress his thorough knowledge and clear understanding of the history of mediaeval and Renaissance science have always been at my disposal. He also kindly undertook the preparation of the photographs required for the illustrations, many of these being taken from works in his own library, others from volumes in the Harvard Library and the Boston Medical Library.

To these two libraries I wish to express thanks for the courtesies afforded and I also desire to make grateful acknowledgments to the Library of the University of Toronto, the Toronto Public Reference Library, the Library of the British Museum, and the London Library for the opportunities and privileges granted for the study of the works of Leonardo in their possession. The Leonardo drawings have been reproduced from the facsimile editions enumerated in the bibliography at the end of this volume, except three of them derived from photographs of the firm D. Anderson of Rome. Some pre-Leonardian documents have been borrowed from the publications of Karl Sudhoff and Charles Singer, whose courtesy is appreciated. More specific acknowledgments will be found in the list of illustrations below. Finally I am deeply indebted to Dr. R. K. George for assistance in proof-reading and for the preparation of the index.

J. Playfair McMurrich

University of Toronto
December 16, 1929

PREFACE

It is always useful to place a work in its historical perspective. The reader's interest in it is awakened or increased as soon as he knows its genesis and development. This preface is primarily meant to gratify such legitimate curiosity. The fact that I can not speak of the genesis of Dr. McMurrich's work without speaking of my own studies will not be brought against me, I hope. It can not be helped.

When I was appointed Associate in the History of Science by the Carnegie Institution of Washington in 1918, I undertook to make a thorough study of Leonardo's thought.[1] However, I soon realized that a proper appreciation of it would be impossible without a deep and accurate knowledge of mediaeval science. To measure Leonardo's originality it was necessary to be able to distinguish the mediaeval elements which he had assimilated. But was it expedient to include these mediaeval investigations, which are almost endless, in a history of Leonardo's thought? Was it wise to write a history of mediaeval science around his own personality? After all, however mediaeval Leonardo had remained, the Middle Ages were one thing and Leonardo was another. It was better not to mix the two stories. The example unconsciously given by the great French scholar, Pierre Duhem, was a good warning. His *Etudes sur Léonard de Vinci* (3 vols., Paris, 1906–1913) were really misnamed. Duhem devoted considerably more space to mediaeval than to Leonardian thought. This seemed to me a bad method. It would be at once simpler and more rigorous to make as complete an inventory of mediaeval knowledge as possible, studying each layer of it independently and in due succession. Thus would we know how much knowledge each age had added to that of the preceding ones, and when Leonardo's age would finally be reached, the analysis of his own thought would become relatively easy. I foolishly thought that the making of that inventory—the drawing of that intellectual map of the Middle Ages—would take only a couple of years. That was in 1918–19. I am writing this in August 1929, more than ten years later, and I know that many more years will elapse before the task is completed and Leonardo finally overtaken.

To return to the present work, I realized happily at the very beginning that there was a part of Leonardo's activity, a major part, for which the investigation of mediaeval sources was relatively simpler and less essential, than was Leonardo's anatomy. Whatever Leonardo had learned from books, it is clear that the mainspring of his anatomical

[1] Carnegie Inst. Wash. Year Book No. 18, 1919, 347–349.

knowledge was to be found in his own autopsies. In this field as opposed to others (*e.g.*, mechanics, optics, geology) once that the need of direct observation had been really understood—and this was on the whole Leonardo's outstanding contribution, the source of every one of his discoveries—the observations themselves were relatively easier. Anatomical facts are more tangible than geological and mechanical facts. It is not necessary to isolate them from others; they are already isolated. This does not mean that anatomical observations were easy, far from it, but the program of observation was more obvious in this field than in any other, and the harvest more abundant. Thus with regard to Leonardo's anatomy, the general procedure might reasonably be reversed. Instead of studying the past first, and climbing up to Leonardo, century by century, year by year, it would be legitimate in this case to begin by investigating his drawings and comparing them with the anatomical realities. However, this could be done only by a professional anatomist. Leonardo's drawings could not be understood nor their genuineness and correctness appreciated except by one thoroughly familiar with the objects represented. A theoretical knowledge of anatomy was in itself insufficient for such a task. The historian must be able to visualize the anatomical details which the artist interpreted—remember, a drawing is always an interpretation—he must be able to recall their very appearance under similar conditions.

This situation having been explained to the President of the Carnegie Institution of Washington, he approached Dr. McMurrich, who kindly agreed to undertake this important share of the Leonardo project. This was very fortunate, for Dr. McMurrich is not only one of the leading anatomists of America, a man of considerable experience, but he has shown a lifelong interest in the history of anatomy. In him are happily blended the technical and historical qualifications, the scientific and artistic leanings, which are but too often dissociated, and yet which are equally essential for the making of a complete historian of science.

This was more than ten years ago. Many and heavy were the duties—scientific, educational, and administrative—heaped upon Dr. McMurrich's shoulders, and to Leonardo he could but give his leisure hours. The Carnegie Institution was not impatient. It knew it was losing nothing by waiting a little longer, and that in the fulness of time the task which Dr. McMurrich had promised to undertake would be accomplished.

And here it is! No further introduction of it is needed, and this preface might end here. But the author will forgive me if I take advantage of his book to say a few words of the studies on the history of science which have been promoted by the Carnegie Institution. This is necessary because the activities of the Institution are so many and so diversified, that very few people realize what it has already done in our own field. Its publications on the History of Science, important as they are, are lost among many others, which are probably just as important if not more, but deal with other subjects.

The Institution's first effort in that direction was to publish the *Collected Mathematical Works* of George William Hill (4 vols., 1907). Later two ancient catalogues of stars were carefully edited, Ptolemy's, by C. H. F. Peters and E. B. Knobel (1915); Ulūgh Beg's, by Knobel alone (1917). A fundamental *History of the Theory of Numbers* was composed by L. E. Dickson (3 vols., 1919–23). Nearer to the present work is George W. Corner's *Anatomical Texts of the Earlier Middle Ages* (1927). Finally I may be permitted to mention my own *Introduction to the History of Science*, of which volume 1, From Homer to Omar Khayyam, appeared in 1927; volume 2, From Rabbi ben Ezra to Roger Bacon, is almost ready to be printed; Volume 3, dealing with the fourteenth and fifteenth centuries, will probably be ready in 1933. An assistant, Dr. A. Pogo, is preparing materials for Volume 4, to be devoted to the sixteenth century. It should be noted that while the volumes of my *Introduction* appear necessarily at distant intervals, they were all begun by me at the same time. That is, materials for these four volumes, and for many subsequent ones, have been systematically collected by me since 1911. A great many of these materials have been published, as they became available, in Isis, since 1913.

These explanations are not given solely for the sake of the Carnegie Institution, though it was worthwhile to bring into light a part of its abundant activity which is generally unknown. There is, I believe, a better reason for giving them. The reader will be helped by them to realize the existence of a new branch of knowledge, of an independent discipline, having its own unity, its own organization, its own methods, and deserving as well as any other to occupy the whole of a scholar's attention and energy. How strange it is, that in this age of science, it should be considered perfectly natural for a man to dedicate all of his time to, say, American or Canadian history, and that hardly any are allowed to devote themselves with the same continuity to a subject which is far more difficult, because it is at once more complex and less standardized? And yet is not the History of Science the very core of the history of culture? How else can we measure man's progress, except by the growth of his knowledge? Indeed the history of mankind is essentially the history of a gigantic struggle between light and darkness, between knowledge and ignorance. As the light gradually conquers the surrounding gloom, as science gradually destroys superstition, as rationality gradually replaces irrationality, and order, chaos, so—and not otherwise—does civilization increase. Just think of that and then remember that our universities provide for the study of every kind of history, except the very one which would enable us to understand the progress and the very nature of civilization.

The main trouble with our studies is not so much that they are neglected, but that they are considered fair game for any kind of amateurish efforts. This is of course a natural consequence of the fact that only a very few men are given an opportunity to engage in them as a profession. In so much as so few scientists have yet realized it, one could not repeat too often that the History of Science is itself a legitimate branch of science, that it is just as scientific as we make it, and that for it as for other branches, no good can ever be expected out of idle dilettantism or hasty book making. Whatever advance is made in our knowledge of it, will be due exclusively to honest and patient efforts, such as those made by Dr. McMurrich during the last ten years.

Nowhere does Leonardo's peculiar genius appear more clearly than in these anatomical investigations. To use the author's striking comparison "Vesalius was undoubtedly the founder of modern anatomy—Leonardo was his forerunner, a St. John crying in the wilderness." Leonardo's originality was due not only to his inherent genius, to the penetration and comprehensiveness of his mind, but also to his ignorance—I almost said, to his innocence. To speak of him as an Hellenist is ridiculous; he was not even a Latinist. We have evidence from his Manuscripts that his knowledge of Latin was very meager. It is probable that he had never made a systematic study of it in his youth; apparently he tried to make up for that deficiency in later years, but we all know that a man's linguistic limits are largely determined before maturity, especially when his life is a busy one and when he has consecrated himself to a definite and inflexible purpose. Leonardo's knowledge of Latin was that empirical knowledge which an intelligent Italian would easily obtain, in the quattrocento even more easily than now, because the Italian language was then so much nearer to its Latin origins. It was sufficient for simple needs, but utterly insufficient for abundant reading. Thus Leonardo was mercifully spared the oppressive load of that dialectical and empty learning which had accumulated since the ruins of ancient science and made true originality more and more difficult. To be sure, that learning was not wholly barren, but the little amount of gold which it contained, the timid attempts at experimentation, would filter through to such a man as Leonardo in more than one way. Such experimental knowledge did not need a learned language to be transmitted; nay, it would reach the botteghe of artists and craftsmen more directly than the cabinets of scholars. Thus the best of mediaeval science would be sure to reach Leonardo's inquisitive mind, while the dross was kept out by the insuperable barrier of his ignorance.

And yet such is the strength and pervasiveness of tradition that in spite of his prophylactic ignorance and aloofness, Leonardo could not entirely escape its prejudices. The barrier was not insuperable after all. There is nothing to prove that he had read Galen. Of course he knew Galen and spoke of him even as most of our contemporaries speak of Einstein or Freud without ever having read them. The physiological knowledge which had been transmitted to him by Mondino, Chauliac, or Benedetti, or better still by the intermediary of his conversations with surgeons or brother craftsmen, that knowledge was purely Galenic. Galenic prejudices were part of the very atmosphere which he was breathing; they were beyond the need of scrutiny or dispute. And so it was that this keen observer saw things not always with his own eyes, but sometimes with those of Galen! The best example of this aberration is Leonardo's reference to the heart's septum as sievelike. Not only does it occur repeatedly in his notes, but he even drew a portion of the septum showing pores which do not exist. Galen's triumphant dogmatism made even a Leonardo see the inexistent. But for this illusion which sidetracked him hopelessly, Leonardo might conceivably have discovered the circulation of the blood before Harvey, for he had as much anatomical and mechanical knowledge as was needed. He had all that was necessary to see the truth, except that in this particular case he was blinded by an overpowering prejudice.

One could not illustrate better the limitations of genius. A man of genius sees further than his fellowmen, further and more clearly, but for all that his range of vision is limited. Leonardo was an extraordinary man, yet he belonged to his environment—fifteenth century Italy—almost as completely as his humbler contemporaries. What else could we expect? This father of modern science was still in many respects a child of the Middle Ages.

This is very well proved in Dr. McMurrich's memoir. He has admirably brought out not only the outstanding merits of Leonardo's anatomical studies, their thoroughness and originality, but also their weaknesses, which had to be acknowledged, though they were almost unavoidable. Indeed his purpose was not to write a panegyric but to make a conscientious analysis of Leonardo's anatomy. He shows clearly how much of it was truly new and prophetic of our modern knowledge, but he also shows and with equal clearness that much of it was less original, or even entirely conventional and wrong. Leonardo was the greatest scientist of his time, but he was imperfect and fallible, even as the greatest scientists of our own time, and for that matter, of all times. One of the main lessons that the History of Science can teach us is this very one—the continual growth of man, and his continual, if slowly decreasing, imperfection.

To conclude I wish to express in the author's name as well as in my own, our deep gratitude to the Institution, whose enlightened generosity encouraged the preparation of this work and made its publication possible.

George Sarton

Cambridge, Massachusetts,
August 1929

Leonardo da Vinci
THE ANATOMIST
(1452–1519)

Ille velut fidis arcana sodalibus olim
Credebat libris: neque, si male gesserat usquam
Decurrens alio, neque si bene—quo fit, ut omnis
Votiva pateat veluti descripta tabella,
Vita senis.

Horace. Sat. II, I, 30.

CHAPTER I

INTRODUCTORY

Much has already been written concerning Leonardo's standing as an anatomist; indeed, each successive publication in facsimile of his note-books has called forth reviews and critiques. But now that practically all his manuscripts that deal with anatomical matters have been made accessible in facsimile, a more certain estimate of his achievements as an anatomist and of his place in the history of anatomy may be made.

In attempting to frame such an estimate many factors must be taken into account. No piece of work can be isolated from its environment and judged of its merits solely by modern standards. What had already been accomplished along similar and cognate lines, the extent to which the knowledge of this was available, how far the results manifested an emancipation from the obscurantism inherent in the intellectual tendencies of the period, how great was their influence on later progress in the same field of study, all these are questions that must be considered, as well as the thoroughness and accuracy of the work itself. Indeed, its title to originality both in fact and method and its consequences must be considered of greater importance than even its accuracy in detail; for a new viewpoint, a new method of investigation, may do more for scientific progress than an abundant recital of mere facts.

Leonardo lived in a time of great intellectual awakening, when the literary renaissance inaugurated by Petrarca and Boccaccio in the fourteenth century was at its height. One must inquire, therefore, how far he was an expositor in science of the new movement, how far he was a forerunner of the scientific renaissance that came to maturity with Copernicus and Galileo, how far he emancipated himself from the blind reliance on authority that had held anatomical investigation in thrall for over twelve centuries. His span of life almost paralleled that of the great printer-publisher, Aldus Manutius; to what extent did he avail himself of the older literature made accessible by the Italian printers and how far did his observations surpass in accuracy and detail those of the authors known to him? He was primarily a great artist and his early training was in the atelier of an artist; to what extent were his anatomical studies limited by their application to the problems of his art, or did he surpass such limitations and find in the structure and functions of the human body scientific problems independent of their applications? These are some of the questions to be considered.

The majority of the writers who have considered his anatomical studies agree in according him a high place as an anatomist, Holl (1905) even bestowing upon him the title of "auctor statorque anatomiæ humanæ." But while the general conclusion has been most favorable, eulogistic indeed, there have been those, notably Roth (1907), who have failed to find in Leonardo's work that almost superexcellence that others have ascribed to it and, while admiring the artistic skill shown in many of Leonardo's sketches, have criticized them unfavorably as regards their scientific accuracy. In Roth's opinion Leonardo was an artist who wished to understand the form and movements of the body; he was not a scientist, but merely a dilettante in anatomy. He approached anatomy from the artistic rather than from the scientific standpoint and "Ein Arzt (*i.e.* Vesalius) war es, der moderne Anatomie schuf, nicht ein Künstler."

Roth's unfavorably critical attitude may be understood when it is recalled that he is the author of an authoritative biography of Vesalius, usually regarded as the founder of modern anatomy. Like many biographers he seems to have felt that he held a brief for a client, and his criticism of Leonardo was called forth by the appearance of two papers accusing that client of plagiarism. One of these papers was by von Töply (1903) who accuses Vesalius of having appropriated from Estienne (Stephanus) without acknowledgment, the figures of the skeleton published in the *De fabricâ corporis humani* (1543); this does not concern Leonardo da Vinci and need not be given further consideration here, except to state that Roth (1905) has brought forward strong evidence to show that Vesalius' figures antedated and were probably the inspiration of those of Estienne.

The other accusation does, however, involve Leonardo and is more serious. It was made by Jackschath (1902, 1902[1]) and is to the effect that the *De fabricâ corporis humani*, generally ascribed to Vesalius, was in reality the work of Leonardo, representing the proposed treatise of anatomy mentioned several times in his note-books, but of whose publication there is no record. No wonder that Roth arose in his might to refute such an accusation and he was ably assisted by Forster (1904) and Holl (1905). Jackschath based his contention on several points, some of which are inconclusive and others erroneous. He considered it unlikely that a man of Vesalius' age when the *De fabricâ* was published (28 years) could have written such a book, but before 1543 Vesalius had been studying anatomy assiduously for three years at Paris under Sylvius and had held the chair of surgery at Padua for five years. Jackschath claimed that the symbols used on Vesalius' plates were the same as those employed by Leonardo and were characteristic, but Forster's careful study of these symbols demonstrated the claim to be without foundation. Further argument was based on the similarity of the descriptions of the eye given by the two authors; both, it is true, described the lens as occupying the center of the eyeball, but this merely implies that both Leonardo and Vesalius had accepted as correct the description of the eye in the Arabistic texts of the day. Finally, to mention one other instance of the evidence Jackschath sets forth in support of his theory, it is held that the *De fabricâ* must have been written before 1500, since there is no reference in it to sixteenth century anatomists. But as Roth points out, while Vesalius does not mention them by name, references to statements by Berengarius, Dryander and Guinterius are to be found in his book.

Leonardo's proposed treatise on anatomy will be considered later; here it need only be mentioned that he has given a detailed plan of how he hoped to present the subject in that book, but that plan is not followed in the *De fabricâ,* nor does it seem possible that Leonardo, unfamiliar and unskilled as he was in medical affairs, could have written that book. It is difficult to understand, too, why if Stephen von Calcar copied the illustrations for the *De fabricâ* from Leonardo's drawings, he was allowed to represent the curvatures of the spinal column and the inclination of the pelvis so erroneously, when essentially accurate drawings of the same parts by Leonardo were available. And furthermore there is the statement of the scholarly founder of Caius College, Cambridge, that while he was studying at Padua he lived for eight months in the same house as Vesalius "what time he wrote and drew his books de fabricâ humani corporis."

In short the evidence against Jackschath's views is so strong that it is difficult to take them seriously. There is a possibility that Vesalius may have heard of Leonardo's drawings after he reached Italy; he may even have seen them, but there is no evidence that he did so. He was already an experienced anatomist and convinced of the necessity for a reform in anatomical instruction when he went to Padua in 1537; that reform was the result of the publication of the *De fabricâ.* Leonardo was working along the same lines, but his great work, so far as is known, never reached fulfilment, and his anatomical studies remained unknown to the scientific world for three centuries. Vesalius was undoubtedly the founder of modern anatomy—Leonardo was his forerunner, a St. John crying in the wilderness.

CHAPTER II

ANATOMY FROM GALEN TO LEONARDO

Since, then, a just estimate of Leonardo's contribution to anatomy can only be arrived at when the state of that science in his day is understood, it will be advisable to consider the opportunities for anatomical studies available during the Middle Ages, the methods employed and the results.

With the death of Galen at the end of the second century of our era, the study of Anatomy entered upon its dark days and for nearly thirteen centuries scarcely a single fact was added to the knowledge of the structure of the human body. Nor does this statement, strong as it is, sufficiently express the condition of anatomical knowledge during this long period; not only was there no progress, there was retrogression. Throughout the Byzantine period synopses of Galen satisfied all demands, the most celebrated being the *Collecta medicinalia* of Oribasius, compiled at the request of the Emperor Julian and setting forth in concise and orderly succession the statements of the garrulous Galen. Theophilus Protospatharius in the seventh century does seem to have interested himself in dissection and to have added slightly to anatomical knowledge, but such activity was exceptional; and while the period produced some works of importance in the history of medicine and surgery, as far as anatomy was concerned it was almost barren. Later, in Europe the feudalism of the Middle Ages suppressed personal initiative among the mass of the people, each man's actions and behavior being dictated by the behests of his feudal lord; and among the clerics, from whom light might have been expected, the dogmas of the Church, formluated by the great Councils of the fifth and sixth centuries, defined within narrow limits the mode of thought. Life in all its aspects became highly conventionalized; feudalism produced such conventionalisms as knight-errantry, trial by combat, courts of love and, the climax of them all, the science of Heraldry; philosophy became conventionalized into rhetorical contests between Realists and Nominalists; and art, employed almost exclusively for religious instruction, became stereotyped into the stiff expressionless forms characteristic of early Christian paintings.

Conventionalism is dogmatism crystallized, and dogmatism means finality. What wonder then that the formulation of Christian theology, with its attendant sectarian bitterness, persecutions, riots, and even massacres, resulted in a belief that the last word had been spoken on matters theological. The essence of that theology was absolute faith in the dogmas of the Church; faith and not reason was the foundation of knowledge of both the supernatural and natural worlds, and of the two worlds it was the supernatural that held the chief place in men's minds. For their knowledge of natural phenomena they were content to rely upon the statements contained in the writings of the Fathers, these statements in turn being based upon those of earlier writers, provided that these did not conflict with the patristic interpretation of the Scriptures. The character of mediaeval philosophy has been aptly stated in these words:

> "A reversed pyramid, whose base was occupied by spiritual matters and of which the imperceptible point of the apex was constituted by man and nature, as things transitory and fleeting—that is the symbol of mediaeval doctrine." (Solmi, 1910.)

Under such circumstances there was naturally no incitement to personal observation, and experiment and science languished. It became conventionalized largely according to the Galenic tradition, and this tradition came to possess a finality; it was complete and unassailable, there was nothing to be added to it and nothing to be corrected. The word tradition is used advisedly because during the middle ages the original Galen had become practically unknown. Except in Constantinople and probably in such centers as Salerno and Montpellier, Greek had become to all intents a dead language, and Hippocrates, Aristotle and Galen were known only through tradition that had filtered down from the past. Fortunately the works of these authors were not destined for oblivion; they were saved to the World and restored to Europe through the appreciation by the Arabs of what was best in the philosophy and science of the Greeks.

The rôle of the Arabs in the history of the intellectual development of Europe was an interesting one. Primarily a pastoral and more or or less nomadic people, divided by intertribal feuds, they were welded into a nation by the religious enthusiasm of Mahomet and his small band of early converts, and, after a remarkable career of conquest, they settled down in their capitals to cultivate the arts of peace, just as the Ptolemies had done centuries before in Alexandria. Bagdad and Cordova became centers of learning in which Arabian sages studied and expounded the wisdom of the Greeks. But the Arabs had no knowledge of the Greek tongue and their first care was to secure the services of Syrians, Jews and Nestorian Christians to translate into Arabic the works whose contents they desired to master, and it was not long before all the important scientific and philosophical treatises of classical times appeared in an Arabic guise. From these translations as a source, there flowed a stream of abstracts, commentaries and treatises by Arabian authors, which, however, added little to the volume of human knowledge. For the Arabs showed little originality; what they handed on was Greek science and philosophy with, it is true, some oriental color in its presentation and application, but still essentially Greek. The Arabs contributed little, but they were the keepers of the Light through the Dark Ages and they restored it to the Western world where it had become well-nigh extinct.

The activities of the Arabian commentators could not indefinitely remain unknown to the scholars of western Europe. Already in the latter half of the eleventh century Constantinus Africanus, after spending forty years of his life among the Arabs, was received into the Monastery of Monte Cassino, not far from Salerno, and interested himself in the translation into Latin of Arabic versions of Galen's *Ars parva* and Hippocrates' *Aphorisms*, as well as of treatises by Ali Abbas and other Arabian commentators of less renown. The capture of Toledo from the Moors by Alfonso VI in 1085 also revealed to the Christian conquerors something of the wealth of the Arabic literature and awakened desire for a better acquaintance with the wisdom of the Arabs. But it was in the twelfth and thirteenth centuries that Arabian influence became most pronounced in Europe. In the twelfth century Toledo became the seat of a bureau of translation organized by the Archbishop Raymond and in the thirteenth century the capture by the Christians of such cities as Cordova and Seville brought further treasures into the hands of the conquerors. Especially under Alfonso X, surnamed The Wise, earnest attempts were made to utilize these treasures to the full; the observations of the Arabian astronomers were collated to form the Alfonsine Tables, while the work of translation went on apace.

But not only were the conditions in Spain favorable for the dissemination of Arabian learning, circumstances made Italy at this same time especially ready for its reception. The Hohenstaufen rulers of Sicily and Naples were strongly biased in favor of the eastern customs and their courts were oriental rather than occidental in their ceremonials. This was especially true in the case of Frederick II, who, notwithstanding that he was under the ban of the Church, led a crusade to the Holy Land and gained important concessions from the Sultan of Jerusalem, with whom he swore a blood-brotherhood. In 1241, Frederick promulgated an edict setting forth the requirements necessary for a license to practice medicine and surgery within his dominions, these requirements demanding that the candidate should have studied the science of logic for at least three years and thereafter should have pursued the study of medicine for five years and have practiced for one year under the guidance of a reputable physician, after which he must satisfy the masters at Salerno of his fitness by satisfactorily undergoing a public examination chiefly on the works of Hippocrates, Galen and Avicenna. It is evident that at this time Arabistic medicine was thoroughly established at Salerno, then at the height of its renown as a center for medical training, but soon to give place to the younger universities of Montpellier and Bologna.

In these, too, Arabian influences became predominant in the thirteenth century. Arnald de Villanova, probably a Spaniard and familiar with both Greek and Arabic, came to Montpellier toward the end of the century, and by his learning, originality and independence contributed greatly to the overthrow of the scholastic methods and to the substitution therefor of the forgotten precepts of the ancient masters, preserved and elaborated by Rhazes and Avicenna. Indeed, he was more than an Arabist; like his contemporary Roger Bacon he advocated and practised observation and experiment as the sources of scientific knowledge, thereby gaining for himself, as did Bacon, reputation as an exponent of the Black Art. His alchemistic predilections did not, however, lead him into mysticism, and his skill as a physician gave an authority to his appreciation of the Arabian contributions to medicine and found a reflection in the compendiums and commentaries of Arabian medical writers that came from representatives of the Montpellier school during the fourteenth century.

The University of Bologna primarily possessed but two faculties, those of Arts and Law, each with its own rector, and although it seems probable that medicine was taught there as early as the eleventh century, it was not until 1260 that the teaching of Thaddeus Alderotti, commonly known as Thaddeus Florentinus, began to attract students in considerable number, and in 1306 the Medical faculty was given an independent rector. Thaddeus was well versed in the medical lore of his day, both Greek and Arabic, and he and his pupils added to the list of commentaries on the works of the ancient and more recent writers. Of these works those chiefly studied by the students were, as at Salerno, the *Ars parva* of Galen and the *Aphorisms* of Hippocrates, but acquaintance was also required with other works of those authors and with the *Colliget* of Averrhoes, the *Canon* of Avicenna and the *Almansor* of Rhazes. (Rashdall.)

In the thirteenth century, accordingly, the three great medical schools of Europe were deeply under the influence of Arabian authors, and while these restored a better knowledge of the Greeks, they also imposed limitations, since that knowledge came bound by the restrictions imposed by Arab custom. Chief among the results of these restrictions was the divorce of medicine and surgery, which was so pronounced during the Middle Ages. It was due in part to the influence of the oriental tradition against the use of the knife and in part to the general attitude inculcated by Scholasticism. Medicine lent itself more readily to the dialectic dear to the Scholastic, to argumentation as to causes, principles and treatment; whereas surgery required prompt and effective action, and in the foundation of the

Universities it was medicine that was taught and practised by the Faculties of Medicine, and surgery was largely left in the hands of barbers, bathkeepers and even public executioners. There were, it is true, some learned surgeons, such as Theodoric and William of Saliceto of Bologna, Lanfranchi and de Mondeville of Paris and Guy de Chauliac of Montpellier, but their number was small and for the most part the physician deemed it beneath his dignity to undertake the treatment of wounds or fractures or operations such as couching and lithotomy, to say nothing of bleeding and tooth extraction. For the physician an intimate knowledge of anatomy was unnecessary; if he knew the position of the various organs of the body and their presumed functions he had all he required, and this he could obtain from a translation of an Arabic summary of Galen's anatomical treatises, such as is found in Avicenna's *Canon*. The original treatises, and especially the *de administrationibus anatomicis*, remained neglected, even though an Arabic translation of the latter had been made by Honein (Johannitius) or his son-in-law Hobeisch as early as the ninth century. It was translations of Arabic versions of the *Ars medica* (commonly known to the Arabists as the *Microtechne*) and the *Methodus medendi* (*Megatechne*) that were especially studied during the Middle Ages: and while the *de usu partium* awakened some interest for Galen's anatomical treatises, the summation of the anatomical knowledge of his day, the learned physician felt no need and the barber-surgeon was too ignorant to make use of them.

So the study of anatomy became conventionalized into the reading of a translation into Latin of an imperfect summary by an Arab of Galen's teaching, and, since its source was Galen, the complete submission to the dictates of antiquity that characterized the Middle Ages gave it an authority and finality that well-nigh suppressed all stimulus to further inquiry. Indeed, ignorance of the original treatises concealed the fact that Galen's contributions to anatomy were based on the dissection of animals, chiefly monkeys, that his anatomy was not in reality human anatomy, and when this fact was revealed by the investigations of Vesalius in the sixteenth century their unshaken confidence in the infallibility of Galen led at least one of the Galenists to the conclusion that the structure of the human body must have altered materially in some respects during the centuries that had elapsed since Galen's day.

But notwithstanding the profound subservience to dogma, the faint flicker of revolt against it shown by such men as Roger Bacon and Arnald de Villanova was not entirely extinguished, for the thirteenth century witnessed the encouragement of the study of anatomy by direct observation, such as had not been given since the days of Galen. The Emperor Frederick II, when prescribing the course of study to be pursued by those wishing to practice medicine within his dominions, enacted that no surgeon should be allowed to practise unless "Above all he has learned the anatomy of the human body at the medical school and is fully equipped in this department of medicine, without which neither operations of any kind can be undertaken with success, nor fractures be properly treated."[1] This does not necessarily mean that the prospective surgeon must have learned his anatomy by the actual dissection of a human body; the School of Salerno was indeed noted for its interest in practical instruction in medicine, but there is no record of a dissection of a human body having been performed under its auspices. Toward the close of the eleventh century, at the period when Arabic influences were beginning to supplant the Greek tradition that had persisted in the School, one Copho, a member of that school, wrote a brief treatise on the anatomy of the pig, *Anatomia porci*,[2] consisting in its printed form of about two and a half pages and amounting to little more than an enumeration of the various organs to be seen in opening the body of the animal. It describes an autopsy rather than a dissection, but is of interest as evidencing some appreciation of the importance of a knowledge of anatomy based on personal observation. Somewhat more detailed was the *Demonstratio anatomica* by an anonymous author of the same school, also based on the autopsy of a pig, but these early attempts of the Salernitans to revive the practical study of anatomy were destined to be supplanted by treatises based on the study of the human body, the first attempts in this direction of which there is record, since the days of the Alexandrian anatomists.

It is to Bologna that the credit for the revival of practical human anatomy is due, and it is interesting to note that the long-continued repugnance to the dissection of human cadavers was only gradually overcome by the desire for a more definite knowledge of the pathological changes produced by disease or by the demands of justice for definite evidence in cases of suspected poisoning. The first instance on record of such a revival was a legal autopsy performed by the Bolognese surgeon William of Saliceto on the body of the nephew of the Marchese Uberto Pallavicino, who was suspected of having died from the administration of poison. William of Saliceto was the author of a Cyrurgia, written in 1275, the fourth book of which is devoted to a compendium of Anatomy in five chapters. It is Galenic anatomy, similar to that found in mediaeval manuscripts, and, to judge from the use of Arabic terms for certain parts, was based upon an Arabic source, probably Avicenna. That William, "qui Gulielmina dicitur,"

[1] J. J. Walsh, *Mediaeval Medicine*, London, 1920. The translation is made from a copy of the edict published in Huillard-Brehollis' *Diplomatic History of Frederick II, with Documents*, Paris, 1851–1861.

[2] A translation of this and also of the *Demonstratio* mentioned below will be found in G. W. Corner, *Anatomical Texts of the Earlier Middle Ages*. Carnegie Inst. Wash., 1927.

had practical experience in dissection is indicated by the directions he gives as to how the incisions should be made for the exposure of various parts and by his statement that a certain duct, wrongly described by his source as existing, was unknown to him.

A few years later (1286) a Parmesan or Lombard physician is reported to have made autopsies of the bodies of persons who had died of an aposthematous pestilence (Solmi, 1906) and in 1302 a post-mortem examination was ordered of the body of one Azzolino, who was suspected of having been poisoned. The examination was made by Bartholomeo da Varignana, a famous teacher and practitioner in Bologna, with four associates, and these reported—

"quod dictum Azzolinum ex veneno aliquo mortuum non fuisse, sed potius et certius ex multitudine sanguinis aggregati circa venam magnam quæ dicitur vena chilis, et venas epatis propinquas eidem, unde prohibita fuit spiritus per ipsam in totum corporis effluxio, et facta caloris innati in toto mortificatio, seu extinctio, ex quo post mortem celeriter circa totum corpus denigratio facta est, quam paxionem adesse prædicto Azzolino prædicti Medici sensibiliter cognoverunt *visceribus ejus anathomice circumspectis*."[3]

The recognition of autopsies given by the authorities in this case was no doubt an important factor in bringing about a greater freedom in the investigation of human cadavers, and it seems probable that early in the fourteenth century advantage was taken of this freedom for the performance of autopsies at Bologna as a means of anatomical instruction. In 1316 there appeared a text-book of anatomy from the pen of Mondino di Luzzi which was destined to supplant that portion of the first book of Avicenna's *Canon* which treated of anatomy.[4] It remained the favorite anatomical text-book for over two centuries, partly because of its directness and simplicity of statement, partly because of its recognition of the practical application of anatomy and partly, and largely, because in the treatment of the subject it followed the order in which the various organs would be exposed in an autopsy. In other words it was a Manual of Practical Anatomy rather than a systematic treatise of the subject. It bears evidence in its arrangement that its author is treating his subject on the basis of personal practical experience and, indeed, in the text there is a statement that in 1315 he performed autopsies on two female subjects; but nevertheless the work makes no contribution to the more accurate knowledge of anatomy; it gives nothing beyond what was contained in the Arabian treatises; it repeats their errors and shows their influence in

[3] M. Medici, *Compendia Storico della Scuola Anatomica di Bologna*, Bologna, 1857.

[4] See G. Martinotti, *L'insegnamento dell'Anatomia in Bologna prima del secolo XIX*, Bologna, 1911, page 61, where is quoted a portion of a statute of the University of 1405 in which, in the prescription of texts to be studied in the successive years of the medical course, the first book of Avicenna is mentioned always with the addition of the words "excepta anathomica."

the use of Arabic terms for many of the organs. The contents of Mondino's work will later be considered more in detail, since it was one of the sources of Leonardo's knowledge of anatomy; its present significance is that it indicates an increasing interest in the practical study of the human body and it probably had influence in further promoting that interest.

After Mondino's time the dissection of human cadavers for the purpose of instruction became of frequent occurrence. Guido de Vigevano, who was physician to the French King Philippe de Valois, in the concluding chapter of his *Liber notabilium,* which consists mainly of excerpts from translations of Galen and was written in 1345, endeavors to demonstrate the structure of the human body by a series of eighteen figures, which he believes himself capable of doing "cum pluribus et pluribus vicibus ipsam (anathomiam) feci in corpore humano."[5] Similarly Guy de Chauliac, the greatest of the surgeons of Montpellier, states in his *Grande Chirurgie* that his Bolognese teacher, Bertucci, who died of the Black Plague in 1347, performed many Anatomies, each consisting of four lessons, as follows:

"In the first he considered the nutritive organs because they perished soonest, in the second the spiritual organs, in the third the animal organs, and in the fourth the extremities."[6]

Nor was the performance of Anatomies or autopsies limited to Bologna. Gentilis da Foligno, who for a time taught at Bologna and at Perugia and who like Bertucci, fell a victim to the Black Plague, is recorded as having performed an autopsy at Padua in 1341, in which he discovered in the gall bladder of the subject "a green stone,"[7] and further it is also on record that the anatomists of Perugia, when making an anatomy in 1348, found in the neighborhood of the heart a small sac full of poison, the subject having died of an epidemic (Solmi, 1906).

The performance of Anatomies was not, however, allowed to proceed without let or hindrance. Even in Mondino's time there is record (1319) of a trial in Bologna of four Masters who were accused of having disinterred the body of an executed criminal and of having transported it to the house in which a certain Master Albertus of Bologna was accustomed to lecture, a witness testifying that there he had seen Master Alberto with four other Masters and others persons—

"existentes super dictum corpus cum rasuris et cultellis et aliis artificiis et sparantes dictum hominem mortuum et alia facientes quæ spectat ad artem medicorum."[8]

[5] E. Wickersheimer, *L'"Anatomie" de Guido de Vigevano, medecin de la reine Jeanne de Bourgogne* (1345), Arch. f. Gesch. der Medizin, vol. 7, 1913.

[6] Guy de Chauliac, *La Grande Chirurgie, restituée par M. Laurens Joubert,* Rouen, 1632. This is one of the many printed editions of this famous work, which was originally written in 1363.

[7] M. Roth, *Andreas Vesalius, Bruxellensis,* Berlin, 1892.

[8] See M. Medici, *loc. cit.* p. 12.

In France, or at least in Paris, it would seem that in the fourteenth century the dissection of the human body was prohibited by the clerical authorities except under a special privilege, concurrent evidence to that effect being furnished by Henri de Mondeville and Guido de Vigevano. De Mondeville was by birth a Frenchman, but he was probably educated in Italy, although there is no direct evidence in support of this idea. At all events he was at Montpellier in 1304 and demonstrated anatomy there, or rather, as Guy de Chauliac informs us, he "pretended to demonstrate anatomy" by the use of thirteen figures. Thence he passed to Paris where he became surgeon to Philippe le Bel, to whom he dedicated his *Chirurgie,* begun in 1306 but never completed. In the first part of this he treats Anatomy, essentially on the basis of Avicenna's teaching, but with indications of the methods to be pursued in demonstrating it and in this connection he states—

"Si debeant (corpora) servari ultra 4 noctes aut circa et exinde a Romana Ecclesia speciale privilegium habeatur, findatur paries ventris anterior a medio pectoris usque ad pectinem. . . "[9]

Guido de Vigevano, whose early training was presumably obtained in Italy, also based his teaching on figures, making these, indeed, the essential part of his chapter on anatomy, giving as his reason for so doing "Quia prohibitum est ab Ecclesia facere anothomiam in *corpore humano.*"[10] It is noteworthy that both these works were written in Paris at a time when autopsies were being freely performed in Italy, a fact which suggests that the prohibition may have been a local one. No general enactment of the Church on the question of Anatomies is known, but it has been held that the Bull of Boniface VIII *De Sepulturis,* issued in 1300, had a prohibitory effect on the practical study of anatomy. The Bull had, however, quite another purpose as is shown by its title which may be translated thus:

"Those eviscerating the bodies of the dead and barbarously boiling them in order that the bones, separated from the flesh, may be carried for sepulture into their own country are by the act excommunicated."[11]

It was called forth by a practice that had arisen during the Crusades, and while it is possible that it was interpreted by the Parisian clergy as setting a ban on Anatomies, no such interpretation, apparently, was placed upon it in Italy, or if it was, it was short lived. Indeed Alessandro Benedetti, a contemporary of Leonardo, states in his

[9] J. L. Pagel, *Die Chirurgie des Henri de Mondeville,* Berlin, 1892.

[10] E. Wickersheimer, *loc. cit.,* p. 13.

[11] The Bull is quoted in its entirety in a paper by J. J. Walsh, *The Popes and the History of Anatomy,* Medical Library and Historical Journal, vol. 1, 1904. See also *Mediaeval Medicine,* London, 1920, by the same author.

Historia corporis humani (1497) that anatomists were even in the habit of preparing skeletons by boiling without fear of excommunication.

The Humanistic movement, born in Italy in the fourteenth century, manifested itself primarily in literary studies, but soon expanded to include other fields of intellectual activity. Underneath the literary movement and bearing it along was the awakening spirit of the Renaissance, the yearning for emancipation from the domination of dogma, the dissatisfaction with knowledge acquired at second hand, the desire to learn and know from personal observation. This manifested itself in an increasing demand for opportunities for Anatomies, sufficiently insistent to compel from the authorities enactments providing a definite supply of cadavers to be used for such purposes. The first of these enactments of which there is record was passed by the Great Council of Venice in 1368, decreeing that an Anatomy should be made once in each year before the physicians and surgeons, the dissections, according to Nardo,[12] being performed in the Hospital of Ss. Peter and Paul. Shortly after, probably in 1376, a similar privilege was granted to the Medical faculty of the University of Montpellier, this privilege being confirmed several times in later years up to the close of the fifteenth century.

It was in that century, however, that the granting of such a privilege became generally established in Italy, indicating a widespread interest in the study of Anatomy. It has been shown that early in the fourteenth century autopsies and Anatomies had been conducted with some frequency at Bologna, but no records have yet been found of decrees legalizing the practise in that municipality. In the early days of the Universities, the relations between the students and teachers were more intimate than in later days. The Italian Universities were primarily guilds of students as contrasted with the guilds of Masters of which the University of Paris was the prototype:[13] the students selected their own Masters, the instruction they received was according to personal arrangements into which they entered with their Masters and much of the teaching was done in the houses of the Masters. Martinotti[14] has shown that even anatomy was taught in this extra-mural fashion and continued to be taught privately long after the institution of Public Anatomies, even, indeed, until Galvani's time, at the close of the eighteenth century, and later. The responsibility for the supply of subjects for these private Anatomies appears in the early days to have rested with the students, an arrangement that naturally led to disturbances and conflicts, to obviate which the Statutes of the University of 1405 prescribed that no one, doctor or student, should be allowed to have possession of a body, unless he

[12] Quoted by Bottazzi (1907).
[13] H. Rashdall, *The Universities of Europe in the Middle Ages*, Oxford, 1895.
[14] G. Martinotti, *loc. cit.*, p. 12.

should previously have obtained a license for that purpose from the Rector. But this plan, apparently, was not quite satisfactory, and in 1442 it was modified by requiring the Podestà of Bologna to furnish each year at the request of the Rector, two cadavers upon which Anatomies might be made, a condition being made, however, that the cadavers must be obtained from places not less than thirty miles distant from the city of Bologna. This limitation was removed in 1561, after which date the bodies of persons who had been resident even in the suburbs of Bologna might be taken, "modo cives honesti non sint et superioribus ea dare placeat."

Nor was Bologna the only Italian city in which the practical study of anatomy was zealously conducted during the fifteenth century, indeed, the renown of Padua as a center for medical instruction was almost, if not quite, as great as that of the sister university. The charter of the University of Padua was granted by the Emperor Frederick II in 1222, and it is probable that it undertook instruction in medicine from its foundation. It is also probable that Anatomies were conducted there even in the fourteenth century, for it was a professor from Padua who performed the first Anatomy in Vienna in 1404. At the beginning of the fifteenth century Padua fell under the domination of Venice (1405) and after that date it quickly rose to great prominence as an anatomical center. Autopsies are on record as having been performed in 1429 and again in 1430, and Montagnana in his *Consilia*, written in 1444 while he held a professorship of medicine at Padua, states that he had witnessed fourteen Anatomies. There is record of a public Anatomy held in 1465 at which the doctors discussed all the doubtful points concerning the structure of the body, "atque tandem corpus cum maxima festivitate humatum." It was not until 1495, however, that a statute was passed requiring the annual delivery to the University for anatomical purposes of two bodies, one male and one female.[15] A similar regulation was in force in the fifteenth century at Siena, Perugia, Genoa and Ferrara, and in 1501 at Pisa, while it is known that early in the sixteenth century dissections were made at Pavia by Marc Antonio della Torre.

It is evident from these data that in the time of Leonardo, the latter half of the fifteenth and the beginning of the sixteenth century, the dissection of the human body was a well-recognized feature of medical instruction; the long-standing prohibition of it, imposed partly by general sentiment and partly by religious opinion, had given way to the spirit of the Renaissance. It will be of interest later to consider the conditions obtaining at Florence, where Leonardo entered upon his anatomical studies, but here a brief account of the methods adopted in the performance of an anatomy will not be amiss,

[15] M. Roth, *Andreas Vesalius, Bruxellensis*, Berlin, 1892.

since it will explain the failure of the early anatomists of the Renaissance to advance in their knowledge of anatomy and the greater success of Leonardo.

Why was it that with all their opportunities for direct observation, the anatomists of the fourteenth and fifteenth centuries added little or nothing to the scanty and superficial description of the human body contained in the *Canon* of Avicenna? Why did they fail even to reach the standard of exposition set up by Avicenna? Because, in the first place, Avicenna was epitomizing the anatomy of Galen while the more modern writers were either epitomizing Avicenna's epitome, not yet having access to the original Galenic treatises, or else, as in the case of Mondino, were describing on the basis of Avicenna's epitome what could be seen in an Anatomy, and their Anatomies were limited in their duration, since they possessed no means of preserving the bodies from putrefaction, and in the warm climate of Italy the work could not be prolonged over more than three or four days. Nor was it carried on without intermission during the available time, but apparently was divided into usually four demonstrations in the manner described by Bertucci (see p. 13); and furthermore the time available for observation was frequently greatly curtailed by prolonged discussion by the Masters present, of moot points suggested by the demonstration. With these limitations of time it is evident that in the Anatomies of the fifteenth century only a superficial examination of the more conspicuous organs of the body could be made; of detailed dissection there was none. Mondino excuses himself for omitting a discussion of the "simple parts" because these were not perfectly apparent in dissected bodies, but could only be demonstrated in those that had been macerated in running water. He was also accustomed to omit consideration of the bones at the base of the skull, because these were not evident unless they had been boiled, and to do this was to sin, and, similarly, he omitted the nerves which issue from the spinal column, because they could be demonstrated only on boiled or thoroughly dried bodies and for such preparations he had no liking. So too Guy de Chauliac and Berengarius da Carpi maintained that the muscles, nerves, blood-vessels, ligaments and joints could only be studied in bodies that had been macerated in flowing or boiling water or else thoroughly dried in the sun, and there is no evidence that such preparations were demonstrated at the Anatomies. These were little more than demonstrations of the organs contained in the three *ventres* of the body, the abdomen with the *membra naturalia*; the thorax with the *membra spiritualia* and the head with the *membra animalia*.

But not only were the Anatomies incomplete, they were rendered ineffectual by the method in which the instruction was imparted. Several illustrations of Anatomies have come down from the end of the fifteenth and the first half of the sixteenth century and these show such uniformity in the details of the scene, that they may be taken as representing what had become the customary ritual. In 1491 a German, Johann Ketham, who had lived in Italy, published under the tital *Fasciculus Medicinæ* a collection of medical treatises, among which was the *Anathomia* of Mondino. This original edition was in Latin, but in 1493 an Italian translation of it was published by Sebastiano Manilio Romano, and in this the treatise of Mondino was supplied with a colored frontispiece showing an Anatomy (fig. 1). Seated in what may be termed a pulpit, whose canopy is supported by two dolphins, is the professor, who is delivering a lecture or more probably reciting passages from Mondino. Before him, stretched out upon a rough wooden table is a male cadaver and near one end of the table stands a demonstrator, holding in his left hand a short wand with which he points to the thorax of the cadaver, indicating the point at which a third person, a surgeon or barber, who holds a curved knife, is to begin his incision. Six other persons represent the spectators, for whose edification the Anatomy is being performed. What is essentially the same illustration appears in the 1495 edition of Ketham, but it has been reëngraved and presents a number of minor changes. Thus the demonstrator no longer holds a wand, but indicates the place for the incision with his finger, and the professor instead of lecturing or reciting is now reading from a book which lies open on the desk before him. So it is also in an illustration of an anatomy contained in Berengario da Carpi's *Commentaries on Mondino* published in 1535, and in this case the demonstrator wields a wand.

Sometimes the demonstrator is omitted, as in the illustration forming the title-page of the Mellerstatt edition of Mondino (1493), in which the only actors in the scene are the professor seated in an imposing chair with a book in his lap and a youthful assistant who is performing the dissection under direction of the professor. And, indeed, there are illustrations which show the professor condescending to do the actual work of dissection himself as in the Anatomy figured in the French translation by Bartholomæus Anglicus (Lyons, 1482)[16] and in Guido da Vigevano's anatomical figures (1345) (fig. 2). But it is to be noted that the illustrations which show the professor holding himself aloof from the practical side of the anatomy are associated with various editions of Mondino's *Anatomy*, which was for so many years the popular text-book. This fact alone would lead to the belief that these illustrations show the custom generally followed by those who used the book, which is as much as to say that they show the custom generally followed in Anatomies during the latter part of the fifteenth and the sixteenth centuries. But there is further and stronger

[16] Reproduced by C. Singer in his *Studies in the History and Method of Science*, Oxford, 1918.

Fig. 1. An "Anatomy." From the *Fasciculo di Medicina* (Venice, 1493). After facsimile published by C. Singer, Florence, 1925, p. 64.

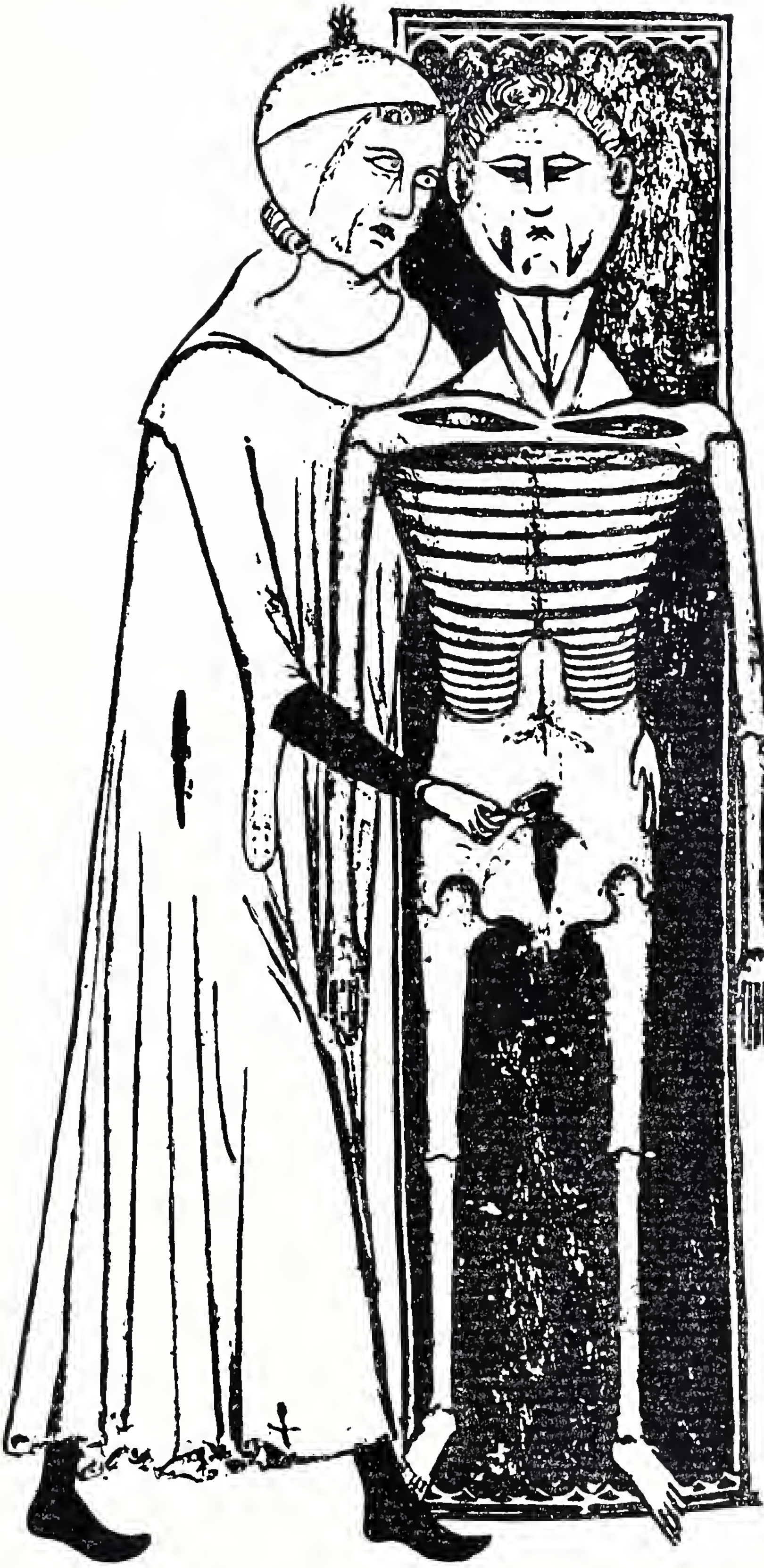


Fig. 2. A dissection by Guido da Vigevano (1345). Archiv für Geschichte der Medizin, vol. 7, pl. 1, 1914.

evidence in confirmation of this belief in the scathing statements of Vesalius in the preface to his *De corporis humani fabrica* (1543), where he speaks of an Anatomy as—

"A detestable ceremony in which certain persons are accustomed to perform a dissection of the human body, while others narrate the history of the parts; these latter from a lofty pulpit and with egregious arrogance sing like magpies of things whereof they have no experience, but rather commit to memory from the books of others or place what has been described before their eyes; and the former are so unskilled in languages that they are unable to describe to the spectators what they have dissected."

The recollection of former experiences undoubtedly accounts for the sting of these words, but they tell the same story as the illustrations, the aloofness of the lecturer and his reliance on the written text, and the inefficiency of the dissector. Add to these the haste with which the Anatomy had necessarily to be conducted and it is not difficult to understand why, for so long a period, there should have been no essential progress in anatomy.

CHAPTER III

POSSIBLE LITERARY SOURCES OF LEONARDO'S ANATOMICAL KNOWLEDGE

In studying Leonardo's manuscripts, one notes from time to time a drawing or sketch showing anatomical conditions that do not actually occur, but are representations of traditions handed down from earlier times and especially from Galen. These traditions had gained a strong foothold during the Middle Ages when observations were at a standstill, and even Leonardo, with all the keenness of observation and artistic accuracy shown in his anatomical studies, was yet strongly under the influence of Galen's physiological theories, and occasionally endeavored to give them visual expression in a drawing. It is evident, then, that Leonardo was familiar with these traditions and it may be of interest to consider the possible sources from which he may have had knowledge of them. He was little affected by the literary Renaissance which was at its height in his day; the principles of the artistic Renaissance that he imbibed as an artist led him in his scientific studies past the methods of the humanists, past their reliance upon classical authority, to the modern methods of observation and deduction. He was, indeed, accused by the humanists of being unlettered, but replied that the things that interested him were revealed by experiment rather than by words, and he boasted experiment to have been his mistress in all things (CA, 119). Those who rely on authority in maintaining their opinions were, he claimed, exercising their memory rather than their judgment (CA, 76), and he held that all science that ends in words has death rather than life. He found much worthy of imitation in the works of antiquity, but, nevertheless, had nothing but condemnation for those who followed them servilely, when "the grandest of all books, I mean the Universe, stands open before our eyes." "Those," he said, "who study only the ancients and not the works of Nature are step-sons and not sons of Nature, the mother of all good authors" (CA, 141).

But while he thus condemned reliance upon authority, he did not disdain the works of his predecessors as guides or aids to observation and interpretation. As has been stated, Leonardo's ideas as to the ultimate constitution of the body and his physiology were essentially those of the Galenic tradition, and one may assume that he did not start on his anatomical observations without some knowledge of the anatomy of the day. His distrust of the works of the ancients was not of the works themselves, but of an implicit reliance upon them which could serve only as a bar to progress. His desire was to prove by observation the teachings of his predecessors, but when he found observation and tradition at variance, he promptly accepted the results of observation.

There are two ways by which indications of these sources may be obtained; firstly, by noting the authors mentioned in the manuscripts and, secondly, by studying Leonardo's anatomical nomenclature. The first of these methods suffers from the disadvantages that in Leonardo's day accurate reference and quotation had not come to be regarded with the reverence bestowed on them today, and, furthermore, one has to deal with Leonardo's note-books and not with a completed and explicit treatise. Consequently such references as occur are, as a rule, of the briefest, a mere mention of a name it may be; and citations, when made, are not always accurate and in some cases are difficult to verify.

The favorite treatise on anatomy in Leonardo's time was the *Anathomia* of Mondino di Luzzi, which custom in Italy had prescribed as the guide in the performance of an Anatomy. Mondino was professor at Bologna and an Arabist, and although he refers to dissections that he himself had performed, his book is mainly founded on the anatomy of the *Meliki* of Albucasis and the *Canon* of Avicenna.

Leonardo mentions Mondino in two passages and evidently refers to him in a third, and it is noteworthy that he mentions him only to criticize. In one passage (QI, 12) it is objected that if, as Mondino asserted, the testes secrete a saliva-like fluid and not sperm, then there is no reason why the spermatic vessels should have the same origins in the male and female. In a second passage (AnA, 18) he disputes a statement that he attributes to Mondino, to the effect that the muscles that raise the toes are located in the outer part of the thigh (coscia) and that there are no muscles on the dorsum of the foot. But, as Roth (1907) has suggested, he must either have quoted from memory or else from an inaccurate manuscript, for what Mondino taught was that the tendons that extend the digits of the foot arise from muscles that are in the outer part of the crus (*in tibia in parte silvestri*), not the thigh, since the dorsum of the foot ought to be destitute of flesh, lest its weight be increased. It was the latter part of Mondino's statement, however, that interested Leonardo, for he proceeds to direct attention to the *extensor digitorum brevis* which was apparently unknown to Mondino, although it had been described long before by Galen. Leonardo states in connection with a drawing—

"Experience shows that the muscles *a*, *b*, *c*, *d* (the *extensor digitorum brevis*) move the second pieces of the bone of the digits and the muscles *r*, *s*, *t*, (*extensor communis digitorum* and *ext. longus hallucis*) move the ends of the digits. There is need to enquire why all do not arise in the foot or all in the leg."

In a third passage (AnA, 17) Leonardo evidently refers to the same statement, without, however, mentioning Mondino, and this time directs his criticism to the supposed origin of the extensors of the toes in the thigh.

"For" he says "if the thigh be squeezed a little above the knee and the toes be moved up and down you will feel no movement in the tendons or muscles of the thigh."

Mondino's *Anathomia* was written in 1316 and for a century and a half, until the invention of printing, numbers of manuscript copies of it must have been made and disseminated widely throughout Italy and possibly Germany. The first printed editions were published at Pavia and Bologna in 1478, and from that date onward until 1580 edition rapidly succeeded edition. What edition or editions may have served as Leonardo's guide in beginning his anatomical studies, it is impossible to say with any certainty; he may have used a manuscript copy. But there is one piece of evidence that suggests a possibility that he may have been familiar with the edition that was published at Bologna in 1482, re-published in 1484 and later included in Ketham's *Fasciculus Medicinæ*, published in Venice in 1495. This edition was edited *ab eximio artium et medicinæ doctore magistro Petro Andrea Morsiano da Ymola in almo studio Bononiæ cyrurgiam legente,* who also edited the *Chirurgia* of Avicenna in 1482 and, according to Roth (1907) is credited with having performed an anatomy at Bologna in 1499. On the verso of the cover of manuscript G, mention is made of one Andrea da Imola, not, however, in connection with matters anatomical, but with regard to his objection to Leonardo's theory as to the cause of the light of the moon (*i.e.* the reflection of the light of the sun from the surface of a lunar sea). But the indications are that Leonardo knew him personally and, if so, it seems probable that he knew of his edition of the *Anothomia*. However, Solmi (1919) has pointed out that there was a second Andrea da Imola, Andrea Mainarmi da Imola, who was the author of a *Discorso sulla milizia*, published in Milan, and he, after all, may have been the Andrea mentioned.

But even while the *Anothomia* may have served as an introduction to Leonardo's anatomical studies and may have given the foundation for his anatomical nomenclature, it can hardly have done more. It is a small book, forty octavo pages, and much of the space is given over to surgical and pathological data and much teleological physiology transmitted from Galen through Arabic interpreters. The organs of the body are briefly described as they are exposed in opening up the three ventres, abdomen, thorax and head, but their descriptions are exceedingly superficial and devoid of detail. The bones are merely enumerated, the muscles of the limbs, to which Leonardo devoted so much attention, are practically unnoticed, since, in Mondino's opinion, they can not be demonstrated in an Anatomy. And the same is true of the nerves and of the blood-vessels, with the exception of the main trunks. One finds in the book nothing of that striving for a thorough knowledge of all the parts, nothing of that desire to understand the mechanical principles involved in their functionings, which are so characteristic of Leonardo. Mondino was a mediaeval anatomist; Leonardo was seized with the spirit of the Renaissance and betook himself to Nature to satisfy his longings, working out his problems by observation and experiment.

Leonardo must have known Alessandro Benedetti's *Anatomice*, since he mentioned it on the cover of Ms.F. Benedetti was born at Lagnano near Verona in 1460 and died in 1525, so that he was a contemporary of Leonardo, though somewhat younger. He was professor of medicine at Padua and published his treatise on anatomy at Venice in 1493. The book had somewhat the same scope as that of Mondino, but Benedetti was a humanist and placed his reliance on Aristotle and Galen rather than on the Arabians, although Averroes and Avicenna are cited. That he had some experience in dissection is indicated by the directions given as to the incisions necessary to expose various organs, but the book is superficial—rather a guide to the performance of an Anatomy than a treatise on anatomy. Benedetti's reputation rests rather on his *De re medica* than on his *Anatomice*.

On QII, 14 there is a reference to "Pladina and other writers on the gullet (*gola*)" or at least so it is translated. It is evidently a reference to Bartolommeo Sacchi, who took the name of Platina as a latinization of his native town Piadeno near Mantua. On coming to Rome he endeavored to revive the old pagan customs and so came into collision with the Church. He was twice imprisoned, but on his final release was appointed librarian to the Vatican Library by Sixtus IV and died while holding that post in 1481, at about the age of sixty. He was the author of a work *In vitas summorum Pontificum* and of a brief *History of Mantua*, but the work referred to is probably his *De honesta voluptate et valitudine*, first published at Venice in 1475, a collection of culinary recipes, with remarks upon their dietetic value. Perhaps the word *gola* should be translated "gluttony" rather than "gullet."

A work of the fourteenth century which almost equalled in repute the *Anothomia* of Mondino, especially among the adherents of the school of Montpellier, was the *Collectorium artis chirurgicalis medicinæ*, later known as the *Cyrurgia magna*, of Guy de Chauliac. The author was a native of the Auvergne and obtained his medical education partly at Montpellier and partly at Bologna, where he studied anatomy under Bertuccio, one of Mondino's pupils. After receiving his doctor's diploma from the University of Montpellier he practised for a time at Lyon, but later became physician to the papal court at Avignon, and, while there, wrote his *Cyrurgia magna* (1363). He was renowned as well for his learning as for his skill as a surgeon, and was fortunate in having access to the translations of Galen's works made by Nicolaus of Reggio, which, he says, were of a loftier and more perfect style than those translated from the Arabic tongue. He was not, however, exempt from the prevailing Arabistic tendencies, but his chapter on anatomy is more detailed than the book of Mondino and free from the teleological explanations so dear to that author; indeed Guy sets little store by discussions as to the function of organs, regarding them as more properly pertaining to philosophy, "et hoc est pelagus, in quo non licet medicum navigare."

The earliest printed edition of the *Cyrurgia magna* was published at Paris in 1478, as a French translation, but a Latin version was printed in Venice in 1490 and was followed by several later editions. Leonardo may therefore have known it either in manuscript or printed, and it is probable that the name "Guidone" which occurs in one of his manuscripts was a reference to it. But it, too, fell far short of Leonardo's ideals of what an anatomical text-book should be and its neglect of physiology was not likely to attract to it one whose chief interest in anatomy was the promise it gave for the elucidation of function.

In the *Codex Atlanticus* there is a reference to "Ægidius Romanus *de formatione corporis humani in utero matris.*" Ægidius Romanus, also known as Ægidius Columna, was a distinguished scholastic prelate, who was born at Rome about 1247 and died in 1316. He rose to be Cardinal-Archbishop of Bourges and General of the Augustinian Order and was the author of many philosophical treatises, the most famous of which was his *De regimine principum libri III* written for his pupil, Philippe le Bel. It was first printed in 1473 and subsequently republished a number of times both in the original Latin and in French, Italian and Spanish translations. Of a treatise by him *De humani corporis formatione* there is no record in Graesse, but Haller[1] mentions a work with that title by Ægidius Columna, printed at Venice in 1523, at Paris in 1615, and again at Venice in 1626. Haller characterizes Ægidius as "Barbarus scriptor ex Averrhoe fere sua habet," but from the brief statement he makes as to the contents of the work it seems probable that Ægidius really drew his material from Aristotle's *De generatione.* The facts that Averroes was an Arabic Aristotelian, that Ægidius was a pupil of Thomas Aquinas who removed the ban of the Church from the writings of Aristotle, and that he wrote commentaries on several other works of Aristotle, lend support to this suggestion. Roth (1907) in his discussion of the reference to Ægidius points out that, according to Uzielli, it is not in Leonardo's handwriting, but suggests that it may have been written in his note-book by one of his medical friends as of interest to him in connection with his

[1] A. Haller, *Bibliotheca anatomica*, vol. 2, p. 737, 1777.

embryological studies. If so it must have been a reference to a manuscript copy of the work, but there is also a remote possibility that it may have been an interpolation by a later hand.

That Leonardo knew of the writings of the great Dominican, Albertus Magnus, is shown by two references (F, cover; I, 130) to the treatise *De cœlo et mundi*. This, however, is astronomical, but if Leonardo knew it, he probably knew also of the *De animalibus*, in which Albert has set forth his knowledge of anatomy, zoology and comparative anatomy. Taking into account the century and a half that separated the two, one might say that Leonardo and Albertus were men of much the same type, keen to probe the secrets of all the sciences—Albertus, according to the spirit of his age, with the object of establishing a scientific basis for his theology, Leonardo from a pure love of science. The scholastic, however, was content to set forth the views of others, while Leonardo, inspired by the individualism of the Renaissance, must observe and judge for himself. There is no evidence that Albertus had any personal knowledge of anatomy, except that of the skeleton; he relied very extensively on Avicenna in his exposition of it, not infrequently using his very words. But the influence of Aristotle is also to be seen, and in the chapters on comparative anatomy and zoology the *Historia animalium*, in the translation by Michael Scot, is the main inspiration, although Albertus contributed to the zoology observations not elsewhere recorded. Since Leonardo intended to include comparative anatomy in the scope of his studies and did to some extent, one would have expected to find in his manuscripts some reference to the *De animalibus*. Nowhere else, not even in Aristotle's *Historia animalium*, could he have found so useful an account of the facts of comparative anatomy, for Albertus, after completing his review of human anatomy, takes this as his standard with which to compare the organs of the lower animals. Leonardo's studies in comparative anatomy were undertaken partly in the hope that the arrangements in the lower animals would explain those observed in man, and yet there is no evidence that he turned to Albertus for information that might help to realize that hope.

Of the anatomical treatises of the School of Salerno there is no mention in Leonardo's manuscripts, but there are possible references to commentaries upon the more famous *Regimen Sanitatis Salerni*. Thus the memorandum "Della conservazione della Sanità" (CA) is accepted by Roth (1907) as a reference to a work, probably a commentary on the *Regimen*, by Ugo Benzi di Siena, who is on record as having performed an Anatomy at Padua in 1429. There is another possibility, however, namely, that the reference may be to the *Liber de homine* of Hieronymo Manfredi, of which the first and chief part bore the title *De conservatione sanitatis*, although the text, like Leonardo's memorandum, is Italian. The book was published in 1474 at Bologna, where Manfredi was Professor of Medicine, and passed through several editions,[2] so that it may very well have been known to Leonardo.

Less evident is a reference to "Maghino speculus di M° Giovanni Francioso" (AnB, 2). Roth (1907) identifies "Maghino" with Magninus Mediolanensis, whose *Regimen Sanitatis*, published as early as 1482, is, according to Haller,[3] identical with Arnald de Villanova's commentary on the *Regimen Sanitatis Salernitanum*. Arnald was also the author of *Speculum introductionum medicinalium* and this, Roth suggests, may be identical with the commentary on the *Regimen*, in which case Magninus' *Speculum* would be merely an edition of Arnold's commentary under another name. This suggestion is negatived by the probability that Arnald's *Speculum* is a later work than his *Regimen* and, according to Steinschneider, is based on the *Introductio in medicinam* of Honein ben Ishaq (Johannitius), and this again on Galen's *Ars parva*. The identity of "Maghino Speculus" thus remains unsolved.

The only Arabian authors whom Leonardo mentions by name are Avicenna and Al-Kindi, but indirectly a reference occurs to one other. In the passage in the *Codex Atlanticus* that may refer to the *Regimen sanitatis* there is mention of one Cibaldone, who, according to Choulant,[4] published in Italian two hygienic poems based on the third book of Rhazes' *Almansor*.

Avicenna is mentioned in several passages. In AnA, 18, one finds "Avic. Li muscoli che movano li diti del piè sono 60." But one will look in vain for such a statement in Avicenna's *Canon*; he merely states that the muscles moving the toes are many, giving no definite number.[5] Mondino, however, gives the number of the muscles in question as sixty on the authority of Avicenna and it seems probable that Leonardo in his reference is quoting from Mondino rather than directly from any translation of the *Canon*. At the top of QI, 13v is the sentence "Fa tradurre avicena de govamenti." The significance of this is obscure, since no work of Avicenna with that title is known. Chapters 6 to 13 of the anatomical portion of the *Canon*, those, that is to say, which deal with the structure and functions of the vertebral column, bear the special title *de juvamento dorsi*, but it does not seem likely that Leonardo had this in mind, and even if he had it is not clear

[2] For an account of the work see C. Singer, *A Study in Early Renaissance Anatomy with a New Text: The Anothomia of Hieronymo Manfredi* (1490). *Studies in the History and Method of Science*, vol. 1, 1917.

[3] A. Haller, *Bibliotheca med. pract.*, vol. 1, 449, 1776.

[4] L. Choulant, *Handbuch der Bücherkunde für die ältere Medicin*, Leipzig, 1841. The work is also mentioned by Graesse. Choulant gives the title as follows: *Opera de l'excellentissimo physico magistro Cibaldone electa fuori de libri autentici di medicina utilissima a conservarsi sano.* Neither place nor date is given.

[5] So at least it is in the 1595 edition of the translation of the *Canon* by Gerard of Cremona, and in the French translation by de Koning.

why he should wish to have it translated, since the Latin translation of the *Canon* by Gerardus Cremonensis was published in Milan in 1473 and subsequently was issued in many editions during Leonardo's lifetime from the presses of Venice, Padua and Pavia. It would seem much more probable that Leonardo desired a translation of Galen's *de usu partium* and wrote the name of Avicenna in error. He mentions elsewhere (AnB, 2) "Galieno de utilità" and the existence of that work was therefore known to him, but Latin translations of Galen's works were rare in Leonardo's time, though that edited by Diomedes Bonardus was published in Venice in 1490 and was printed again in 1502 and 1511 (?). A point worthy of note in this conneetion is that Mondino in his *Anothomia* states that he had also written a *Lectura super primo, secundo, tertio et quarto de juvamentis*—evidently Galen's *de usu partium*, and from this statement Leonardo may have obtained knowledge of the work and of the title used on QI, 13v.

A third reference to Avicenna occurs on QIII, 3v, and may be translated thus: "Here Avicenna wishes that the soul generates the soul and the body the body and each member per erata." (The meaning of the last two words is not clear.) One will search in vain for this statement in the anatomieal chapters of the *Canon*, but it may occur elsewhere in Avicenna's writings. The *Canon* was the most popular medical work of the time, used as a text-book in all the schools of medicine and published in many editions during Leonardo's lifetime. Leonardo must surely have known it, even if his references to it are inexact.

A reference to Al-Kindi is of interest, because that author, one of the most encyclopædic of the Arab writers, had written a highly esteemed treatise on geometrical and physiological optics, subjects to which Leonardo gave much attention. This work, *De aspectibus*, had been translated into Latin by Gerard of Cremona, but Leonardo's reference, "Le proporzioni d'Alchino con le considerazioni del Marliano" (CA, 222), is not, according to Solmi (1919), to an original work by Al-Kindi, but to a manuscript commentary on one of these by Giovanni Marliani, who, according to Tiraboschi, was Professor of Medicine in the short-lived University of Milan (1447–1450) and afterward at Pavia, where he died in 1483. He was deseribed in a contemporary document as another Aristotle in philosophy, another Hippocrates in medicine and another Ptolemy in astronomy. It is of interest that Leonardo received the manuscript from Fazio Cardano, the father of the mathematician Gerolamo Cardano.

Of classical authors who might have been consulted, Galen, Pliny, Celsus, Aristotle and Hippocrates are mentioned. The reference to Galen's *de usu partium* has already been considered. Pliny is merely mentioned, as is also Celsus. The name "Cornelio Celso" occurs on Tr, 2v, and shows that Leonardo at least knew of the *de re medica*, which was published at Florence as early as 1478 and many times thereafter. Immediately following the name are the words "The greatest good is wisdom, the greatest evil is bodily pain," a phrase that reads very like one of Leonardo's own aphorisms. At all events it is not to be found in the *de re medica*.

Aristotle is mentioned several times (I, 82v; M, 62), but the citations furnish no evidence that Leonardo had consulted either of the works in which Aristotle treats of anatomy—the *Historia animalium* and the *De partibus animalium*. The reference to Hippocrates (S.K., III) reads—

"Hippocrates says that our semen has its origin from the brain (*celabro*), the lung and the testicles of our parents, where it makes the last decoction; and all the other members contribute of their substance by sudation to this semen, since no path is evident by which they might be able to reach the semen."

This is a fair statement of the opinions expressed in the Hippocratic treatises *De semine* and *De morbo sacro*; but it is nevertheless doubtful whether Leonardo had a first-hand knowledge of the writings. Their first Latin translation, incomplete at that, was not published until 1525, and the first printed Greek edition, that edited by Asulano, came from the Aldine press in the following year, both publications, therefore, occurring after Leonardo's death. He may, of course, have had access to a manuscript, for although he was accused of being unlettered (*omo sanza lettere*, CA, 119v), he seems to have had some knowledge of the Greek language (Solmi, 1910).

With Hippocrates the list of authors who might have rendered Leonardo inspiration in his anatomical studies and who are mentioned by him is completed, and one is forced to the conclusion that his indebtedness to his predecessors in anatomy was practically limited to what he might have obtained from Mondino and Avicenna. These were the preëminent authorities in his day, and to them he would naturally turn at first for guidance, though once he had acquired the rudiments of his subject he relied apparently on his own observations, so far at least as they were strictly anatomical. In his physiological concepts an indebtedness to Galen is strongly indicated, but the indebtedness may have been rather to the Galenic tradition as set forth by Avicennna than to Galen directly. It is to be noted, however, that his single reference to Galen's *De usu partium* occurs in a folio which must be assigned to an early period of his studies (ca. 1489), and it is further to be noted that his association with Marc Antonio della Torre, a pronounced Galenist, might well have awakened a desire for the study of that author.

Holl (1905) in his review of Leonardo's anatomical manuscripts takes essentially the position indicated above, concluding that he could have obtained little assistance from any of the earlier authors available to him, but mentioning of these only Mondino and Avicenna and Galen in Arabistic translations. "Unbefriedigt und vielleicht auch unmuthig wird er die gelesene Werke aus dem Hand gelegt haben." Roth (1907), however, takes a very different view of the question, claiming that "Leonardo's anatomy shows many relations to the literature, more abundant and more intimate relations than Leonardo's scanty citations of authors would indicate." He endeavors to substantiate this by references to a number of special items, the sources for which he traces for the most part to Galen, though many might as well be assigned to Galenic tradition set forth by Mondino and Avicenna. In selecting items for comment Roth, however, does not distinguish between Leonardo's earlier and later efforts, making much, for instance, of the errors shown on the QIII, 3v, which unquestionably belongs to an early period, before Leonardo had begun to rely to any great extent on his own observations. The fact, indeed, that the majority of these errors were corrected in later drawings is evidence of Leonardo's emancipation from the Galenic anatomical tradition and of his reliance on what he saw for himself. But Roth denies that Leonardo made any dissections for himself and in so doing he virtually denies to Leonardo any originality in his anatomical studies; he is forced therefore to find the source of his inspiration in the literature and as evidence in support of this adduces discrepancies in certain of Leonardo's drawings, which, however, are evidently due to the fact that these drawings are largely schematic. Thus in AnB, 27v, in which Roth calls attention to variations in the number of ribs and vertebræ shown, the structures in which Leonardo is interested are the muscles, and the ribs and vertebræ are represented merely schematically; errors in their number must be ascribed to carelessness, since elsewhere the correct number is stated, and carelessness as to details which for the moment seem unessential may be found in drawings of much later date than Leonardo's and may be pardoned in his, made at a time when strict accuracy, even in essentials, had not become the standard in anatomical illustration.

The study of Leonardo's anatomical nomenclature does not throw any great amount of light on the sources of his anatomical information. That which he uses is, like his physiological concepts, essentially that of the Arabistic writers of his time, and shows, for example, a remarkable similarity with that of the *Anothomia* of Hieronymo Manfredi published by Singer[5] from a Bodleian manuscript. Manfredi was a Bolognese, born about 1430 and therefore some twenty years older than Leonardo. He was educated at the University of his native town and became its Professor of Medicine in 1463, holding that chair until his death thirty years later. He was, however, more renowned for his

[5] For reference see foot-note on p. 27.

devotion to astrology than for his skill and knowledge in medicine, although one of his books, *Liber de homine,* principally concerned with diet but also treating of physiognomy, was very popular.

The *Anothomia* was written at the request of the then ruler of Bologna, Giovanni Bentivoglio, who had attended one of Manfredi's Anatomies, and may be described as an enlarged and rearranged Mondino. The similarity of Leonardo's nomenclature to that of the *Anothomia* extends also to many of the ideas expressed, and one is tempted to believe that Leonardo may have made use of Manfredi's treatise, especially if the suggestion (p. 27) that he knew of that author's *Liber de homine* is well made. The *Anothomia,* however, was never printed until Singer made it public, and the researches of that writer indicate that the Bodleian manuscript of it is unique, perhaps the sole copy that was prepared for presentation to Bentivoglio, and the similarities that are so striking may be due to the fact that the *Anothomia,* as Singer expresses it "may be taken to represent, with but little modification, the tradition of Mondino as developed at his own University of Bologna at the end of the fifteenth century."

The Arabic terms found in Leonardo's manuscripts—such as *meri* for œsophagus, *mirach* for abdomen, *sifac* for peritoneum, *raseta* for wrist—are all terms used in the Latin versions of Avicenna and in the *Anathomia* of Mondino, additional evidence of Leonardo's indebtedness to these works and especially to Mondino's, for when there is a difference between the terms used by Avicenna and Mondino, Leonardo and also Manfredi follow Mondino. Thus the Latin Avicenna, that by Gerard of Cremona, uses *venæ soporariæ* for the jugular veins, while Mondino uses *venæ apopleticæ* and so do Leonardo and Manfredi; the word *alchatim* in Avicenna denotes the lumbar vertebræ, while in Mondino, Manfredi and Leonardo (*alcatin, catino*) it stands for pelvis. Indeed it may be said in brief that the evidence furnished by the nomenclature points clearly to Mondino as the primary source for both Leonardo and Manfredi, the Latin Avicenna being Mondino's source.

It may be said that in general, Arabian influence is shown in mediaeval anatomical nomenclature in three ways, the most evident of which is the use of Arabic words. A second way is by the literal translation into Latin of Arabic words used in a more or less metaphorical manner. To this group belong the words *sylvestris* and *domestica* commonly used by the Arabists to denote respectively outer and inner, especially in connection with the surfaces of the limbs, and the terms *focile* or *fucile,* used for the bones of the forearm and crus, and *monoculo* used for cæcum have probably the same origin. Thirdly and less numerous are Greek words, which take on most un-Greek forms because they are transcriptions into Latin equivalents of Arabic transcriptions of the Greek words. An example of this group may be seen in *ahorti* or *adorti* which are more or less accurate transcriptions of *awurti,* the

Arabic transcription of aorta. Examples of all three groups are to be found in Leonardo's manuscripts.

However, three of the terms used by Leonardo seem worthy of further consideration, two of them because they possibly suggest some Salernitan influence on Leonardo's nomenclature, while the third may serve to round off, in the light of further information, certain items discussed in Hyrtl's works on anatomical nomenclature—works invaluable to a student of mediaeval anatomy.[7] On QV, 1 is represented a full-length figure of a man showing the visceral and vascular anatomy and on the right ureter there is the label *"vena cilis"* written from above downward and not in the characteristic looking-glass manner. *Vena chylis* is the term usually applied by mediaeval authors to the vena cava inferior, the word chylis, as Hyrtl has shown, having nothing to do with chyle, but being a corruption, through the Arabic, of the Greek word *koile* = cava. Leonardo himself uses it for the vena cava (*vena del chilo,* QI, 4) and so do Mondino (*chillim*) and Manfredi. On the other hand the usual term for the ureters is the Galenic *pori ureterides,* and Leonardo uses for them a slight modification of that term (*pori ureterici,* AnB, 14). How comes it then that on QV, 1, he labels the ureter *vena cilis*? No satisfying answer can be given to this question, but a passage in the Salernitan *Anatomia porci,* attributed to Copho[8] seems to offer a suggestion. The great vein (vena cava) is described as descending to the level of the kidneys and there bifurcating, and then the passage continues—

"et ibi fit vena chilis in qua infiguntur capillares venæ, quæ præter nimia parvitate sua videri non possunt, per quas urina cum quattuor humoribus mittitur ad renes."

This, evidently, is the expression of Galen's views as to the formation of the urine, but it might be interpreted to mean that since the capillary veins open into the vena chilis, this was the duct leading the urine to the bladder. To aid in such an interpretation is the fact that in the Salernitan treatise the term *pori uritides* indicates merely the openings of the ureters into the bladder.

On QI, 13 is the curious word *astalis* which is correctly translated as rectum by the editors of the volume. Without the aid of Hyrtl it would have been difficult to determine the origin of this word. It is evidently the same as *astale* used by Leonardo's unfortunate contemporary Gabriele Zerbi in his *Liber anathomia corporis humani* (1502), and this is a corruption of *extalis* which the dictionaries give as a comprehensive term for the principal viscera, those upon whose appearance the haruspices based their prognostications. According to Hyrtl *extale* in the sense of rectum is found in the *De arte veterinaria sive mulomedicina* of Publius Vegetius Renatus (circa A.D. 420) and it

[7] J. Hyrtl, *Das arabische und hebräische in der Anatomie,* Wien, 1879; *Onomatologia anatomica,* Wien, 1880.

[8] See foot-note p. 11.

is interesting to note that *extalis* is used in the same sense in the Salernitan *Demonstratio anatomica.* Since the *Demonstratio* is concerned with the anatomy of the pig, its author may have consulted the veterinary treatise of Vegetius; and Zerbi, mis-spelling the word, may have taken it from the *Demonstratio.* Since Leonardo similarly mis-spelled it, it is probable that he borrowed it from Zerbi, whose *Anathomia* may, perhaps, be added to the list of Leonardo's sources. It is possible, of course, that Leonardo and Zerbi may have taken the word from a common source, in which it had already acquired its incorrect spelling. and, further, it is possible that Zerbi may have borrowed it from a Latin version of Avincenna in which, according to Hyrtl, *extale* is given as a synonym of rectum.

The third term is at first sight most puzzling; it is *pomo granato,* denoting the xiphoid process of the sternum. According to Hyrtl the word *pomum* was frequently used by the Arabists for any rounded prominence of the body, and therefore for the prominence of the larynx, and since the pomegranate was the variety of *pomum* most familiar to the peoples of Southern Europe *granatum* came to be added to it. The thyroid prominence being more marked in men than in women the name *pomum viri* was also applied to it and the Hebrew equivalent of *vir* being *adam,* opportunity was afforded in translation to transform *pomum viri* into *pomum Adami.*[9] If this be the correct order of events it would seem that the legend—that the prominence is a reminder of the piece of the fruit of the tree of the knowledge of good and evil that stuck in Adam's throat—followed the name and not the name the legend. But that is another story.

In the Latin Avicenna the larynx is termed epiglottis, the structure now known by that name being called *galsamach,* which later Arabists supplant by *coopertorium* (Mondino and Manfredi) or *linguella* (Leonardo). Pomum granatum and epiglottis were therefore equivalent terms. But the Latin Avicenna terms the xiphoid cartilage the *epiglottalis* and so *pomum granatum* becomes also applied to that structure. But why the shift of cartilago epiglottalis from the larynx to the xiphoid process? Hyrtl endeavors to explain it by supposing that the xiphoid cartilage may sometimes bend forward so as to produce a *pomum* and to this *pomum granatum* was transferred, epiglottalis following. In reality, as De Koning has clearly shown,[10] the transfer of epiglottalis was the first step. The Arabic word used by Avicenna for the xiphoid cartilage was *khanjara* which means sword-like and is therefore the exact equivalent of the Greek word xiphoeides. The first letter, *kh,* of the Arabic word is distinguished from the symbol for *ḥ* only by having over it a diacritic dot. Either this dot may have been omitted in the Arabic text used by Gerard of Cremona or he overlooked it and so read *hanjara* for *khanjara.* And the former means larynx.

[9] Dr. Sarton, however, points out that *adam* is the equivalent of *homo* and not of *vir.*
[10] P. de Koning, *Trois traités d'anatomie arabes,* Leyden, 1903.

CHAPTER IV

ANATOMICAL ILLUSTRATION BEFORE LEONARDO

Great as is the interest attaching to Leonardo's notes as indicating the anatomical problems for which he sought solutions and the methods he adopted in his attack upon these problems, greater still is the interest associated with his illustrations, partly because they are largely records by a consummate master of art of what he had himself observed and partly because of the great importance he attached to illustration as a didactive method. In several passages he expresses his conviction that for a correct appreciation of the form of any structure one must view it from various aspects, and he vaunts the value of such illustrations over mere description. Thus he says—

"Oh Writer! with what words will you describe the entire configuration with the perfection that the illustration here gives? This, not having knowledge, you describe confusedly and allow little information of the true form of the things, deceiving yourself in believing that you can satisfy the auditor in speaking of the configuration of any corporeal object, bounded by surfaces. But I remind you not to involve yourself in words, unless you are speaking to the blind, or if, however, you wish to demonstrate by words to the ears and not to the eyes of men, speak of substantial or natural things and do not meddle with things pertaining to the eyes by making them enter by the ears, for you will be very far surpassed by the work of the painter. With what words will you describe the heart without filling a book, and the more you write at length, minutely, the more you will confuse the mind of the auditor. And you will always have need of expositors (*spositori*) or of a return to observation (*alla sperientia*), which with you is very short and gives knowledge of few things as compared with the whole subject of which you desire full knowledge." (QII, I.)[1]

These are the words of one who is able to speak more eloquently with his pencil than with his pen. His anatomical manuscripts are primarily collections of drawings, the accompanying notes being secondary additions, suggestions of further illustrations that seem necessary, or of problems that require further elucidation by observation. The drawings vary greatly in their finish. Many are sufficiently elaborated as to require no further treatment, others are outline drawings still requiring finishing touches, others again, are frankly diagrammatic; while others are merely crude suggestions—memoranda of themes to be more fully elaborated later. Of the more finished drawings three main types may be recognized. Firstly those that are

[1] Compare passages on AnA, 1v and 14v.

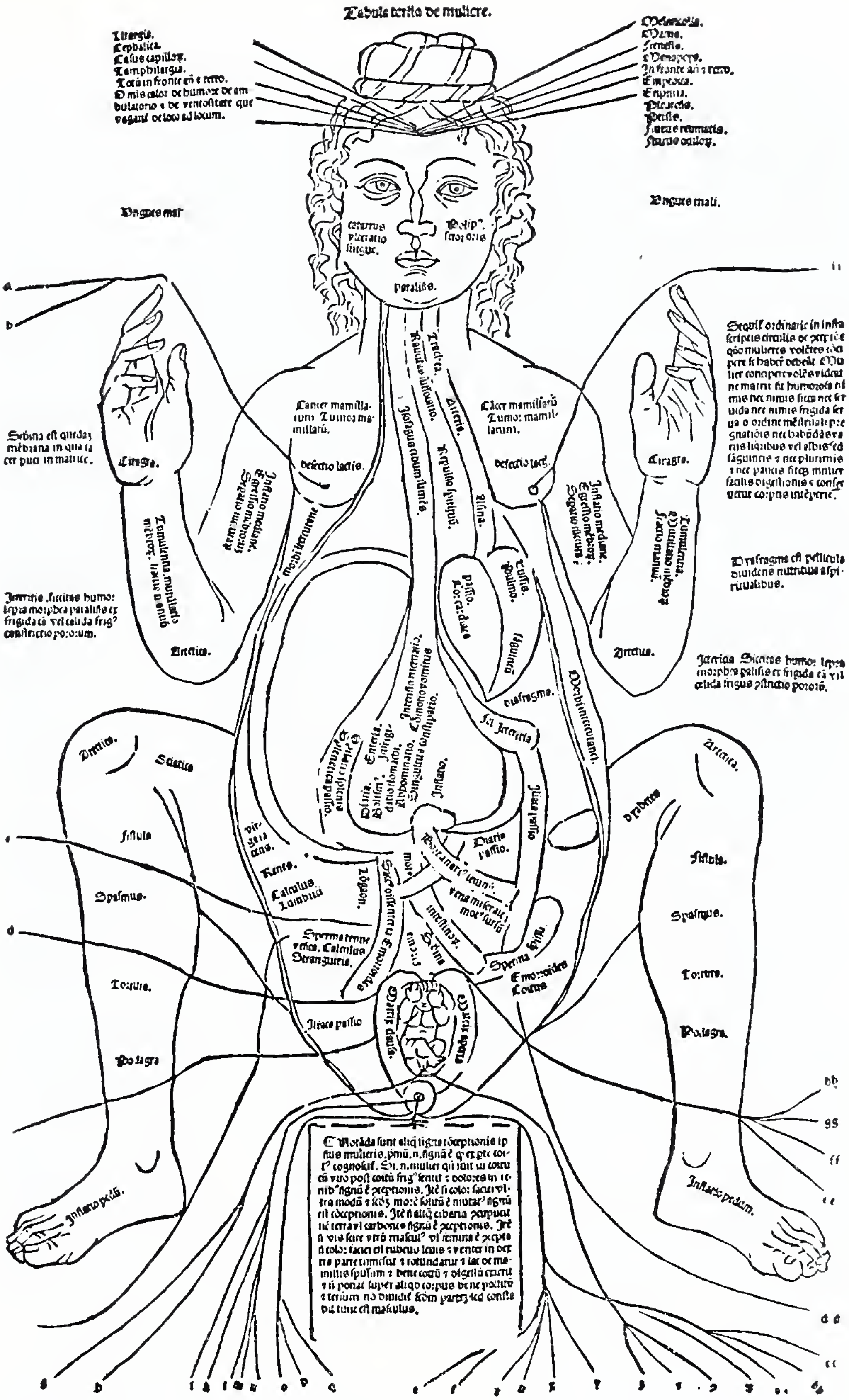


Fig. 3. Situs figure from the *Fasciculus medicinæ* (1491). After the facsimile published by K. Sudhoff and C. Singer, Milan, 10, 1924.

representations of his personal observations, without modifications due to preconceived notions. Of these there are many examples, many that might be selected as suitable for illustration of a modern text-book. But Leonardo was no more infallible than is a modern anatomist and, furthermore, he was a pioneer in anatomical illustration. Consequently one may note that his observation is not always as accurate as might be desired; he pictured what he saw, but sometimes his investigation was not carried far enough and he allowed himself to portray structures as tradition taught them to be. Such drawings constitute the second type, and the third consists of those in which he fell into the same errors as did Galen, by assuming that structures seen in animal dissections were identical with those of the human body. Thus he figured the hyoid bone of a dog in a human throat (fig. 67),[1] the cotyledons of a cow's placenta in that of a human being (fig. 87) and represented the heart of an ox as that of a man. Leonardo appreciated the fact that so far as the musculature and skeleton were concerned, the different conditions in animals required modification of the human plan. But where the functional demands on organs seemed to be identical, it seemed permissible to suppose that their structure would also be identical, since he believed that "Nature always produces its effects in the easiest way and in the shortest time that is possible" (QI, 4), and that "The Author never makes anything superfluous nor defective" (QII, 3)—what would serve in one case would, therefore, serve in another similar case.

But one may forgive Leonardo's inaccuracies because he was doing the work of a pioneer, because, even with them, he was representing the structures of the human body with an accuracy and skill such as never had been seen before and because he was the originator of a revolution in anatomical illustration which was to play an important part in establishing the foundations of modern anatomy.

The earliest printed figure showing the anatomy of the internal organs is that in the 1491 edition of Ketham's *Fasciculus Medicinæ*,[2] published two years after Leonardo had definitely become immersed in his anatomical studies. A glance at the figure (fig. 3) shows that it is highly conventionalized, not one of the organs showing its true form or relations; even the crouching posture, with the arms flexed so that the hands are on a level with the shoulders, smacks of conventionalism and suggests the possibility that the figure is a reproduction of some earlier drawing. This probability has been made a certainty by the researches of K. Sudhoff, who with exceptional skill and ingenuity has traced it to its origin, reconstructing an interesting chapter in the

[2] In his preface to the facsimile reproduction of this work Sudhoff has suggested that Ketham was a corruption of Kirchheim. There was a Johannes von Kirchheim professor of surgery at Vienna, 1445–1470.

history of anatomical illustration.[3] He found in the Hof- und Staatsbibliothek in Munich a manuscript (Codex monacensis germanicus 597) whose contents are chiefly astronomical and astrological, but which includes also a certain amount of gynecological and obstetrical material. It bears the date 1485 and is of interest in the present connection from the fact that on one of the pages there is a water-color drawing of a female figure, strikingly similar to the Ketham figure of 1491 and showing the viscera. It shows a similar crouching posture with the hands up-raised, but, instead of the turban seen in the Ketham figure, the head is covered by a coif. The representations of the viscera are very similar in the two figures, that of the Munich Codex showing the intestines in greater detail and, in order that the rectum may be more clearly shown, having the uterus displaced toward the left; it is noteworthy that the posture of the fetus, with the hands covering the eyes is unaltered. If any doubt could exist as to the common origin of the two figures it would be dispelled by the fact that the legends borne by the various organs are for the most part identical.

Sudhoff also records the occurrence of a figure almost identical with that of the Munich Codex in a manuscript in the possession of Dr. Gustav Klein of Munich and has found another example of a similar figure in a manuscript in the Bibliothèque Nationale, Paris (Ms. Lat. 11229), written some time during the reign of Charles VI (1380–1422). The crouching posture has disappeared in this last figure and the uterus contains two fetuses, but otherwise both figure and legends are essentially identical with those of the Munich Codex. Finally, Sudhoff traces these various figures to one found in a manuscript (Cod. 1122) in the library of the University of Leipzig, dating to approximately 1400. In this the crouching posture is quite marked, the kidneys, omitted in the Munich Codex, are represented and the uterus has its position in the median line, the contained fetus having the characteristic attitude already mentioned. No legends occur in the various parts of this figure.

It is evident then that the figure representing the situs viscerum of the female printed in the 1491 edition of Ketham's *Fasciculus* is a reproduction of a figure that had been in use for at least almost a century and from the first had represented the various organs in a highly conventionalized manner. Nor is it even a faithful reproduction of its prototypes, but was evidently drawn by one unfamiliar with human

[3] Sudhoff's studies are to be found in a series of papers published in the Archiv and Studien zur Geschichte der Medizin. An interesting account of early anatomical illustrations has been given by W. A. Locy in his paper entitled *Anatomical Illustration before Vesalius* (Jour. of Morphology, vol. 22, 1911) and important data are also to be found in F. Wieger's *Geschichte der Medizin und ihrer Lehranstalten in Strassburg vom Jahre 1497 bis zum Jahre, 1872,* Strassburg, 1885.

anatomy, so that the original conventionality became still more conventionalized. It is worthy of note, however, that the figure throughout its history was not accompanied by an anatomical description of the parts delineated. Some of the accompanying legends are names of the parts represented, but the majority are the names of diseases, such as *passio iliaca, ictericia, podagra,* etc., which have their seats in the parts indicated; it is a pathological rather than an anatomical illustration. The Ketham *Fasciculus* of 1491 contains no anatomical treatise; Mondino's *Anathomia* was added to the original medical treatise in the editions of 1493 and 1495, and while the figure, still further modified, appears in these, it illustrates the medical treatise and not the *Anathomia*.

Still the figure must be recognized as a fifteenth century attempt to convey an idea of the anatomy of the human body, and it is interesting to compare with it Leonardo's figure of the female situs viscerum (fig. 4). This too has many inaccuracies, but they are inaccuracies due to insufficient knowledge and erroneous preconceptions and it does attempt to portray accurately the form and relations of the organs, whereas the Ketham figures evidently make no pretentions to accuracy, but are frankly conventional. It is this difference that gives Leonardo's figures a claim to consideration. History was repeating in Science what had already taken place in Art, for just as the conventionalism of Byzantine art had given way to Giotto's example in taking Nature itself for his model, so the overthrowal of conventionalism in fifteenth century anatomical illustration, which was consummated in the sixteenth century, was foreshadowed in Leonardo's drawings, and this meant that in anatomy, as in other sciences, nature instead of theory was being taken as the guide. It would be idle to speculate upon what might have resulted had Leonardo's drawings been made accessible by publication to the scientific world, but it may be truly said that he was the first to strive for accurate representation in anatomical illustration, the first to discard servile adherence to tradition and to recognize the educational and scientific value of accurate illustration. He was the pioneer in a new field that was to be more successfully exploited by his successors, notably by Vesalius and Eustachius.[4]

The female situs viscerum of the 1491 Ketham is taken as a type of that class of early illustrations whose purpose is medical rather than strictly anatomical; other examples would have served to demonstrate the extreme conventionalism that was characteristic of such figures in

[4] The history of the anatomical illustrations of Eustachius in one respect resembles that of Leonardo's drawings. His *Tabulæ Anatomicæ* were completed in 1552 and remained unpublished in the Papal Library at Rome until 1714, when, at Morgagni's suggestion, they were published by Lancisi. They were the first anatomical illustrations to be printed from copper plates.

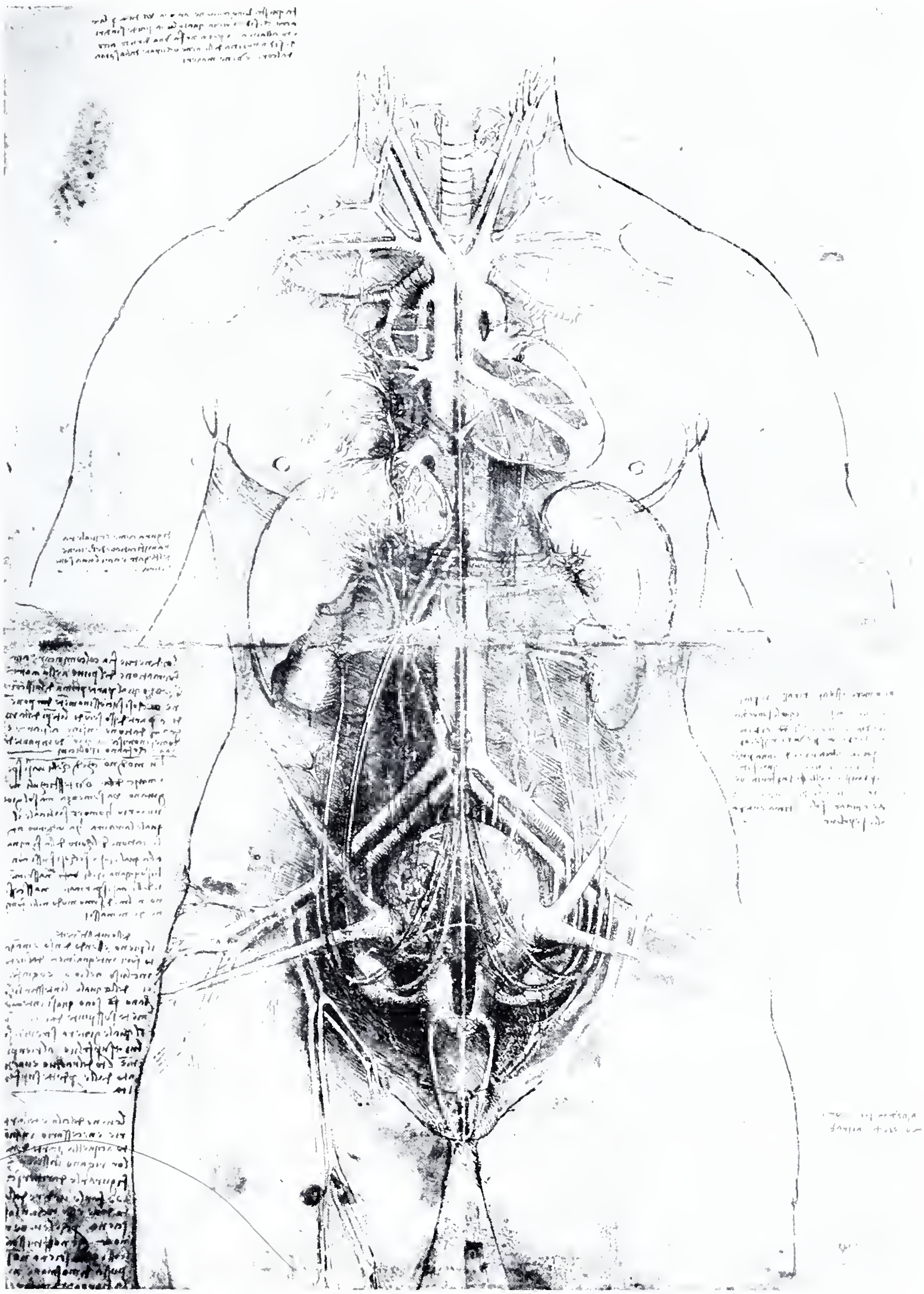


Fig. 4. Leonardo's Situs figure. QI, 12.

Leonardo's time. The 1491 Ketham has altogether six illustrations, which, with some slight modifications, are repeated in the 1493 and 1495 editions, when Mondino's *Anathomia* was added to the original text. These figures are (1) a series of urine glasses arranged in a circle and illustrating the diagnostic significance of modifications of the urine as to color, precipitates, etc.; (2) a male figure showing the regions in which venesection may be satisfactorily performed; (3) the female situs viscerum; (4) a male figure showing the wounds produced by various weapons; (5) a male figure upon which are indicated the regions that are the seats of various symptoms; and (6) a male figure showing the regions supposed to be under the influence of the various signs of the Zodiac. All these are traceable to earlier manuscript prototypes, just as was the female situs viscerum. In the Ms. Lat. 11229 of the Bibliothèque Nationale both the wound man and the symptom man have the hands upraised and the same posture is seen in the wound man of the Munich Codex German. 597, these figures, therefore, showing a relationship to the female situs figure. In later illustrations, as in the Ketham series and the wound man of Brunschwig's *Cirurgia* (1497) (fig. 5), the arms are extended, but in other respects these figures show clearly their derivation from the earlier examples, the wound man being as a rule represented with the body opened so that the viscera are seen and these are of the type shown in the female figures.

The venesection and zodiac men do not, apparently, belong to the same series as the figures just considered. Sometimes the signs of the zodiac are represented on the venesection figure; sometimes there is a separate figure for them, as in the 1491 Ketham, but even here the names of the signs are inscribed in their appropriate regions on the venesection man, although a separate figure is also allotted to them. A close relationship between the two figures is to be expected, since astrological influences were supposed to modify the efficacy of blood letting, as well as purgation, and it was customary for the calendars of the fifteenth century to indicate days suitable for these remedial operations.[5]

It is noteworthy that in none of the venesection figures are the arms upraised. Sometimes the viscera are shown, sometimes not; when they are, they are copies of those of the wound man. In the majority of the figures merely the points at which venesection may be performed are indicated, but the venesection man of Ms. Latin 11229 of the Bibliothèque Nationale shows a crude attempt at a representation of the course of the veins. This is especially interesting as it suggests a relationship between this figure and the representation of the veins in

[5] See K. Sudhoff, *Lasstafelkunst in Drucken des 15 Jahrhunderts*, Archiv für Geschichte der Med., vol. 1, 1908.

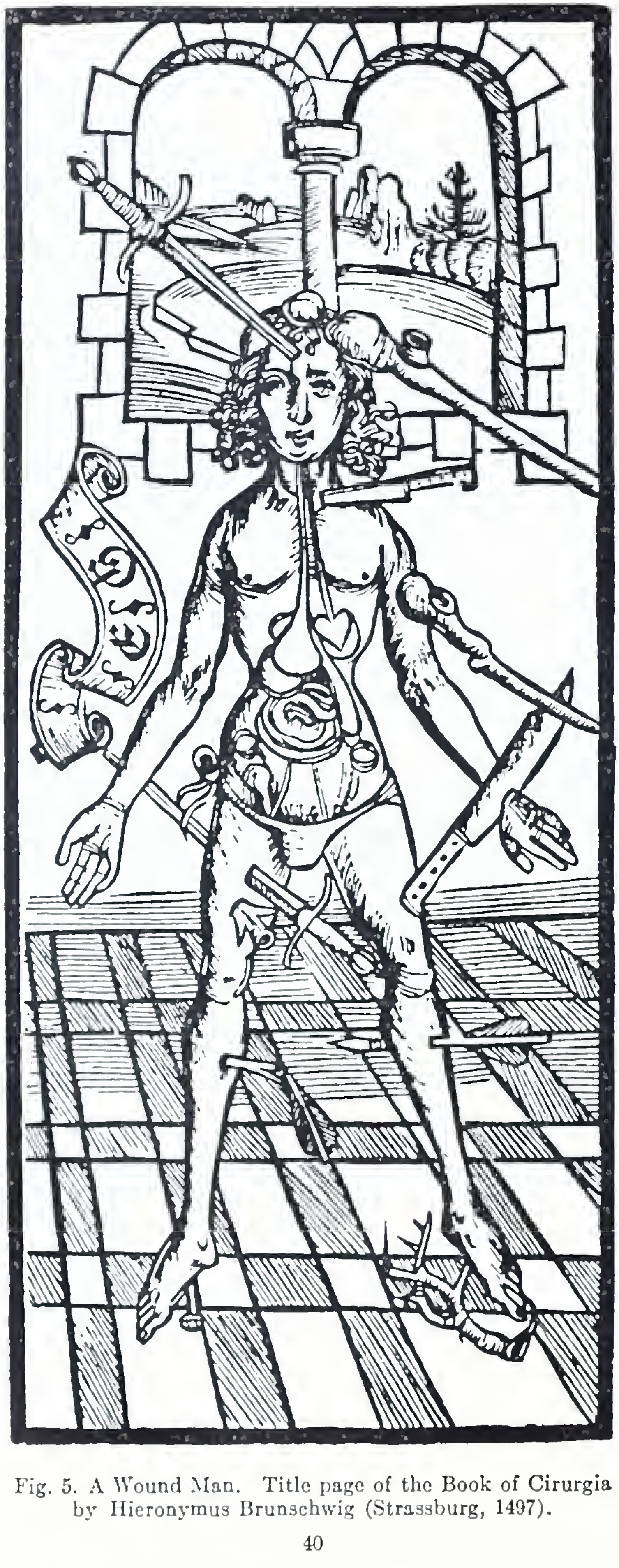


Fig. 5. A Wound Man. Title page of the Book of Cirurgia by Hieronymus Brunschwig (Strassburg, 1497).

the Five-Figure Series of anatomical illustrations whose history has been most interestingly elucidated by K. Sudhoff.[6] He has discovered this series in several European manuscripts of the twelfth, thirteenth and fourteenth centuries and also in Persian and Thibetan manuscripts,[7] and believes that the series may possibly be traceable to a Greek source in the later days of the Alexandrian School. These figures show an extreme conventionalism (figs. 17 and 29) but they do not call for discussion here; their interest lies in their significance as prototypes in anatomical illustration.

The fact that Leonardo was familiar with Mondino's *Anathomia* and the inclusion of that work in the later editions of Ketham's *Fasciculus* render the Ketham figures especially interesting for comparison with Leonardo's. It may be objected, however, that the comparison is hardly just, since the Ketham figures were not primarily anatomical illustrations, but were designed for medical and surgical instruction, in which, according to the standards of the time, anatomical accuracy was not considered necessary. But the Five-Figure Series was a series of anatomical illustrations and shows even a greater conventionalism than does the Ketham series. In addition to these, however, there are for comparison with Leonardo's drawings anatomical figures dating from his time, and these deserve brief consideration. Some early prints of the skeleton may be more conveniently considered later in connection with Leonardo's contributions to osteology, and attention may for the present be directed to the illustrations of Johann Peyligk's *Philosophiæ Naturalis Compendium* published at Leipzig in 1499, the author being at the time Rector of the Faculty of Arts of the University. The greater part of the book is an exposition of the philosophy of Aquinas and Ægidius Romanus, but the concluding pages contain an *Anothomia totius corporis humani suorumque partium principalium*, somewhat similar in scope to the *Anathomia* of Mondino, but briefer and based on the teachings of Aristotle, Avicenna and Constantinus Africanus. Its chief interest lies in the eleven illustrations which accompany it, the first of which, a torso showing the situs viscerum, is reproduced in figure 6. It shows a degree of conventionalism quite as extreme as that which characterizes the Ketham series, but upon somewhat different lines. The five-lobed liver, with the gall bladder resting on its surface, suggests a derivation from the Five-Figure Series, but in other respects there is little resemblance to the figures of that set.

[6] K. Sudhoff, *Tradition und Naturbeobachtung*, Studien zur Geschichte der Med., vol. 1, 1907. See also other papers by the same author in the Archiv für Gesch. der Med., especially that entitled *Abermals eine neue Handschrift der anatomischen Fünfbilderserie* in the third volume of the Archiv, 1910.

[7] E. V. Cowdry (Anatomical Record, vol. 22, 1921) has published some early Chinese anatomical figures which are strongly suggestive of an affinity with the Five-Figure Series, but one may question this author's belief that they may represent the originals of that series.

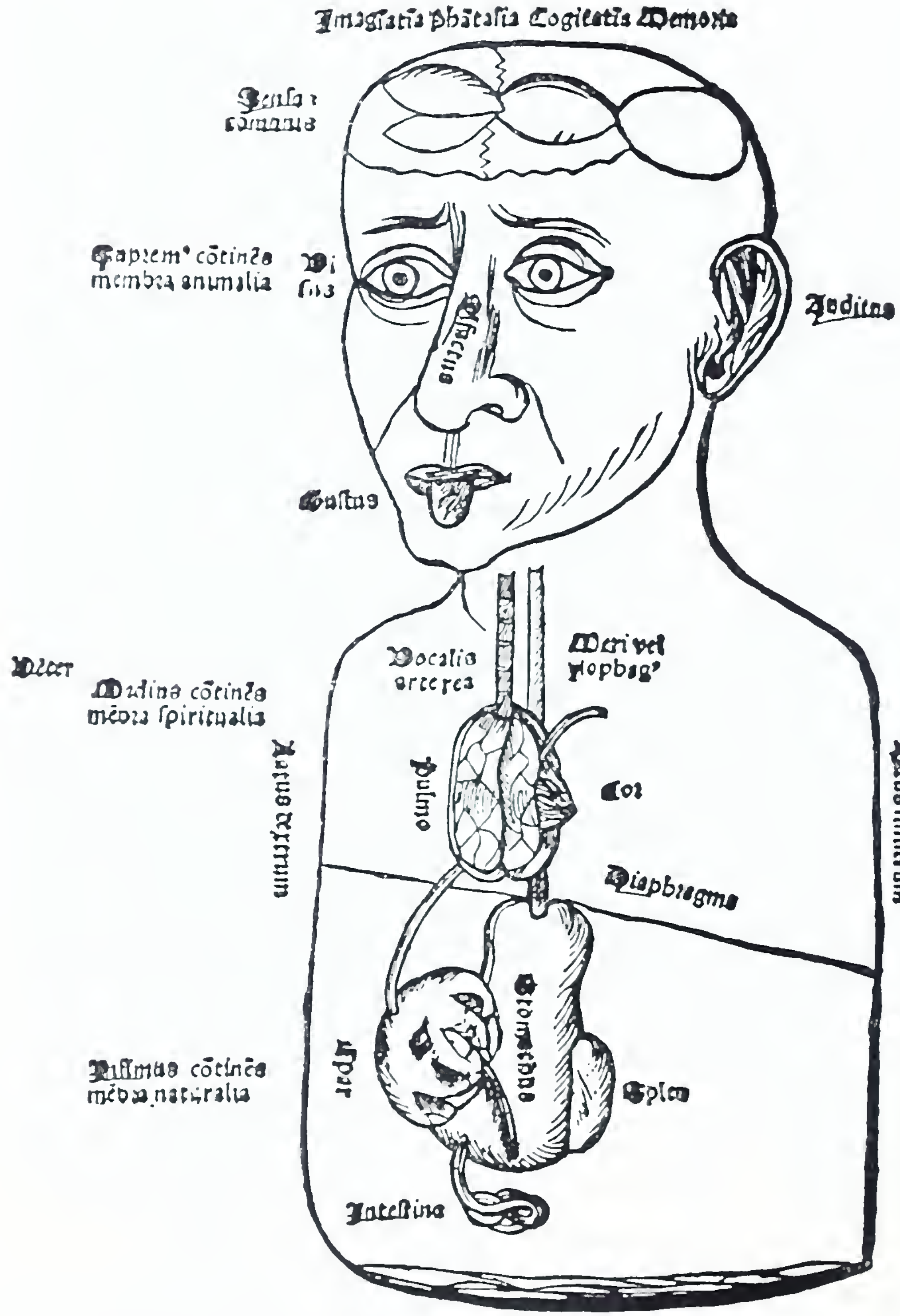


Fig. 6. Situs figure from Peyligk's *Philosophiæ Naturalis Compendium* (Leipzig, 1499). After K. Sudhoff, Studien zur Geschichte der Medizin, Heft. 8, pl. 7, 1909.

The other ten figures of the *Compendium* are representations of individual organs, five of which, those of the stomach and intestines, the trachea and lungs, the liver, the spleen and the brain represented as seen from above in the calvarium, are identical in form with the same organs shown in the situs figure. In addition there are figures of the heart and pericardium, of the kidneys and bladder with the venæ emulgentes, of the calvarium showing the sagittal and lambdoid sutures, of the brain seen from the side, similar to that of the situs figure, but showing very diagrammatically the infundibulum and hypophysis, and of the eye, curiously enough with two pupils.[8] All the figures show the same extreme conventionalism that is manifested by the situs figure. They show very little evidence of careful observation of the organs they pretend to represent, but rather suggest a derivation from some earlier source.

Two years after the publication of the first edition of Peyligk's work, another anatomical treatise made its appearance in Leipzig. This was the *Antropologium* of Magnus Hundt, who had graduated in the Faculty of Arts somewhat earlier than Peyligk and had also been granted the Baccalaureate in Medicine. The *Antropologium* is more strictly anatomical than the *Compendium* and is somewhat more abundantly illustrated, ten of its eighteen figures, however, being identical with the figures of the individual organs that are found in Peyligk's work. The situs figure (fig. 7) is different; the face looks directly forward, the brain is not shown and the tongue does not protrude. In the thorax the lungs occupy the greater part of the cavity, resting on the diaphragm, and the heart is distinctly shown; in the abdomen the stomach is given an oblique position and the kidneys and bladder are represented, but curiously displaced to the right side of the cavity. A comparison of the two situs figures strongly suggests that they were composed independently by assembling within the outlines of a torso the various organs copied from an earlier series of figures of the individual organs, a situs figure having been lacking in that series. Figures 2 to 11 of both the *Compendium* and the *Antropologium* are copied from the series, and it seems probable that some of the additional figures of the latter work were also taken from it. Figure 12 of Hundt's book (fig. 8) is especially interesting in this connection, since it suggests relationships with other examples of early anatomical iconography. It is not included in the Peyligk series of figures, but seems to have been from the same source as the head of that author's situs figure. In both the face is shown in three-quarter view and in both the tongue is protruding; the significance of this protrusion of the tongue is evident in Hundt's figure, but is altogether lost in that of Peyligk, who has

[8] All these figures are reproduced in K. Sudhoff, *Die Medizinische Fakultat zu Leipzig in ersten Jahrhundert der Universität*, Studien zur Gesch. der Med., vol. 8, 1909.

greatly simplified the original figure by omitting the hair, the layers of the scalp, the cranium and meninges and using for the representation of the brain the part of the simpler figure 10 of his series that represents the ventricles.

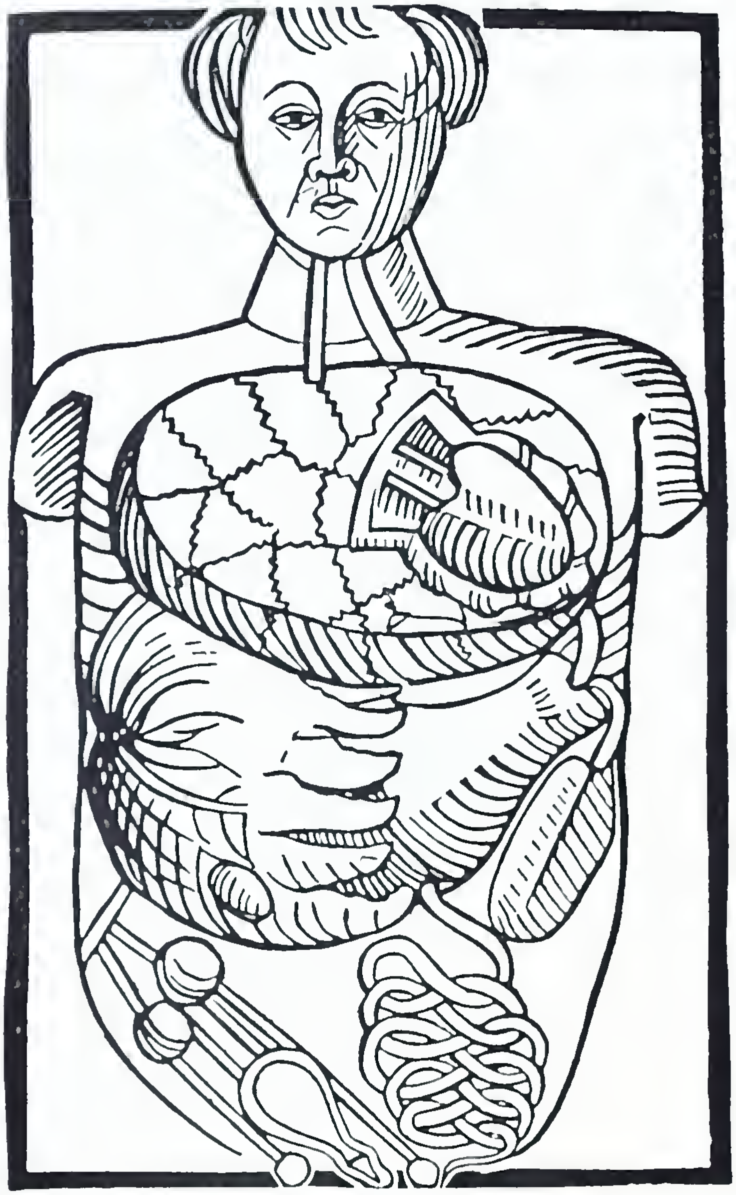


Fig. 7. Situs figure from the *Antropologium, de hominis dignitate* of Magnus Hundt (Leipzig, 1501). After Choulant.

The arrangement of the hair in Hundt's figure 12 recalls the coif that covers the head in some of the earlier examples of the female situs viscerum of the Ketham series, and it is noteworthy that in some of the figures of that series the tongue is shown protruded. Further the representation of the layers of the scalp, the cranium and meninges suggests that this figure or one related to it may have had some influence on Leonardo's diagram (QV, 6v) showing the same structure

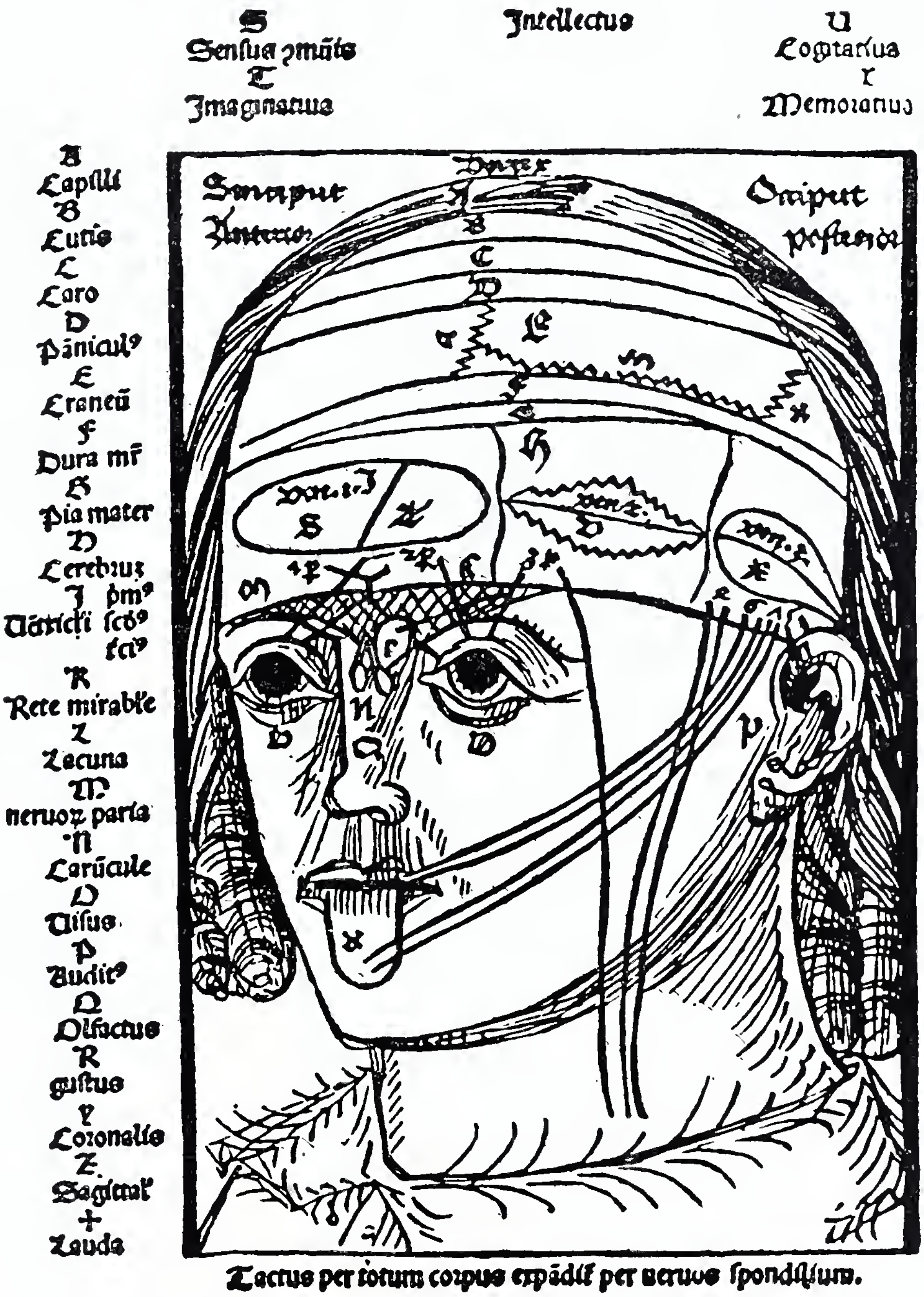


Fig. 8. Brain and sense organs from the *Antropologium* of Magnus Hundt (Leipzig, 1501). After Sudhoff, Studien, Heft 8, pl. 9, 1909.

(fig. 74). If so, the greater accuracy and greater artistic skill shown in Leonardo's diagram is noteworthy. A further suggestion of the Ketham series is to be found in the posture of the venesection man of

Hundt, the left arm being flexed at the elbow, but the remaining figures of the Hundt series do not call for special mention; they include the figure of the uterus and its adnexa, seven uterine cells or chambers being represented, a figure of the hand with chiromantic labels and three very crude diagrams of the vertebræ, the sternum and the abdominal muscles.

The artistic crudity of the situs figures of Peyligk and Hundt is surprising when one considers that they belong to the closing years of the fifteenth century. Hyrtl characterized them as grotesque, but the successful delineation of the grotesque demands no little artistic skill, and this these figures most conspicuously lack; Wieger's comparison of them to caricatures drawn by small boys on walls with a lump of charcoal is more apt. So crude were they that any modifications of them could hardly fail to be an improvement, and such modifications are found in the situs figures of Gregor Reisch's *Margarita Philosophica* published at Strassburg in 1503 and in that of Laurentius Phryesen's *Spiegel der Artzny*, also published at Strassburg, in 1518 (fig. 9). In both of these the representations of the viscera are clearly based on those of Peyligk and Hundt, but in both also there is an attempt, slight in the *Margarita* figure but more successful in the *Spiegel*, to represent with some degree of accuracy and even with some indication of artistic ability the form of the enclosing body.

Such are the illustrations contemporary with those of Leonardo and who shall deny the surpassing excellence of the latter! They combine the appreciation of form and accurate draftsmanship of a great artist and mark the inauguration of a new period in the history of anatomy, when the anatomist and the artist were to collaborate in obtaining and recording a better knowledge of the parts of the body. The importance of this cooperation has been frequently noted, but it still requires emphasis and, indeed, one is tempted to ascribe the greater influence in the movement to the artists.

The art renaissance of the fourteenth century, whose inauguration is usually ascribed to Giotto, was the casting aside of conventionalism and the endeavor to depict Nature naturally. In ecclesiastical art, especially, the depiction of the human body played an important part and the changing modeling of the surface with changing posture incited the desire to understand more accurately the play of the muscles beneath the skin. And so the Renaissance artists of the Florentine school took advantage of opportunities to study the anatomy of the muscles in *cadaveri scorticati*, Pollajuolo setting the example, to be followed by his pupil Verrocchio, and Leonardo was the pupil of Verrocchio. Michel Angelo and Raphael also, as Duval (1890) has put it—

"sought for themselves in dissection the secrets of the nude and the mechanism of movement. And when, under the influence of the Italian Renaissance, the artists of other nations began to reproduce the nude in action they did it with scientific data supplied by the masters of Florence and of Rome."

For the most part these masters approached the study of anatomy purely from the artistic standpoint; they were satisfied with the study of the skeleton or with that of the surface musculature in so far as it

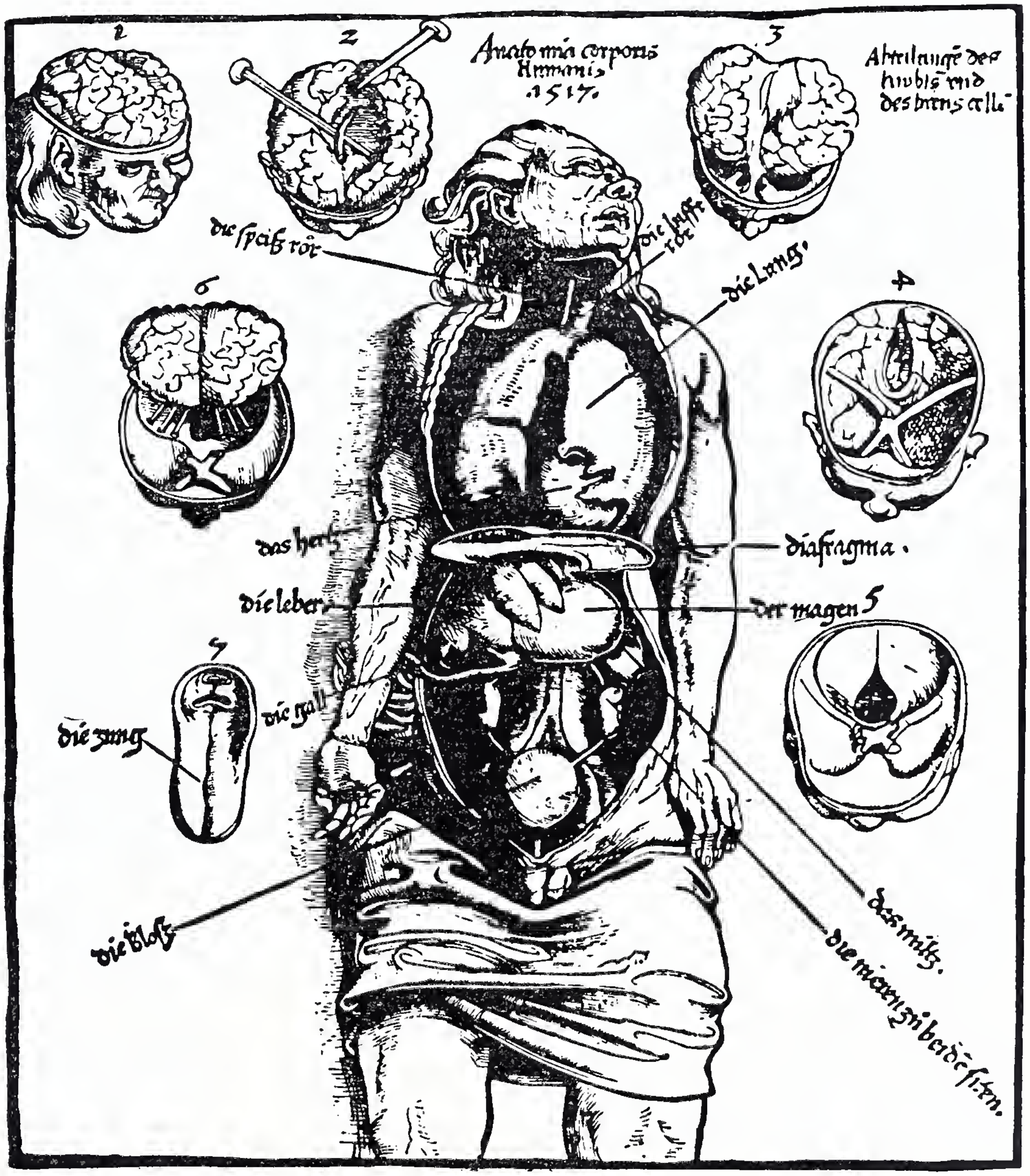


Fig. 9. Situs figure from the *Spiegel der Artzeny* of Laurentius Phryesen (Strassburg, 1518).

affected the modeling of the overlying integument. Possibly Michel Angelo went farther than this in the room and with the bodies that the prior of Santo Spirito placed at his disposal; Leonardo certainly went farther, passing from the artistic to the scientific study of anatomy.

An insatiable desire to understand Nature in all her manifestations led him far beyond mere artistic anatomy, and his genius for mechanics was stimulated by the problems presented by the action of muscles and by the flow of blood through the heart.

The Florentine artists found their opportunities for dissection in the hospitals, Leonardo in the Ospedale Santa Maria Nuova, Michel Angelo in that attached to the Chiesa di Santo Spirito.[9] But the association of artists and hospitals is not an usual one. Why should the former, even granting their desire to perfect their delineation of the human form, have been admitted to privileges usually enjoyed only by physicians? In Bologna the University through the medical faculty gave opportunities in public and private Anatomies for the acquisition of some knowledge of the human frame. But in Florence, during the greater part of Leonardo's residence in that city, there was no university. Earlier efforts had been made looking forward to the establishment of a Studium Generale, and as far back as 1320 the "excellens sapiens et expertus vir, magister Bartholomeus da Varignana" was engaged by the city to teach the art of medicine.[10] In 1348, the year of the Great Plague, a serious attempt was made to establish a Studium Generale including instruction in civil and canon law, medicine, philosophy and the other sciences and the plan received the approval of Pope Clement VI. But the institution maintained but a precarious existence, notwithstanding the granting of an imperial charter in 1364 by Charles IV, Emperor of the Holy Roman Empire, and notwithstanding the appointment in 1373 of Boccaccio as lecturer on Dante. And so it lingered on, unable even with the support of the Medici to compete with the other Italian universities, and eventually in 1472, two years after Leonardo had taken up his residence in the city, the Signoria decided that Florence was not a suitable place for a Studium Generale and ordered its removal to Pisa.

While the University remained in Florence, provision was made by the Statutes for the dissection of two cadavers each year, and

> "In case God grants the Studium to grow, then let the Podesta see to the delivery of not two but three bodies of alien criminals each year; whatever their foul felonies be, let them be hanged (not burned as is the wont with witches, nor beheaded) and delivered the same day, for corruption comes on apace." (Streeter, 1916.)

Thus dissection became a recognized procedure in Florence and one may suppose that even after the removal of the University, the city authorities and those in charge of the hospitals might be willing to countenance it if there were requests for it from responsible persons.

[9] A. Condivi, *Vita di Michelangelo*, Pisa, 1823. Quoted by G. Martinotti, *L'insegnamento dell'anatomia in Bologna prima del Secolo XIX*, Bologna, 1911.

[10] P. H. Denifle, *Die Universitäten des Mittelalters bis 1400*, Berlin, 1885.

Indeed it was during Leonardo's lifetime that Antonio Benivieni, a Florentine, wrote his treatise *De abditis nonnullis ac mirandis morborum et sanationum causis*, a work that has the distinction of being the first special treatise on pathological anatomy. Benivieni was one of three brothers, each of whom gained recognition as an author—Girolamo as a poet, Domenico in theology and Antonio in surgery and anatomy. Of Antonio's life little is known except that he died in 1502, his treatise being published in Florence after his death by his brother, the theologian. It is a record of a number of abnormalities and pathological conditions observed in autopsies, of which, he states, he performed no less than twenty, without counting a number that were made *privatim*, and he gives further evidence of the freedom with which autopsies were then permitted in Florence by considering it worthy of remark that only once was a private autopsy denied him.

But there was another factor in Florentine life that conduced to the recognition of artists as suitable persons to whom the privilege of dissection might be granted. During the Middle Ages the system of Trade Guilds played an important part in the life of the Italian cities and in none more than in Florence. Holding an important place among these Guilds was that of the Apothecaries and Doctors, of which records are in existence dating back as far as the twelfth century.[11] The Guild was under the guidance of four consuls, elected annually from the members and having almost unlimited jurisdiction over all apothecaries, physicians, surgeons, midwives, herbalists, distillers and undertakers, and to these were also added the booksellers, the silk mercers and the artists. The last named placed themselves under the protection of the Guild in 1297, "being beholden for their supplies of pigments to the apothecaries and their agents in foreign lands," but it was not until 1339 that they became a regular corporation under the Guild. Luca della Robbia was several times elected consul and the escutcheon of the Guild, the Virgin and Child in chief supported by pots of annunciation lilies, executed by him, was formerly on the façade of the Palazzo de' Lamberti, the residence of the consuls of the Guild.

The artists were thus brought into intimate business and political relations with the physicians and surgeons, fellow craftsmen as it were, and the privilege of dissection accorded the latter may readily have been extended to the artists. Leonardo was enrolled in the *Compagnia de' Pittori* in 1472, and it is certain that he performed dissections in at least one hospital in Florence.

The effect of what Ruskin has stigmatized as the "science of the sepulchre" on the future development of Art need not concern us here, but that of the intrusion of the artists into the field of anatomy may be considered. Leonardo's anatomical drawings were not, it is true, given to the public until quite recently, but they must have been known to

[11] E. Staley, *The Guilds of Florence*, London, 1906.

the wide circle of his friends and acquaintances and their contrast with contemporary anatomical illustrations must have opened the eyes of physicians to the possibilities for improvement. But whether or not Leonardo's example had anything to do with it, improvement began to show itself shortly after his death. Rosso, also a Florentine artist, who, like Leonardo, took up his residence in France, under the patronage of the then King, Francis I, undertook to prepare for his royal patron a series of anatomical illustrations, which remained incomplete owing to the artist's death in 1541. Only one plate remains, a copperplate reproduction by Domenico Florentino, a pupil of Rosso, who accompanied him to France. It has been reproduced by Choulant (1852) and shows front and back views of a skeleton and of an *uomo scorticato*, the figures being posed and provided with a background of drapery and various pieces of armour. The figures are not up to the standard set by Leonardo at his best, either in drawing or in accuracy, but they are attempts by an artist to represent the structure of the human frame as it really is, quite free from the conventionalism of the past. They belong to the new era of anatomy inaugurated by Leonardo.

The same may be said of the illustrations of the *Musculorum humani corporis picturata dissectio* by Gianbattista Canano, Professor of Anatomy at Ferrara, published probably in 1541.[12] Canano, at the instigation of his friend Bartolommeo Nigrisoli, undertook to publish nature-true representations of the muscles of the body and, doubtful of his own draftmanship, enlisted the services of an artist, Girolamo da Carpi, a pupil of Garofalo, to draw the muscles from his dissections. Only the first part, dealing with the muscles of the arm, was published, for Canano, learning of the excellent illustrations that Vesalius had had prepared for his great work *De corporis humani fabricâ*, suppressed the remaining parts. The illustrations are plain, simple representations of the parts as seen by the artist, without any artistic embellishments, but fine as they are they failed to achieve the excellence of those of Vesalius.

Canano employed an artist and so did Vesalius, and the latter's artist, Stephen von Calcar, was allowed greater artistic freedom, for many of his figures were posed and have sections of a landscape for a background, just as have the Mona Lisa and the Vièrge des Rochers. These additions make manifest the artist's part in the improvement of anatomical illustration. Sometimes, indeed, the artist was allowed to run riot and entirely dominate the picture, as in Charles Estienne's *De dissectione partium corporis humani* illustrated by Etienne Rivière.[13]

[12] G. Canano, *Musculorum humani corporis picturata dissectio* (Ferrara 1541?). Facsimile edition annotated by Harvey Cushing and Edward C. Streeter, Florence, 1925.

[13] This work was not published in its entirety until 1545, but the preparation of the illustrations began long before that date, some of the plates being dated 1530, 1531 and 1532.

Here full-length figures are represented even when a single organ is the *raison d'être* of the illustration, and to this is added a superabundance of architectural accessories, upholstering and drapery, until the essential of the picture becomes an insignificant part of it.

Accurate portrayal demands accurate observation, and it was the artists who led the way to the betterment of anatomical illustration. The anatomists were not slow in perceiving the advantages of accurate representations of their dissections, but all anatomists were not skilful draftsmen, nor were all artists, like Leonardo, skilled anatomists. And so collaboration resulted. Nor was the improvement confined to the illustrations; more accurate delineation led to more detailed description and this to greater care and thoroughness in dissection. The earlier conventionalized descriptions and illustrations were discarded, and with the publication in 1543 of Vesalius' great work, the *De humani corporis fabricâ*, the science of Descriptive Anatomy assumed its modern form and scope.

How great Leonardo's influence in this movement may have been remains uncertain. Perhaps too much importance has been attached to the facts that his anatomical studies were not given publication and that later anatomists did not refer to them. But the artists of his time or slightly later, such as Vasari and Benvenuto Cellini, certainly knew of them and it hardly seems possible that they should have remained unknown to those who worked with him in Verrocchio's atelier, Botticelli, Perugino and Lorenzo di Credi, and to his pupils, Bernardo Luini and Ambrogio Preda. Of anatomists who may have been influenced by him only Marc Antonio della Torre of Pavia may be named, but the close association of the artists and physicians in the Guild of Apothecaries suggests that the latter may probably have had knowledge of them. True no mention of his name is to be found in the works of either Canano or Vesalius, but reference to other authors had not become the *mode* in those days, and, as Roth (1905) has pointed out, while Vesalius does not mention by name Berengario, Dryander, Guintherius and Sylvius, yet references to their works are readily recognizable. If, as has been suggested above, the impulse to the new movement in anatomy came from the artists, Leonardo may well be recognized as its originator and Vesalius as its great protagonist.

CHAPTER V

FORTUNES AND FRIENDS

The story of Leonardo's life has been told so often and so well that attention may here be confined to those incidents that may have had an influence on the origin and progress of his anatomical studies. A child born out of wedlock, he spent a lonely boyhood on the Tuscan hills, where, like Giotto, he amused himself by watching the beasts, birds, insects, trees and flowers that peopled and clothed the hillsides, and by picturing them upon whatever material came to his hands. As he grew to maturity his father, noting his artistic ability, decided to apprentice him to one of the Florentine artists, and probably in his eighteenth year, that is to say in 1470, he entered the studio of Verrocchio.

Here his progress was rapid and soon he surpassed even his master in artistic ability. But here too he no doubt received his first stimulus to anatomical studies, for Verrocchio was one of those who believed in the study of the surface musculature as a prerequisite for the correct delineation of the nude. It is reasonable to suppose that the master may have suggested to his pupil or even have required of him that he should attend "Anatomies" when these were held, or, better still, that he should practice dissection himself. It is reasonable to suppose also that he would have begun his anatomical studies early in his apprenticeage to Verrocchio, as a young man of eighteen or twenty.

Leonardo, then, approached the study of anatomy primarily as an artist, but once having begun it he was carried on by his desire to plumb the depths of knowledge, to pass far beyond the limit of artistic anatomy and to expose the secret arcana of the human body. But while he sooner or later came to study anatomy for anatomy's sake, an appreciation of its importance to the artist never left him, as is evidenced by the large number of drawings in his note-books illustrating surface anatomy and by his extensive series of measurements of the body and its parts, with the object of determining a canon of proportions, and by words as well as by pictures he emphasizes the importance of a knowledge of anatomy for an artist.

"The painter who has knowledge of the nature of tendons (*nervi*), muscles and *lacerti* will readily appreciate in the movement of a member how many and what tendons are the cause of it, what muscle by its enlargement is the cause of the shortening of the tendon, and what *corde*, converted into most delicate cartilages enwrap and enclose the muscle, producing the various effects of form. And he will not do as many do, who in different actions portray the same things in the arm, the back, the breast and in other muscles, which things should not be placed among the little errors." . . .

"Necessity compels the painter to have knowledge of the bones, which form the support and scaffolding for the overlying flesh, and similarly of the joints, which, in bending, increase in size and lessen."

There quotations are from the *Trattato della Pittura*, and other similar passages might be quoted.

Whether one regards the artist or the anatomist as predominant in Leonardo will depend largely upon the point of view. If attention be focused on his achievements as an anatomist, one is in danger of underestimating his excellencies in other fields of knowledge, mechanics, dynamics, hydrostatics, military and hydraulic engineering, aeronautics, astronomy, geology and botany. But his discoveries in all these fields, as well as in anatomy, were the result of excursions from the main path he had chosen to follow. From time to time vistas into unexplored territories caught his attention, and leaving the high road he would follow a side path until his interest in it was satisfied. Anatomy was one of his side paths; painting was his main road. It was as an artist that he entered Verrocchio's studio and it was as an artist that he gained contemporary renown, and even if the story be mythical that on his deathbed he regretted that he had not devoted himself more whole-heartedly to art, nevertheless it is *ben trovato* and an indication of the estimate placed by his immediate successors upon his achievements as an artist compared with those of the scientist.

It has been pointed out that the Studium Generale that had been established at Florence was removed to Pisa two years after Leonardo took up his residence in the former city, and he could not, therefore, have availed himself for any great length of time of the opportunities that the Medical Faculty may have offered for dissections. But failing these opportunities he found others elsewhere, for an anonymous biographer, writing shortly after his death, states that he "made many Anatomies, which he performed in the Hospital of Santa Maria Nuova in Florence," an hospital founded in 1255 by Folco Portinari, the father of Dante's Beatrice. Indeed Leonardo's own words lead one to infer that he made dissections in that institution.

"And this old man, a few hours before his death, told me that he had passed one hundred years and that he was not conscious of any failure in the body, except weakness. And thus sitting on a bed in the Hospital of Santa Maria Nuova of Florence, without any movement or indication of any accident, he passed from this life. And I made an Anatomy of him (*io ne feci natomia*) to see the cause of a death so sweet, and I found it to come from weakness from the failure of the blood and artery which nourishes the heart and the other lower organs, which I found arid, thin and dry. Which anatomy

I described rather diligently and with great ease, on account of the absence of fat and humor, which rather hinder a knowledge of the parts. The other anatomy was of a child of two years, in which I found everything the opposite of what it was in the old man." (AnB, 10.)

Drawings, sketches or memoranda based on the dissection of this centenarian subject are found on no less than thirteen pages of AnB (*viz.* 3v, 4, 10, 10v, 11v, 22, 22v, 32, 32v, 33, 33v, 34, 34v) and give evidence that at the time they were made Leonardo had passed beyond the artist's standpoint in his anatomical studies. He is studying the deeper structure of the body and has become interested in the problems of age and death, problems that he conceived to be capable of scientific elucidation by applying the scientific methods of observation and comparison. How soon he reached this stage in his development as an anatomist is uncertain, but it is perhaps significant that on AnB, 42 there is a note "On the day 2 of April 1489 book entitled De figura humana." This has been taken as an indication that he began his studies in anatomy at that time; in reality it indicates that on that day he began to write or to collect material for a projected book on human anatomy, of which more anon. Before embarking on such an enterprize, Leonardo must have had considerable experience in anatomy, a beginner would hardly venture upon the writing of such a work as he contemplated, and the beginning of his anatomical studies must have been long before 1489.

At that date Leonardo was no longer a resident of Florence; after a stay in that city of approximately thirteen years, in 1483 he took service under Ludovico Sforza, Duke of Milan, known as *Il Moro*. During those thirteen years he had become an independent artist of considerable repute, for to this period belong the *St. Jerome*, the *Annunciation* and the *Adoration of the Magi*, this last remaining uncompleted when he removed to Milan. Not a very abundant harvest for so many years, but it must be remembered that Leonardo was not a prolific artist and he had many other interests that continually distracted him from his painting. Anatomy was one of these distractions, but he was also giving free rein to his genius for invention, as is shown by a letter to the Duke of Milan in which, with naïve confidence, he catalogues the various services he is prepared to render. He could construct portable and yet strong bridges; drain the moats of castles and make scaling ladders; make bombards that will reduce to ruins any fortress; run mines, even under moats and rivers; construct armored cars; make catapults, slings, mortars and cannons different from any then in use; and in case the conflict was at sea he could build ships that would withstand even the largest bombs. In time of peace he could design public and private buildings and construct waterways; he could made statues of marble, bronze or clay and also paint pictures as well as any other, no matter who he might be. Finally, he could construct an equestrian statue "that will be to the immortal glory and eternal honour of the blessed memory of my lord your father and of the renowned house of Sforza." And he was prepared to demonstrate his ability to make good his boasts in the ducal park or wherever else it might please his Excellency.

These accomplishments could not be vain boastings. Leonardo must have thought out and planned the various warlike engines that he catalogues; he must have studied the principles of architecture as they were then known and gained experience in the planning and specifications of buildings; he must have worked in marble, bronze and clay; and he had already begun those studies of waterways and canals which, on a large scale, were to interest him later. Surely all this studying, designing, planning, modeling, inventing and dissection suffice to indicate that these thirteen years in Florence were not spent in idleness, notwithstanding the paucity of his pictures. Surely, too, in carrying on all these activities he must have made many memoranda, in other words, his note-books must have been begun before his migration to Milan. Unfortunately, this must remain a conjecture, since 1489 is the earliest definite date in his manuscripts, although some of them contain indications that they belong to an earlier date. Thus a sketch of a man hanged and the notes accompanying it refer to the execution of Bernardo Bandini, who was hanged from a window of the Capitano in 1479, for complicity in the Pazzi revolt against the power of the Medici. Also, the similarity of a sketch of a head in the Windsor collection to the head of the Madonna in the Adoration of the Magi, upon which work was begun in 1481, is striking, if not conclusive.

It may be assumed, then, that before his migration to Milan in 1483, Leonardo had begun his studies in anatomy and it may also be assumed that he continued them in that city, since six years after he had joined the ducal court he announces his intention of writing a treatise on the subject. The first two years of his residence in Milan were little propitious for work on anatomy. The war with the republic of Venice turned his attention to military engineering, the while the fate of the Duchy hung in the balance, and in 1484–85 Milan was devastated by an outbreak of the plague. With the return of better times his patron insisted on the fulfilment of the promise to create an equestrian statue in memory of Francesco Sforza, and Leonardo plunged into the study of the surface anatomy and proportions of the horse, producing the collection of sketches and drawings now in the Royal Library at Windsor. Perhaps this was not his first experience in this work; he may have owed his initiation into it, as well as into human anatomy, to Verrocchio, who had begun work on his magnificent equestrian statue of Bartholommeo Colleone before Leonardo left Florence. But Leonardo's enthusiasm in the work soon waned and it was not until 1493 that a model of the statue in plaster was erected on the piazza del Castello, a model destined never to be completed in bronze, but to be destroyed by the French soldiers when Milan was in possession of the army of Louis XII.

It is evident that in Milan, as in Florence, other interests drew him away from the chief work he had in hand, the completion of the Sforza statue. There were many distractions arising from his connection with the ducal court and there was the painting of the Last Supper for the refectory of Santa Maria delle Grazie, completed in 1498, but more important to the present purpose was his resumption of his studies in human anatomy, interrupted by his departure from Florence. That they were again taken up is indicated by the declaration of his intention to write a book on the subject (1489) and it is perhaps noteworthy that while the great majority of his drawings illustrating the anatomy of the horse are of the surface anatomy and drawn from the standpoint of the artist, there are certain sketches (AnB 1; QV, 22) that are more detailed, showing the muscles of a horse's thigh compared with the arrangement of the corresponding muscles of a man. The inference is that he was carrying on his studies of human anatomy at the same time that he was studying the horse. Of the conditions under which he carried on his anatomical studies in Milan nothing is known, though it is altogether probable that opportunities were afforded in the Ospedale Maggiore, whose erection had been begun in 1456, and Lanzillotti-Buonsanti (1897) has suggested that he might also have made use of the Collegio dei Nobili Fisici, which was then flourishing and was the chief school of Medicine in Milan. One does not find record of the establishment of a University at Milan, but under the energetic rule of Ludovico Sforza men of repute in literature, science and the arts were attracted to the ducal court and instruction was provided in certain subjects. Leonardo thus found congenial associations with men interested like himself in the acquisition of knowledge and with whom he might discuss the problems and ideas continually occurring to his fertile imagination. In his studies of military engineering, Leonardo had the encouragement of Pietro Monti, the author in later years of works on military art and, in his old age, of a treatise which vainly endeavored to stem the increasing tide of the Protestant Reformation. In architecture he had for colleagues Bramante and Giacomo Andrea of Ferrara, the latter probably his most intimate friend, who forfeited his life to his loyalty to his patron Ludovico. And in mathematical studies Leonardo had a common interest with Fazio Cardano, the father of the more celebrated Girolamo Cardano, but himself a skilled mathematician, though also a devotee of the occult science and a disciple of Raymund Lull.

More important, however, in the present connection, was Leonardo's association with Luca Pacioli, the most accomplished mathematician of his day. Pacioli was born in 1445 in a Tuscan village, situated on the upper waters of the Tiber and known as Borgo San Sepolcro. On reaching full manhood he entered the Franciscan Order and his superiors, recognizing his remarkable aptitude for mathematical studies, gave him opportunity to devote himself to them, the remainder of his life being passed in one after the other of the principal cities of Italy, in lecturing and giving instruction in his favorite science. In 1496 he was invited by Ludovico Sforza to give lectures in Milan and during his four years of residence in that city he lived on intimate terms with Leonardo. During a residence in Urbino, Pacioli had written his greatest work, the *Summa de aritmetica, geometria, proportioni et proportionalità*, published in Venice in 1494, and, as Solmi (1919) has pointed out, this work was already known to Leonardo before the arrival of Pacioli in Milan and may have served as the attractive force which brought the two men into the intimate relations that led to cooperation. For in 1497 Pacioli completed a brief treatise, the *de divina proportione*, published in Venice but not until 1509, the illustrations of which were drawn by Leonardo. The *divine proportion* of Pacioli is what was termed by earlier authors the golden section, that is to say the division of a line into its mean and extreme ratios,[1] a division to which certain mystical attributes have been assigned. The first part of Pacioli's treatise is the application of this proportion to architecture and he then passes on to a consideration of the five regular solids and their modifications, the figures of these being Leonardo's contribution to the work, but in addition he also furnished a figure representing the proportions of the human body and its members, the body being shown inscribed in a square and also in a circle (see Fig. 13). These figures are of interest as showing that Leonardo was at this time engaged in working out his canon of the proportions of the body, a study to which many pages of his manuscripts were devoted. Favaro in his careful study of Leonardo's canon (1917) points out that in the details there is little correspondence between the Pacioli figures and the final results to be deduced from the manuscripts, and it may be that the Pacioli figures were among Leonardo's first efforts in this field of study, drawn at the request of his friend.

The peaceful, busy years of Leonardo's first residence in Milan were brought to an end toward the close of the year 1499. With a view to the success of his political intrigues, Ludovico Sforza in 1494 had enlisted the aid of the French king, Charles VIII, who saw in the alliance an opportunity for the enforcement of his imaginary claims to the kingdom of Naples. The foreign invasion, successful at first, awakened the fears of the other Italian principalities and a league was formed, with the Pope and the Republic of Venice at its head, to drive

[1] Euclid, Book II, prop. 11.

the French from Italy. With this league Sforza felt compelled to join, deserting his former ally, and the new alliance was successful in its object, Charles being obliged to withdraw to his own dominions. On his death in 1498, his successor, Louis XII, took up his claims and added to them one to the duchy of Milan, inherited from his grandmother. To guard against failure of his plans he entered into alliance with Venice and with the Pope, and thus secured from interference his conquest of Milan was an easy task. The city was occupied by the French in October of 1499 and for two months Leonardo endured the disturbances and disorders consequent upon the occupation, but in December of that year he left Milan, accompanied by his friend, Luca Pacioli, and made his way to Venice, breaking the journey by a short stay in Mantua. Their stay in Venice was, however, of brief duration, too brief for any extensive anatomical observations, though it is to be noted that the conduct of Anatomies in Venice was at this time in the hands of Alessandro Benedetti, who, by his enthusiasm and skill as an expositor, was able to attract such large and influential audiences to his demonstrations as to warrant a proposal for the erection of an anatomical theater similar to the temporary ones that had been constructed at Verona and Rome. One is tempted to assume that Leonardo would not have failed to make use of the opportunity presented by his stay in Venice to discuss problems in anatomy with Benedetti and even, if the occasion offered, to witness one or more of his demonstrations. As has been pointed out Leonardo was familiar with Benedetti's treatise on anatomy, but the note-book in which the reference to it occurs is of later date than the Venetian visit, for on its first page one finds the words "Cominciato a Milano addi 12 di Settembre 1508," and one can not say whether the reference recalls a personal acquaintance with Benedetti or merely indicates a knowledge of his treatise *Anatomice sive Historia corporis Humani.*

In February 1500 Ludovico Sforza was able to regain possession of Milan, but only temporarily, for in April of the same year, when confronted by the French army near Novara, his Swiss mercenaries deserted him, and in endeavoring to escape from the field of battle he was made prisoner and later conveyed to France, where he died in captivity. With the overthrowal of Sforza, Leonardo was deprived of the patron under whom he had served for so many years and, as a result, he determined to return to Florence, reaching that city, still accompanied by Luca Pacioli, toward the end of April (1500). Of his activities during this second residence in Florence there is evidence in a letter from the Carmelite Petrus de Nuvolaria to Isabella Gonzaga duchess of Mantua, who had written to him requesting that he should endeavor to induce Leonardo to undertake a picture for her *studio* or, if he were reluctant, to try at least to induce him to paint "uno quadretto de la Madonna, devoto e dolce, come è il suo naturale." To this request the worthy Carmelite replied that Leonardo's interests were varied and very indefinite, as if he lived from day to day, that he had completed the cartoon of the *Santa Anna Metterza* and that he "was working much at geometry and was very impatient with the brush." This was in 1501 and gives no indication that Leonardo had resumed his anatomical studies; his interest in geometry was then predominant.

But new distractions were in store for him. In 1501 the Pope Alexander VI had bestowed upon his son, Cæsar Borgia, the title of Duke of Romagna, and this handsome, talented, unscrupulous man, master of the perfidious diplomacy of his time, Macchiavelli's Prince, at once began by force of arms and hideous treachery to carry out his plan for the establishment of an hereditary principality, to be composed of the central Italian states, Umbria, Romagna and the Marches. After some preliminary success he requisitioned the services of Leonardo as a military engineer, commissioning him to inspect the citadels and fortresses of his state and to make in them such alterations and additions as might be deemed necessary, and in accordance with his appointment Leonardo spent the summer of 1502 and the winter of 1502–3 in traveling from city to city of central Italy, as they fell in succession before the arms or the perfidy of the Borgia. But in the spring of 1503 he again returned to Florence and resumed his anatomical studies in Santa Maria Nuova, it being probably to this period that the dissection of *il vecchio* belongs. It was at this period also that Leonardo painted the ill-fated fresco of The Battle of Anghiari, intended for the decoration of the large council chamber of the Palazzo Vecchio; and it may be an indication that while painting this picture he was also carrying on in anatomy, that on QVI, 13, in addition to some anatomical drawings, there is a sketch in red crayon outlined in ink of three figures, one on horseback, engaged in combat; it may very well be a sketch for The Battle of Anghiari.

During a short retirement to Fiesole in 1505, Leonardo resumed his study of the flight of birds that had been commenced in Milan, a small note-book (Sa.), dating from that year and edited by Sabachnikoff, being filled with various sketches bearing on the subject. It would seem that at this time he had completed his design of a flying machine, of which sketches are to be found in various note-books and especially in the *Codex Atlanticus* (C. A. 308–314v), and in connection with which his bird studies were mainly carried on. For he planned that his "great bird" should take off from the slope of Monte Ceceri, one of the hills in the neighborhood of Fiesole, "filling the universe with wonder, filling literature with its fame and eternal glory to the nest where it was born" (Sa., 18v).

Before the end of 1505, Leonardo had returned to Florence and completed the portrait of Mona Lisa, upon which he had been engaged for some time. But requests for his services were being pressed upon the Florentine Signoria by Charles d'Amboise, who, in the absence of Louis XII, acted as Governor of Milan. Unwillingly the Signoria finally, in 1506, acceded to the request of the French Governor and loaned him the services of Leonardo for a period of three months, a period which was later extended indefinitely, and Leonardo took up his second residence in Milan. Here he was to remain until 1513, except for some brief visits to Florence, necessitated by legal complications arising out of his father's will, and during this period of his life, more than ever before, he was able to devote himself to scientific studies, among which anatomy occupied an important place. That he had taken up again his anatomical studies shortly after his return to Milan and was prosecuting them with assiduity is shown by his statement that he hoped to complete his anatomy in the spring of 1510 (AnA., 17). The hope, indeed, proved to be vain, but it was at about that time that he became associated with Marc Antonio della Torre, an association to which great importance has been attributed by several writers. This is no doubt due to the statement of Vasari who, after alluding to Leonardo's studies of the anatomy of the horse, goes on to say—

> "In addition[2] he gave attention, but with great care, to the anatomy of men, aided by and in turn aiding in this messer Marc Antonio della Torre, a distinguished philosopher who then lectured in Pavia and wrote on this subject. And he was among the first (as I have heard said) to commence to elucidate the affairs of medicine by the doctrine of Galen and to shed true light on anatomy, which, up to that time, had been involved in a great and most extensive darkness of ignorance. And in this he made marvelous use of the genius, labor and skill of Leonardo, who made a book (of anatomical drawings) done in red crayon and outlined with a pen, which he dissected with his own hand and drew with the greatest diligence. In this he showed the whole skeleton and to this he added in order all the nervi and covered it with muscles, the first attached to the bones, the second holding them firm and the third moving them. And among these, here and there he wrote descriptions in rough characters, which were made reversed with the left hand so that no one unskilful in reading can understand them, since they can only be read with a mirror."

One might suppose, assuming the accuracy of this statement, that Leonardo's anatomical studies were carried on only in association with Marc Antonio, indeed Blumenbach seems to have read into it the idea that Leonardo acted merely as the artist who made drawings of the preparations dissected by Marc Antonio. Marx (1848), who made a special study of the relations of the two men on the basis of

[2] The word here translated "in addition" (*dipoi*) may also be rendered "then" and has been taken to indicate that Leonardo began his studies of human anatomy only after he had completed his studies of the anatomy of the horse. It has been seen that this is highly improbable and the suggestion of Solmi (1919) that *dipoi* may be regarded as equivalent to *inoltre* has been adopted.

data available in his time, recognized in Leonardo a higher degree of independence than either Vasari or Blumenbach, but still regarded Marc Antonio an important factor in his development as an Anatomist, associating him on terms of equality with Leonardo as one of the founders of anatomical illustration. And more than fifty years later, Forster (1904) interrogatively suggests the possibility that Leonardo's drawings were intended for the illustration of a work written by Marc Antonio, being influenced by the idea that anatomy was Marc Antonio's life work, while with Leonardo it was merely a side issue.

With the fuller knowledge of Leonardo's work and of the periods at which it was done, a more just estimate of his relations with Marc Antonio has been reached by de Toni (1900) and Bottazzi (1907). Unfortunately, even the careful researches of the former have failed to furnish as full an account as is desirable of the life and character of Marc Antonio, who, for a brief period, shone among the luminaries of the Renaissance. Descendant of an ancient Italian family he was born at Verona in 1481, having for his father Girolamo della Torre, of some renown as a physician and for a time Professor of Medicine in the University of Padua. Following his father's profession, he was appointed, while still a young man of twenty, public instructor of Medicine at Padua, later being advanced to the Professorship of the Theory of Medicine, and, the fame of his knowledge spreading, he was called to Pavia, then under the dominion of Ludovico Sforza, to be director of the department of anatomy. Either at Pavia or on a visit to Milan, some time in 1510 or 1511[3] he met Leonardo and it may be supposed that a common interest in anatomical studies linked together in the bonds of friendship the young professor of thirty and the artist who was but little short of double that age. This friendship was, however, destined to be brief, for in 1511 Marc Antonio fell a victim to the plague, while ministering to the stricken inhabitants of Riva.

Marc Antonio della Torre grew to manhood at a time when the art of printing was lending its powerful aid to the development of the humanistic Renaissance, at a time when Aldus Manutius and his associates were editing and publishing the ancient classics in their original purity. Of this new-old learning he became an ardent student and early acquired such a reputation as a scholar that by one of his eulogists, Chiocco (quoted by Marx), he was regarded as of equal rank with Pico della Mirandola, the two being characterized as *duos Phœnices doctrinæ*. To his erudition in the humanities he added knowledge of medicine, his interest in that subject having perhaps been fostered by his father, and so precocious was his learning that at

[3] De Toni (1900) points out that Leonardo was in Milan in March 1510 and at Fiesole in May 1511, and concludes that he may have spent the winter of 1510–11 and the early spring of 1511 at Pavia, working with Marc Antonio.

the time of his first appointment as an instructor in Padua he had only attained his twentieth year. Of his work at Pavia little is known; Chiocco states that he illustrated his teaching of anatomy both by public Anatomies and by published writings,[4] and his pupil Paulus Jovius also asserts that he was the author of a work on anatomy.[5] Of this work nothing now remains, and even a transcription of his lectures in Anatomy, given at Pavia, which according to De Toni was made by one Girolamo Mantua in 1510, seems to have disappeared.

Judging from the data now available, it seems improbable that Marc Antonio could have influenced Leonardo's anatomical studies to any considerable extent, and it is certain that Leonardo did not play merely the subordinate rôle assigned to him by Blumenbach. So far as is known, the two men did not meet until 1510 or thereabout and Leonardo's anatomical studies had been in progress long before that date. Even if 1489 be taken as the date at which they were begun, it is evident that Leonardo had already entered upon these studies at a time when Marc Antonio was a child of eight years of age, and if, as seems probable, his studies began while he was still in apprenticeship to Verrocchio, they date back to a period before Marc Antonio's birth, and at the time of their meeting Leonardo had been interested in practical anatomy for nearly forty years. During that time he had made hundreds of anatomical drawings, which were intended for a book he hoped himself to write—not as illustrations for a treatise written by Marc Antonio. Nor can even the suggestion of Solmi (1919) be accepted, that it was the influence of Marc Antonio that stimulated Leonardo to study anatomy as a science in itself, independently of its applications to painting and sculpture. Even in 1489 Leonardo had progressed beyond the limits of artistic anatomy, indeed it was the the very essence of his genius that he looked beyond the immediate applications of a science to the fundamental principles of that science.

"Those," he said, "who are enamored of practice without science are like the navigator who embarks on a ship without rudder or compass; he never knows with certainty where he is going. Practice should always be built upon good theory" (G. 8).

He needed no outside influence to guide him to a study of anatomy for its own sake. Approaching it from the standpoint of an artist, at once his attention was focused on the problems of organization, func-

[4] "Anatomicam disciplinam eorum temporum primus et sectione publica et scriptis editis illustrans." This is quoted from Marx; it may be true as regards Pavia, but there were both public Anatomies and public treatises before his time.

[5] "Elaborabat is (M. Ant. Turrianus) profitendo simul atque secando damnatorum cadavera anat. volumen ex placitis Galeni." Quoted from M. Roth, *Andreas Vesalius Bruxellensis*, Berlin, 1892.

tion, growth, life and death and he sought their solution by observation and experiment, firm in his belief that—

> "Experience never deceives, it is our judgment only that deceives us, expecting from experience what is not in its power." (C. A. 154.)

Marc Antonio, like Benedetti, was a hellenist; steeped in the humanistic revival of the classics, he preferred the teaching of Galen as he read it in the Greek text to the more or less perverted versions of it presented in the Arabistic translations. He endeavored, as Vasari (1912) puts it, "to elucidate the affairs of medicine by the teaching of Galen," and he is said to have applied for permission to substitute Galen for Mondino, whose *Anathomia* was the prescribed text in the Italian Universities. Leonardo can not be classified as a hellenist, nor does the very modern attitude that he took in matters of science allow of his being termed an Arabist. But the foundations of his anatomical knowledge were derived from Arabistic sources and the terminology used in his anatomical and physiological writings smacks strongly of these same sources. If Marc Antonio's influence had been dominant with him, one would expect in his later writings an avoidance of Arabistic terms, but this is not what one finds, Arabisms still occurring on the folios of Quaderni II, which are probably referable to the year 1513 or thereabout.

It is noteworthy, too, in this connection, that Leonardo never mentions Marc Antonio's name in connection with his anatomical studies. He does not, it is true, make frequent references to authorities, but, if his indebtedness was as great as has been supposed, one might expect some indication of it in his writings. On QIII, 8 there is a reference to one Marc Antonio, "libro del acque a messer Marcantonio," but even, as seems probable, this is a mention of Marc Antonio della Torre, it does not connect him with anatomical studies, but with some problem in hydraulics. Vasari, an artist, writing of Leonardo as an artist, might well be inclined to explain his remarkable achievements in anatomy by his association with a distinguished anatomist. But Leonardo's anatomical studies were his own; he was engaged in them long before he met Marc Antonio and they were continued for several years after the death of the latter, nor is there any evidence in his later writings that he had gained a new viewpoint for his studies, or that his problems had been materially modified as the result of his association with Marc Antonio.

Another of Leonardo's friendships should be noted. During the early months of 1507 he was residing at Vaprio, not far from Milan, at the villa of Gerolamo Melzi, whose son, Francesco, then a lad of fourteen, showed signs of artistic ability. Between the master and the pupil a friendship developed that in time came to resemble the relation of father to son, and when fickle Fortune forced Leonardo to resume his wanderings, the young Melzi elected to follow him, even to an alien land, and remained in his service until the master passed to the Great Beyond. In gratitude for the faithful services rendered by Melzi, Leonardo in his last will and testament bequeathed to him "all and every of the books which the said testator has at present," and so Melzi became the possessor of the precious note books.

The vicissitudes of Italian politics were again to bring troublous days for Leonardo, and again he was to be forced to seek another residence than Milan. In 1508 the Pope, Julius II, who had succeeded Alexander VI, allied himself with the emperor Maximilian, with Ferdinand of Aragon and with Louis XII of France in the League of Cambrai, with the object of recovering the states of the Church that had been captured by the Venetians. This object having been successfully accomplished, the Pope in 1510 broke his alliance with the French and began a campaign to drive them from Italy. Maximilian and Ferdinand, jealous of the growing power of France, were ready to assist in her humiliation, Henry VIII of England was persuaded to revive an ancient claim to the throne of France, and with these monarchs and with the Venetians the Pope entered upon a so-called Holy League and declared war against France. Charles d'Amboise, with the aid of Gaston de Foix was for a time successful in resisting the efforts of the League to drive him from Milan, but his death in 1511 brought discouragement to the French and the fall of Gaston de Foix before the walls of Ravenna early in 1512 deprived them of all hope. Milan came into the possession of the allies, and, with their consent, again passed under the control of the house of Sforza in the person of Maximilian, the son of Ludovico.

The death of Charles d'Amboise deprived Leonardo of his patron, and the son of his former patron naturally could not look with favor upon one who had thrown in his lot with the enemies of his House. The situation in Milan again became impossible, but this time, instead of returning to Florence, Leonardo journeyed to Rome. Julius II died in 1513 and was succeeded by Giovanni de Medici, second son of Lorenzo the Magnificent and himself a patron of the Arts. His elevation to the Papacy, under the title of Leo X, attracted to Rome the most distinguished artists of the day, and, following the example of Fra Bartolommeo, Michel Angelo, Luca Signoretti, Bramante, Sodoma, Raphael and others, Leonardo in September 1513 left Milan for the Holy City, especially attracted by the presence there of the younger brother of the Pope, Giuliano de Medici, from whom he had already received marks of appreciation and esteem and into whose service he entered on his arrival at Rome.

Quarters were assigned to him in that part of the Vatican known as the Belvidere and he at once resumed his artistic and scientific activities. Just as in Florence he had been able to obtain cadavers for his anatomical studies at the Hospital of Santa Maria Nuova, so in Rome he was afforded opportunities for continuing those studies in the Ospedale di Santo Spirito. But this privilege was of brief duration. A German mirror-maker, known to the Italians as Giovanni degli Specchi, conceiving the idea that Leonardo had supplanted him in the good graces of their common patron, Giuliano de Medici, seized upon every opportunity that presented itself for annoying and depreciating his supposed rival. He incited to base ingratitude a fellow countryman, a mechanic who had been placed under Leonardo's orders that he might assist in the manufacture of certain instruments and machines and to whom Leonardo had shown that kindness and consideration he was wont to extend to his subordinates, and, not content with such annoyances, Giovanni spread abroad malicious reports concerning Leonardo's anatomical studies, imputing to him cynical and sacrilegious motives. Unfortunately these evil machinations had their effect upon the Pope and upon the Prior of Santo Spirito and Leonardo was forbidden entrance to the Hospital.

Thus ends the record, all too imperfect in its details, of Leonardo's anatomical investigations. There is no evidence to show that after this discouragement he again found opportunities for resuming his studies. Indeed, shortly after this incident the current of his life was again altered. Francis I, who had succeeded Louis XII on the throne of France in 1515, at once prepared to carry out the intentions of his predecessor by the recapture of Milan and led a powerful army over the Alps in that year. Giuliano de Medici was entrusted with the task of opposing the advance of the French, and Leonardo, despite his advancing years, accompanied him in the campaign. The story of its failure, of the success of the French, of Leonardo's reception by his former friends, of his engagement to serve the French King, of his residence in France, a voluntary exile and the pensioner of a foreign monarch, this story need not be told here. Leonardo's studies in anatomy ceased in 1514; the last five years of his life offered no opportunities for their further prosecution.

CHAPTER VI

LEONARDO'S MANUSCRIPTS, THEIR REPRODUCTION AND HIS PROJECTED BOOK

Leonardo was in the habit of recording his observations and ideas in note-books which he made for the purpose, sometimes expressing himself in more or less elaborated sketches or drawings, sometimes in writing, sometimes in both. Being left-handed he developed the art of writing from right to left, looking-glass writing as it is now termed, and occasionally a passage is begun on the *verso* of a folio and continued on the *recto*, as for instance in AnB, 31v, 31, 30v, and frequently in F. During his lifetime Leonardo no doubt presented occasional sheets of designs to friends and these may account for scattered examples now to be found in various museums and collections. But the note-books, one hundred and twenty in number according to Leonardo's own statement (QI, 13v,)[1] were preserved intact, and after his death in France, according to the provisions of his last will and testament, they passed into the hands of Francesco Melzi. Melzi returned to Vaprio in 1550 bringing with him the note-books, which, until his death in 1570, he cherished as an almost priceless memorial of his friend and master.

For his son Orazio, however, the books had none of the tender associations that made them precious in the father's eyes and in the course of time they were consigned to trunks and stored under the eaves of the villa as useless lumber, still later to be handed with mistaken generosity to friends who might express a desire for them. The story of their dispersal and final fate has been very thoroughly worked out by Solmi (1910), Uzielli (1896), Seailles (1906) and Piumati (Sa.) and has recently been told for English readers by McCurdy (1923), but the main incidents will bear repetition here.

In 1587 Lelio Gavardi, a tutor in the house of Melzi, abstracted thirteen books, taking them to Pisa. There he showed them to Ambrogio Mazzenta, a Milanese at that time pursuing legal studies at the University, and Mazzenta persuaded him to entrust them to his keeping that he might return them to Melzi. Melzi at first declined to receive them, but eventually accepted seven, leaving six in Mazzenta's possession. Two of these later have apparently disappeared; one was presented to Cardinal Federico Borromeo and was deposited

[1] This statement probably dates to about 1514.

by him in the Ambrosian Library of Milan, which he founded in 1603; it constitutes what is now known as Codex C of the Institut de France. Then there appeared on the scene one Pompeo Leoni, whose father, a pupil of Michel Angelo, had placed his talents as an architect and sculptor at the disposal of the King of Spain, Philip II, and was desirous of presenting some of Leonardo's note-books to his royal patron. The son, consequently, proceeded to bribe Melzi with offers of political preferment and was successful in obtaining possession of the seven volumes that Mazzenta had returned, as well as others, how many is unknown. Later he succeeded in obtaining the three volumes that remained in the hands of Mazzenta's heirs, and with this precious booty he departed for Madrid.

In the seventeenth century two volumes of Leonardo's manuscripts are mentioned in a catalogue of the Royal Library at Madrid, but later these had disappeared. Two others are known to have passed into the hands of Don Juan de Espinas, and both these and the two of the Royal Library were probably part of the collection that Leoni conveyed to Spain. Some other books of the collection were dismembered by Leoni, the pages rearranged and bound together to form a large volume, now known as the *Codex Atlanticus*, and others of the note-books were similarly treated and bound together in a smaller volume, which was entitled *Disegni di Leonardo da Vinci restaurati da Pompeo Leoni.*

Leoni died in 1610 and the books passed to his heir Cleodoro Calchi, who sold some of them in Spain and took the rest to Italy, where they were purchased by Count Galeazzo Arconati and presented by him in 1637 to the Ambrosian Library. This bequest included the codices now known as the *Codex Atlanticus*, codices A, B, E, F, G, H, I, L and M of the Institut de France and the Trevulzian Codex. The last subsequently disappeared from the Library and was replaced by Codex D whose provenence is unknown. Beltrami (Tr.) has suggested that the withdrawal of the Trevulzian codex and its replacement by codex D was by Count Arconati himself, who in the deed of gift reserves the right to transfer to his own house any of the volumes presented by him. The codex Trevulziano as it now is, was purchased in Milan about 1750 by Giovanni Carlo Trevulzio and is now the property of Prince Trevulzio; its history after its disappearance from the Ambrosian Library until its purchase by Trevulzio is unknown. Codex C, as has already been stated, was presented to the Library by its founder, Cardinal Federico Borrommeo. Codex K is probably that presented to the Library by Count Orazio Archinti in 1676, but its previous history has not been traced.

This completes the list of the codices of the Ambrosian Library as they were until 1796. In that year Napoleon Bonaparte in his Italian campaign, as each city yielded to his armies, piratically levied upon its treasures of art and literature, sending the booty so acquired to Paris. From Milan, among other things, he seized the entire collection of Vincian manuscripts, depositing the *Codex Atlanticus* in the Bibliothèque Nationale and the rest of the codices in the library of the Institut de France. When the allies entered Paris, after Waterloo, they properly ordered the return of the confiscated treasures; the *Codex Atlanticus* was restored to the Ambrosian Library, but the remaining volumes were overlooked and still remain in the library of the Institut.

Their adventures, however, were not yet at an end. Some time before 1848 Count Guglielmo Libri succeeded in purloining from the library of the Institut a number of pages from codices A and B, and also a small volume of twenty-six pages that formed an appendix to codex B. The pages from A and B were sold by Count Libri to Lord Ashburnham in 1862, by whose name they are now known; in 1888 they passed to the custody of the Bibliothèque Nationale. The appendix to B was sold by Libri in 1865 to Count Giacomo Manzoni di Lugo and was later published in facsimile by Sabachnikoff and Piumati with the title *Codice sul volo degli Uccelli;* subsequently it was presented to Queen Margherita di Savoia.

For the story of the manuscripts now in the Royal Library at Windsor, the principal records of Leonardo's anatomical studies, it is necessary to return to a consideration of the note-books carried to Spain by Pompeo Leoni. Not all these were brought back to Italy by Calchi. It has already been stated that Leoni separated the leaves of several of the note-books, reassembled them and had them bound in two volumes, the larger of which was the *Codex Atlanticus,* the smaller the volume entitled *Disegni di Leonardo da Vinci restaurati da Pompeo Leoni.* In 1623, when a marriage was being negotiated between the Prince of Wales, afterwards Charles I, and the Infanta of Spain, the Prince, accompanied by the favorite Buckingham, visited Madrid for the purpose of carrying on his own wooing. The insolence of Buckingham did much to bring the negotations to an end and, instead of a wedding, a war with Spain ensued. The visit, however, had one good result, the purchase by the Prince of a portion of the Leoni collection, probably the volume of *Disegni,* and its transference to the Royal Library at Windsor. It was deposited in a special cabinet, together with some portraits by Holbein, and there it remained through the stormy days of the Commonwealth, Restoration and Revolution, safe but forgotten, until it was rediscovered in the reign of George III.

That the volume purchased by the Prince was the second of Leoni's volumes is indicated by the fact that when the rediscovery was made the book was brought to the attention of John Hunter, then the most outstanding English anatomist, and in his *Two Introductory Lectures,* published in 1784, he mentions the anatomical drawings with high appreciation and states that they formed a stout folio volume labeled *"Disegni di Leonardo da Vinci restaurati da Pompeo Leoni."* A little later they were inspected by Blumenbach and in the Medicinische Bibliothek (III, 1, 1788) Hinüber gives the further information that the volume originally consisted of 235 large folio pages, some of those at the end of the volume being views of Vesuvius, evidently by another hand than Leonardo's and dated 1571.

The cover of Leoni's volume is still preserved at Windsor, but its pages are now detached and mounted. Indeed, even when Richter (1883) studied the collection, the sheets had been detached and rearranged in nine sets, four of which had for their contents the anatomical drawings, one the studies on the proportions of the body, another studies of the horse, another studies of the geography and hydrography of Italy, while of the other two one was a collection of maps and the other a number of miscellaneous sheets. The total number of pages, according to Richter's enumeration amounted to 437 and those contained in the four anatomical sets amounted to 266, a number greater than that given by Hinüber for the Leoni volume, without counting the sheets on the proportions of the body, which numbered nineteen. It is evident, therefore, that the Windsor collection contains many sheets in addition to those of the Leoni volume, and the question of their origin naturally suggests itself.

It is known that two note books of the Leoni collection had come into the possession of Don Juan de Espinas and it is also known that Thomas Howard, the second Earl of Arundel and the father of English art connoisseurs, made endeavors to secure them. Marks (1875) quotes the following from a letter written in 1629 by one Endymion Porter:

"Of such things as my Lord Embassador Sr. Francis Cottington is to send out of Spain for my Lord of Arondell; and not to forget the book of drawings of Leonardo da Vinze which is in Don Juan de Espinas hands."

And, further, from a letter written by the Earl of Arundel in 1636 to Lord Aston, then Ambassador to Spain—

"I beseech ye be mindful of D. Jhon. de Spinas booke, if his foolish humour change."

Also there is record in Mary F. S. Harvey's *The Life, Correspondence and Collections of Thomas Howard, Earl of Arundel,* of a letter written in 1631 by Arthur Hopton to the Earl, which may or may not refer to the de Espinas books. Hopton, who, apparently, was an agent for Lord Arundel writes—

"The gentleman that is the owner of the booke drawne by Leonardo da Vinci hath bin of late taken from his house by order from the Inquisition, who after some time of restraint at Toledo, was permitted to goe to live at Sevill where he now is. All the diligence that I can use therein is to procure to have advice when either by his death or otherwise his goods are to be sould and therein I will be very watchful."

There is no direct evidence that the Earl was successful in obtaining the book or books owned by Don Juan de Espinas, but he certainly succeeded in acquiring a number of Leonardo's manuscripts. Thus the codex in the library of the British Museum, consisting of five hundred and sixty-six pages is labeled "Arundel 263," and that some of his acquisitions found their way to the Royal Library at Windsor is indicated by the fact that in a collection of engravings by Hollar (1645) there is said to be one of a design by Leonardo da Vinci inscribed "Leonardus da Vinci sic olim delineavit W. Hollar fecit 1646 ex collectione Arundeliana," and this design is now in the Windsor collection. Whether the British Museum or the Windsor designs engraved by Hollar or both of them represent the note-books once held by Don Juan de Espinas, it is impossible to say. Nothing is known at present as to how they were acquired by the British Museum or the Royal Library, nor is it known whence Lord Arundel obtained them. Solmi (1910) is of the opinion that certain of the Windsor manuscripts were purchased by Charles II in Holland at the sale of the Earl of Arundel's collection, but whether this be correct or not it seems evident that the Windsor collection consists of the book of *Disegni restaurati da Pompeo Leoni* with additions from the collection of the Earl of Arundel and probably from other sources. For Richter found at Windsor Castle an inventory prepared toward the beginning of the nineteenth century which lists a drawing by Leonardo that belonged to the Buonfiluolo collection, of which nothing is known except that it was purchased at Venice.

Four other codices may be mentioned to complete the list of the note-books known to be still in existence. One of these is the Leicester codex which was purchased in 1660 from the effects of the sculptor Guglielmo del Porta. Some time prior to 1775 it was acquired by the Earl of Leicester, probably during his residence in Rome. The other three form the Forster collection in the South Kensington Museum. They were purchased by Lord Lytton in Vienna and subsequently passed to Mr. James Forster, by whom they were bequeathed to the Museum in 1876.

It has already been noted that Leonardo collaborated with Luca Pacioli in the *Divinâ proportione* to the extent that he contributed the drawings of the regular solids that are figured in the book. In addition there are ornamental capital letters and a drawing of an arch which may or may not have been by Leonardo; but two human heads, crossed by lines that indicate their proportions, are drawn by such a firm, true hand as to warrant the belief that they were Leonardo's work.

Pacioli's book was published in Venice in 1509 and it contains a statement that the figure of a man with upstretched arms may be inscribed in a circle whose center is the umbilicus and if the arms and legs be outstretched it may be inscribed in a square. In the first printed edition of Vitruvius published at Venice in 1511 there are two figures illustrating this statement; they were evidently drawn by Leonardo and the original from which they were copied is now in the Royal Gallery at Venice.

Considerably more than a century was to elapse ere any further reproductions of Leonardo's drawings were made, and the first to appear after his death was the engraving by Hollar mentioned on page 70. Hollar's collection of engravings according to Séailles (1906) was first published in Antwerp in 1645 with the title "Variæ figuræ et probæ a Wenceslao Hollar collectæ et aqua forti aeri insculptæ." A later edition appeared in London in 1666 and it is possible that the Vincian reproduction was included only in this edition, since the date of its execution is given as 1646.[2]

Choulant (1852) states that the Comte de Caylus in 1730 published at Paris reproductions of a number of grotesque heads drawn by Leonardo, and later, in 1784, Carlo Giuseppe Gerli published in Milan a collection of designs by Leonardo that are interesting in that the collection includes a number of plates illustrating human anatomy. The collection was republished in 1830 with the addition of notes by Giuseppe Vallardi. More important, however, are the reproductions of figures from the Windsor manuscripts published by John Chamberlaine in his *Imitations of Original Designs by Leonardo da Vinci* (London, 1796), and again included in his larger work, *Original Designs of the Most Celebrated Masters of the Bolognese, Roman, Florentine and Venetian schools* (London, 1812). Choulant reproduces one of his plates, somewhat reduced in size, but still showing the skill and accuracy of the artist, even the manuscript notes, in the crabbed looking-glass script almost invariably employed by Leonardo, being reproduced, though not entirely satisfactorily. This plate is the *verso* of folio 4 of the Fogli d'Anatomia A of Piumati and Sabachnikoff, the others apparently are folios from Fogli A or Fogli B, except one which is the *verso* of folio 3 of the third volume of the Quaderni d'Anatomia, the principal drawing on it being two figures *in coitu*, an attempt to illustrate the anatomy of coition.

This last plate has a history of its own. It seems highly probable that, as Choulant has suggested, some at least of the plates of Chamberlaine's volume were sold separately. Blumenbach is known to have possessed a copy of the coition plate, probably Chamberlaine's repro-

[2] Several of the works referred to in this section have been inaccessible and the statements concerning them are made largely on the authority of other authors, notably Choulant.

duction, and from it, or from another copy, a lithograph was made in 1830 and published with the title *Tabula anatomica Leonardi da Vinci summi quondam pictoris e bibliotheca augustissimi Magnæ Britanniæ Hannoveræque Regis deprompta, venerem obversam e legibus naturæ hominibus solum convenire, ostendens* (Lunaeburgi, 1830, 4, sumptib. Heroldi et Waldstabii, typis exscripserunt Fr. Vieweg et filius, Brunsvigae). The artist has taken some liberties with the original, the female figure being supplied with a foot, which is lacking both in Leonardo's original drawing and in Chamberlaine's engraving, and there are other minor differences, so that the Lunaeburg plate is a less accurate reproduction of the original than is Chamberlaine's.

Choulant (1852) mentions two other collections of plates which include reproductions of Leonardo's drawings, one by Charles Rogers (London, 1778) and the other by William Young Ottley (London, 1823) and still other reproductions occur in the *Great Artists and Great Anatomists: a Biographical and Philosophical Study* (London, 1852), by the brilliant but unfortunate Robert Knox. Roth (1907) speaks of some plates which he describes as the proofsheets of a London reproduction made in the seventh decade of the nineteenth century and never published. If this description be correct these reproductions can not be those of either Rogers, Chamberlaine or Ottley, which are too early as to date and all of which have been published. Perhaps a suggestion as to their source is to be found in a statement by Marks (1878) that the Windsor folios were being photographed by a Mr. Stephen Thompson; it is possible that prints were made of these photographs.

In 1883 there appeared the first edition of J. G. Richter's *The Literary works of Leonardo da Vinci Compiled and Edited from the Original Manuscripts*, a work that first brought to the knowledge of the world the untold wealth of art, science, invention, literature and philosophy contained in the Vincian manuscripts, and shortly thereafter, in 1890, Duval and Bical published their *L'Anatomie des maitres*, with thirty plates of reproductions from the old masters, many of them from Leonardo, mostly from the manuscripts in the Windsor collection, but some from those in the Ambrosian Library and from two sheets in the Royal Gallery at Venice.

All the reproductions hitherto mentioned were by engraving or lithography, but even before Richter's work appeared the systematic publication of the manuscripts as photographic facsimiles had begun, and today the majority of them have thus become easily accessible. It will not be necessary here to refer to more than those that are especially of anatomical interest, and to these only briefly.

The photographic reproduction of the Windsor manuscript by Mr. Stephen Thompson seems to have remained uncompleted and the first facsimiles to be published were those of the collection in the Institut de France. These were published in twelve volumes (A-M) by Ravaisson-Mollien, the publication beginning in 1881 and extending to 1891. Then followed in quick succession the reproduction by Sabachnikoff of the *Codice sul volo degli Uccelli* (Rouveyre 1895) and that of the *Codex Atlanticus* by Piumati, begun in 1894 and completed in 1904, under the auspices of the Regia Accademia dei Lyncei and with the aid of subventions from the Italian government. In the meantime Sabachnikoff and Piumati edited a number of selections from the anatomical manuscripts of the Windsor collection, their first volume, *Dell' anatomia fogli A*, appearing in 1898 and the second, *Dell' anatomia fogli B*, in 1901, and in this latter year Rouveyre published a complete set of the Windsor manuscripts in twenty-three volumes. Finally the excellent *Quaderni d'anatomia* edited by Vangensten, Fonahn and Hopstock, began to appear in 1911 and reproduced all those anatomical folios of the Windsor collection that were not included in the volumes of Sabachnikoff and Piumati. There are thus two separate editions of the Windsor anatomical folios, that by Rouveyre and that represented by a combination of the volumes of Sabachnikoff and Piumati with the Quaderni. The latter duplicate the Rouveyre edition so far as the Folios related to human anatomy are concerned, but the Rouveyre plates include many folios not represented in the Quaderni—those on the anatomy of the horse for example. Such duplication as there is finds justification, however, in the fact that the Rouveyre edition gives no transcription of the difficult script of the text, the value of the edition being thus greatly lessened, since Leonardo's looking-glass chirography can be interpreted only at the expenditure of much time and with much vexation of spirit. It may be added that the Trevulzian and Leicester codices have also been reproduced in facsimile, the former in 1891 under the editorship of Luca Beltrami and the latter in 1909 under the editorship of Gerolamo Calvi.

It was long a prevalent belief that Leonardo had written a treatise on human anatomy which had since disappeared, a belief founded upon a statement by Vasari (1912) that Leonardo had "made a book illustrated by drawings in red chalk and outlined with a pen, made from his own dissections and drawn with the greatest diligence." This, however, is evidently a reference to one of the note-books and not to a treatise on anatomy, and it is to the note-books that Leonardo refers when he speaks (QI, 13v) of having composed one hundred and twenty books and when, in his will, he bequeaths to Francesco Melzi "all and sundry the books which the said testator has at present."

But it is equally clear that he intended to write such a treatise and indeed sometimes speaks of it as if it were a *fait accompli*. Thus in **E.** 3, speaking of the effects of movements in the shoulder joint on the position of the scapula he says "and you will find all the causes of this in the book of my Anatomy," and again he writes—

> "The articulations of the shoulders and of the other moveable members will be spoken of in their places in the Treatise on Anatomy, where will be shown the causes of the movements of all the parts of which a man is composed." (TP, 264)

But it seems highly improbable that the treatise was ever written, or, at all events, ever completed. It had not been written in 1508, for in that year he was becoming alarmed at the multitude of his notes and their lack of arrangement. On the cover of BM in Leonardo's handwriting is the following:

> "Commenced at Florence in the house of Piero di Braccio Martelii, on the 22d of March 1508; and this makes a collection, without order, composed of many sheets, which I have here copied, hoping later to put them in order in their places according to the matters of which they treat. And I fear that before I make an end of this I shall have to repeat the same thing many times, and so, reader, do not blame me because the things are many and the memory can not retain them and say 'This I do not need to write, since I have written it before.' "

Nor had it been written at the beginning of 1510, for he expresses the hope that he might be able to finish it in the spring of that year (AnA, 17). But he was still carrying on his anatomical studies at Rome in 1513 and 1514, and while he may have worked at his treatise during those years, it seems highly improbable that he could have found occasion for its completion during the troublous years that followed or during his residence in France. There is no doubt that Leonardo planned to write a treatise on Anatomy, but it also seems certain that the plan was never carried into effect. His interests were so wide and so varied that he had no time—probably, too, little inclination—for the drudgery that would have been entailed in the preparation of his notes for publication.

But while there is no evidence that the projected treatise was ever completed, there are many memoranda of the topics that were to be considered in it and of the method in which they were to be presented, and from these some idea of the scope of the work may be obtained. Leonardo's interest was not in planning or executing small things; his dreams were panoramic and his visions vast. On AnB, 20 there is a lengthy passage, headed by the words "Of the order of the book," in which he sets forth a general statement as to the scope and plan of the treatise.

> "This work should begin with the conception of man and describe the nature of the womb, how the child inhabits it, to what degree it resides therein, the manner in which it is vivified and nourished, its growth, what interval elapses between one degree of growth and another, what expels it

from the body of the mother and why sometimes it is expelled from the belly of its mother before the proper time. Then you will describe what members are those that grow more than the others after the child is born, and give the dimensions of a child of one year. Then describe the grown man and the woman and their measurements, the nature of their complexions, colors and physiognomies. Then describe how he is composed of veins, nerves, muscles and bones. This you will do at the end of the book.

"Then represent in four histories four universal conditions of men, to wit: Joy, with various acts of laughing, and represent the cause of laughter; weeping, in various manners with its cause; quarrels, with various movements of killing, flight, fear, ferocity, homicides and all things pertaining to such cases. Then represent fatigue from dragging, pushing, carrying, stopping, supporting and similar things. Then describe the attitudes and movement.

"Then perspective through the agency of the eye and hearing. You will speak of music and describe the other senses. Then describe the nature of the five senses."

This plan of the treatise was written probably at a comparatively early period of his anatomical studies, for the sheet on which it occurs evidently belongs to the same series as that already mentioned as bearing the date 1489. In other passages in the same series he amplifies and gives further details of the topics he proposes to consider. Thus one finds on AnB, 1 the following list:

"The tendons (nervi) that raise the shoulders, those that raise the head, those that lower it, those that turn it and those that bend it sideways, incline the spinal column, bend it, twist it, raise it. Write on physiognomy."

And again on the verso of the same sheet (AnB, 1v) there is a list of physiological problems that are to be considered.

"The cause of breathing, the cause of the movement of the heart, the cause of vomiting, of the descent of food from the stomach, of the evacuation of the intestines, of the movement of the superfluities of the intestine, of swallowing, of coughing, of yawning, of sneezing, of the numbness of different members, of the loss of sensation of any member, of tickling, of desire and other needs of the body, of urination and similarly of all the natural actions of the body."

In still another passage (AnB, 20) he says—

"Note which are the important tendons which, when they are cut, do the greatest damage to the animal, and which are of less importance; and this you will do for each member. Note the proportions of the bones one to the other and the use served by each. Different muscles are revealed in the various movements of animals and there are different muscles which in such variety of movements remain hidden; and of this it is necessary to make a long treatise in connection with the knowledge of places injured by wounds and in connection with sculpture and painting."

And again (AnB, 21)—

"Figure whence is derived catarrh, tears, sneezing, yawning, trembling, falling sickness, madness, sleep, hunger, lust, anger when it acts on the body, fear similarly, fever, disease, where poison acts. Describe the nature of all the members, why lightning kills a man and does not injure him and if the man blows his nose he will not die, because it acts on the lungs. Describe what the soul is. Of Nature, which of necessity makes the vital and actual instruments in the proper and necessary form and positions; how Necessity is the companion of Nature. Figure whence comes the sperm, whence the urine, whence milk; how the food is distributed by the veins; whence drunkenness, whence vomiting, whence gravel and the stone, whence *mal di fianco,* whence dreaming, whence frenzy by disease; why it is that, the arteries being compressed the man sleeps, why when the neck is pierced the man falls dead; whence come tears, whence is it that in turning the eyes the one follows after the other, of sobbing."

The problem of the movement of the eyes is mentioned a second time (AnB, 42v) at the beginning of another list of topics, most of which have been already noted, but among which is the following:

"Try to describe the beginning of a man when he is produced in the womb and why an eight months child can not live."

And another memorandum reads:

"Begin the series with the beginning of the formation of the child in the womb, stating which part begins first and successively placing its parts until birth. And how it is nourished, partly learning from hen's eggs." (QI, 12.)

While in still another place he writes—

"Commence your anatomy with the perfect man, then make it on an old and muscular one; then go on removing (parts) by degrees up to the bones. And you will then do the child, with a drawing of the womb." (AnA, 16.)

It has been well said that what Leonardo planned was not so much a treatise on human anatomy as an encyclopædia of man. And this encyclopædia was to have been illustrated with a completeness that had never before been contemplated. For Leonardo, the artist, was thoroughly convinced of the superiority of pictorial representation over verbal description as a means of conveying accurate knowledge.

"And ye who wish to represent by words the form of man and all the aspects of his membrification, get away from that idea. For the more minutely you describe, the more you will confuse the mind of the reader and the more you will prevent him from a knowledge of the thing described. And so it is necessary to draw and describe." (AnA, 14 v; *Cf.* QII, 1.)

He therefore purposed to represent every member of the body from several aspects.

"The true knowledge of the form of any body will be from views of it from different aspects. And so to give knowledge of the true form of any member of man, *prima bestia infralli animali,* I shall observe this rule, making of each member four representations from the four sides. And in the case of the bones I shall make five, cutting them through the middle and showing the cavity of each of them." (AnA, lv.)

As an afterthought he notes that all the bones should be represented from the four aspects in duplicate, once showing them "Joined to their correspondents as Nature makes them" and again separated so that "the true form of the ends that are joined together" may be seen. Nor was this liberality of illustration to be confined to the bones. He says—

"We will represent the instrumental figure of man in drawings, of which the first three will be the branchings of the bones, *i.e.* one from in front which will show their positions and forms in the width; the second will be seen in profile and will show the depth of all the parts and of their positions; the third drawing will show the bones from behind. Then we will make three other drawings from similar aspects with the bones sawn, by which their thickness and cavities will be seen; three other figures we will make of the bones entire and of the nerves which arise from the spinal cord and the members to which they are distributed; then three with the muscles and three with the skin, the proportions of the figure being shown; and three of the female to show the womb and the menstrual veins that come to the breasts." (AnB, 20v.)

If, as seems proper, the memorandum "On the day 2 of April 1489 book entitled De figura humana" (AnB, 42) be interpreted as meaning that on that day Leonardo began to write, or at least to plan, his treatise on anatomy, and if the statement that he hoped to complete his anatomy in the spring of 1510 (AnA, 17) also refers to the treatise, it is justifiable to conclude that in the interval Leonardo must have written some portions of it. Indeed it seems exceedingly probable that passages on certain of the folios may have been intended for incorporation in the projected book, and these, though fragmentary and disconnected, are of no little interest.

Such passages occur on folios 2 to 8 of QI, which evidently belong to the later period of Leonardo's life, probably to the time of his residence in Rome (1513–14). QI, 2 would serve as an introductory chapter; it is headed "Ordine del libro" and, after explaining that the true form and relations of the various parts of the body can only be revealed by numerous dissections, he points out that his illustrations, representing each part from various aspects, will yield the desired knowledge.

"Accordingly, here, by fifteen complete figures, the cosmography of the microcosm (minor mondo) will be demonstrated to you in the same order that was employed before me by Ptolemy in his Cosmography. And likewise I shall then divide the members, as he divided the whole into provinces, and then I shall describe the use of the parts from every side, placing before your eyes the knowledge of the whole form and strength of man, in so far as it has local motion by means of its parts."

On the margin of this folio is another passage headed "On the hand from within," but this is evidently a later addition, being written in a darker ink and with somewhat heavier letters. It is a memorandum for his own use as to the figures required for a demonstration of the anatomy of the hand. It is interesting to note, as an indication of the prodigality with which he proposed to illustrate his work, that he planned no less than ten figures of the hand as seen from the palmar surface, and then proposes to similarly figure it from the inner side, the dorsal surface and the outer side.

The verso of folio QI, 2 gives a passage headed "On the muscles which aid in yawning and sighing and in dilating the lung in all its excessive dilations," and in the margin is a sketch of the muscles by which he supposes the elevation of the ribs is effected, together with diagrams showing how they act. Below the main passage is a second heading "On the muscles that draw the ribs downward and replace them in their former position," but the corresponding passage has not been written.

Folios 3 and 4 are devoted to a consideration of the structure and action of the heart, subjects in which Leonardo was greatly interested, and the verso of folio 4, which, like the recto, is headed "On the heart" ends in a discussion of the significance of the curvature of the diaphragm. Folio 5 is also headed "On the heart" and begins with a short passage, unfortunately not completed, under the heading "If the veins of the lung do not return the blood to the heart, when it contracts in expelling the air." Leonardo's thoughts, however, quickly turn back to the diaphragm and the rest of the page is occupied by a discussion of its form and the mechanics of its action. It is doubtful, however, if this passage was intended to be a part of the treatise; it was perhaps rather a memorandum of data which were to be elaborated in the final manuscript. But on the verso of the same folio there is a passage under the heading "On the muscle termed the diaphragm and on its uses" which does seem to have been intended for the treatise and it is followed by a passage also with its own heading and discussing the condensation in the larynx of the air expelled from the lungs. On the margin is a note on the effects on the stomach of the contraction and relaxation of the diaphragm and the abdominal walls, a subject already touched upon in the passage on the diaphragm.

Folio 6 is headed by the word "Natomia" and immediately there follows the heading of a passage considering the question whether the position of the heart changes at death, a question already briefly referred to on folio 4v. On the verso, headed "Anathomia," the diaphragm and its action on the stomach is again taken up in a series of paragraphs, each with its own heading, and in folio 7, which is headed "Nathomia," Leonardo passes on from the stomach to the intestines and the movement of their contents, continuing this discussion on the verso. Finally in folio 8 there is a single uncompleted passage under the heading "What uses do the muscles of the ribs subserve," an extension of the topic considered on folio 2v.

These seven folios are all characterized by being essentially pages of text rather than of figures, these, when they occur, being merely suggestive sketches and relegated as a rule to the margin of the page. Furthermore the text is arranged in a series of sections, each with a special heading, somewhat after the manner of the anatomical treatises of the period, those of Mondino and Avicenna, though with greater detail. The fact that folios 6 and 7 have for a general heading the word "Anatomia" in one or other of its variants is not without significance, and, furthermore, the folios belong to the later period of Leonardo's life when he had expressed his intention to set his notes in order.

But it is not only in QI that one finds paragraphs with headings; they occur also in QII, and the folios of this also undoubtedly belong to the later years of Leonardo's scientific activities, for they form a series uniform as regards the quality and tone of the paper, and one of them bears the date 1513. Two of the paragraphs contained in this Quaderno are especially interesting as representing drafts of introductory sections to chapters of the proposed work. QII, 18v bears the heading "Definitions of the organs (*strumenti*)" and for subheading "Discourse on the nerves, muscles, tendons, membranes and ligaments," what follows being very much in the style of the descriptions of the *partes similares* found in nearly every treatise on anatomy down to the time of Bichat,[3] but, it is interesting to note, somewhat more detailed than is usually the case and more nearly anticipating Bichat's recognition of the tissues. QII, 15 has no heading but the paragraph which follows has. It is a general statement of the various forms of muscles to be found in the body, just such a statement as might be expected to introduce a discussion of the musculature. In QIV one also finds a folio (fol. 2) interesting in the present connection, although it is not concerned with anatomical matters. It gives a series of paragraphs, each with a heading, dealing with principles of hydrostatics, and its interest lies in the indication it affords that Leonardo in his later years was endeavoring to get into order his observations in other fields than anatomy. For there is reason to believe that at least folios 1 to 3 of this Quaderno were from approximately the same period as the collection contained in QII.

All, then, of the projected treatise that has survived is represented by these few fragmentary and unconsecutive passages. It was to have been a book of encyclopædic contents, of even wider anatomical and physiological scope than the *De animalibus* of Albertus Magnus and, furthermore, it was to have been illustrated most lavishly, indeed, prodigally. No wonder that Leonardo had doubts as to the likelihood

[3] It is worthy of note, however, that the *partes similares* are not mentioned individually by Mondino "quia earum anathomia non perfecte apparet in corpore deciso, sed magis liquefacto in gurgitis aquarum." They are mentioned, however, by Avicenna.

of its being published as he had planned it. For in a folio (AnA, 8v), chronologically of the same series as AnA 17 in which he hopes for the completion of the work in 1510, after a memorandum that the cervical vertebræ should be figured conjoined from three aspects, separated from three aspects and again from below and from above, he proceeds—

"Thus you will give true knowledge of their form, of which it is impossible that the ancient and modern writers would ever be able to give true knowledge without an immense, tedious and confused amount of writing and of time. But by this very brief method of representing them from different aspects, full and true knowledge is given of them. And in order that I may give such a benefit to men, I teach the manner in which they should be reproduced in order, and I pray you, O successors, that avarice will not oblige you to make the reproduction in . . ."

Thus the passage ends, unfinished; Bottazzi (1907) plausibly explains the last sentence as an indication that Leonardo, after the overthrowal of his patron, Ludovico Sforza, despaired of obtaining sufficient funds to adequately publish his great work on anatomy and so bequeathed it to his successors with the injunction that they should not, through fear of the expense involved, curtail in any way the plan he had drawn up.

Probably shortly after Leonardo's death a collection of memoranda from his manuscripts was compiled by some person unknown, though it has been suggested that it may have been by Francesco Melzi or by another of his pupils, Salai. An imperfect copy of this collection was published in Paris in 1651 by Raphael Trichet Du Fresne, under the title *Trattato della Pittura di Leonardo da Vinci* and in the same year a French translation of the same copy was published by Roland Frèart, Sieur de Chambrai, both volumes being illustrated by drawings by Nicholas Poussin. In 1817 Guglielmo Manzi, librarian of the Barbarini Library, which was then united with that of the Vatican, discovered in the Vatican a complete copy of the collection, which he transcribed and published, though not with the editorial exactitude that is desirable, and it was not until 1882 that Heinrich Ludwig published a satisfactory edition, with both the original Italian text and a German translation, under the title *Leonardo da Vinci: Das Buch von der Malerei.*

As the title given it indicates, it consists for the most of a series of memoranda by Leonardo dealing with the art of painting, with draftsmanship, with the effects of light and shadow, with color contrasts and with perspective. Many of the items it contains can be identified in the original manuscripts now in existence, others may have been taken from manuscripts now lost, and others may have been precepts imparted orally by the master to his pupils. But while it is essentially a treatise on painting, it contains remarks on anatomy and on the proportions of the body, and it is the chief source of information as to the extent of Leonardo's knowledge of the structure and physiology of plants. These are the reasons why the book is briefly mentioned here, these and the fact that until the publication of Richter's work it was the only published collection of excerpts from Leonardo's manuscript notes.

CHAPTER VII

LEONARDO'S ANATOMICAL METHODS

Leonardo's opportunities for anatomical studies were no better than those available for others of his time. Why then did he, an artist, far excel in his results even the professed anatomists who were his contemporaries? The answer is to be found in the spirit of the man and in the methods he employed. He was in possession of an overmastering desire to know all things, to prove all things for himself, while his contemporaries were content to rely more or less implicitly on the statements of their predecessors and to interpret what observations they might make in accordance with those statements.

Leonardo's methods of acquiring knowledge were observation and experiment. He followed the Aristotelian method and found little use for the Platonic method of introspection so generally relied upon during the Middle Ages, when argument and the appeal to authority were the chief methods of settling disputed points in natural philosophy as well as in theology. Not but that there were men in mediaeval times, such as Roger Bacon, Grosseteste and Albertus Magnus, who exercised their powers of observation for the advancement of knowledge, but their works stand out like beacons across a dreary sea of compilations, such as the *Speculum Majus* of Vincent of Beauvais. For authority Leonardo had little respect, "Whoever" he says "in discussion adduces authority, uses not intellect, but rather memory" (CA, 76). If he wished knowledge he sought it himself by observation, and was assured that when observation failed to give the results desired, the fault was with the observer, not with the method.

"Wrongly do men blame innocent experience, accusing her of deceit and false results." . . . "Experience is not at fault, it is only our judgment that is in error in promising itself from experience things that are not in her power." (CA, 154v.)

His method was what we are pleased to term the modern method—it is the method of Hippocrates and of Aristotle—and it was his use of it that compels our recognition of him as a giant amongst the pigmies of the scientific world of his day. Indeed, one may almost speak of him as ultramodern on account of his belief that no scientific fact or theory is complete until it may be expressed in mathematical terms.

"No human investigation" he says "can be termed true knowledge if it does not proceed to mathematical demonstration" (TP, 1). . . "And therefore, O students, study mathematics and do not build without foundations." (QI, 7.)

When one considers Leonardo's numerous statements as to the value of personal observation and experimentation or, as he termed them, of experience, it seems strange that Roth (1907) could have asserted that—

"We are now certain that Leonardo did not dissect himself, but his dissections, as was then customary, were made by surgeons."

And could have maintained that—

"This cardinal error in his method explains for us the poverty and confusion of his technique, the incompleteness, the insufficiency, the contradictions, the corrupted Galenism of his Anatomy."

The provocation that lay back of Roth's criticism of Leonardo has already been mentioned (p. 4); it led him to overlook the essentially pioneer character of Leonardo's work and to judge him by present-day standards. Using the same standards one might also apply Roth's disparagements to Vesalius, who, too, was a pioneer; but pioneers are to be judged rather by what they accomplish than by what they of necessity leave undone.

The charge that Leonardo did not personally make dissections is open to discussion. It is based mainly on the undoubted fact that in the public Anatomies of the time it was customary that the actual dissection should be done by some subordinate, a surgeon for choice, the rest of those present, with the exception of one who was the expositor and a second who demonstrated the parts exposed, having the rôle of spectators (*cf.* p. 18). But in Florence and Milan, in which, in Leonardo's time there were no universities, public Anatomies were in all probability rarely if ever performed, and what dissection there was, was done *privatim*, under circumstances in which the formalities of the public demonstrations were neglected. Indeed, since the dissections in which Leonardo took part in Florence and Rome were performed in hospitals, it seems probable that they were not only *privatim* but *privatissime*. If Leonardo did not himself dissect it is difficult to understand the success of the accusations of Giovanni degli Specchi which resulted in Leonardo's exclusion from the hospital at Rome as "a heretic and cynical dissector of cadavers" (Solmi).

But we have Leonardo's own words for it. When he speaks of the dissection of *il vecchio* he does not say "I was present at an Anatomy of him" but "I made an Anatomy of him (*io ne feci notomia*)," and it is difficult to believe that he meant to say that he was merely a bystander and spectator of the Anatomy. In one of two passages on QI, 13v, undoubtedly a continuation of the passage on QI, 2, which is regarded as part of the preface to the projected treatise on anatomy,[1] Leonardo

[1] See page 77.

presents an apologia for the new departure. The fact that the succeeding passages end with "Vale" is further evidence that they were intended to be a preface. He planned, in making his book, an atlas rather than a text-book. He says—

"And if you say it is better to see an Anatomy performed than to see such pictures, you would speak rightly if it were possible to see all the things that are shown in such pictures in a single body, in which with all your genius you will not see and will not have knowledge, unless it be of some few veins. Concerning which to have a true knowledge of them, I have dissected more than ten human bodies, destroying all other parts, consuming even to the minutest particles the flesh that surrounded these veins, without causing them to bleed, except for an insensible bleeding from the capillary veins. And a single body did not suffice for so much time, so that it was necessary to proceed with as many bodies, one after the other, as would complete the entire knowledge; which (work) I twice repeated in order to observe the variations." (QI, 13v.)

Roth (1907) quotes only the first few lines of this passage and these might be interpreted to convey the impression that Leonardo set little store by dissection. But it means just the reverse and contains a definite statement that he dissected. His contention is that the knowledge to be obtained by attending an Anatomy as a spectator would be far inferior to that to be obtained from his illustrations, worked out by careful and repeated dissections. And he continues—

"And if you have love for such a thing [meaning dissection] you will perhaps be prevented by your stomach, and if this does not prevent you, you may perhaps be prevented by the fear of passing the night-time in company with bodies quartered and flayed and fearful to look upon. And if this does not prevent you, perhaps you will lack the good draftsmanship that should belong to such drawing, and if you have the draftsmanship it may not be accompanied by perspective. And if it is so accompanied you may lack the principles (*ordine*) of geometrical demonstration and the principles for the calculation of the forces and power of muscles; or perhaps you may lack patience, so that you will not be diligent." (QI, 13v.)

Surely the dread of a night-time spent with bodies quartered, flayed and fearful to look upon is a recollection of personal experiences; it can not refer to a spectator at a public Anatomy. Nor is it likely that a mere spectator of an Anatomy could give such minute instructions for a dissection as are contained in the following passage.

"You will separate the substance of the brain as far as the contours of the dura mater, which is interposed between the basilar bone and the substance of the brain. Then note all the foramina where the dura mater penetrates the basilar bones, with the nerves covered by it, as well as by the pia mater. And this knowledge you will observe with certainty, if, with diligence, you raise the pia mater gradually, beginning at the ends and noting from part to part the location of the said foramina, commencing first with the right or left side, figuring it in its entirety, and then you will follow the opposite part, which will give you knowledge whether the former one is well placed or not and also will make you understand that the right part is like the left. And if you find variations, look back on other Anatomies, if such variation is universal in all men, women, etc." (An B, 35.)

A study of the drawings and text of the Windsor collection should surely bring conviction that Leonardo was representing with his pencil what he himself had observed by dissection. There are his own repeated and definite statements that he dissected human bodies, and to these may be added his reported statement to Cardinal Louis of Aragon, when that prelate visited him at Amboise, that he had made Anatomies of more than thirty bodies, both male and female and of every age.[2] He undoubtedly dissected various animals with a view of obtaining suggestions leading to a more definite knowledge of the parts of the human body and, indeed, the whole endeavor and chief characteristic of the man was the striving to discover for himself the secrets of both Art and Nature in all its fields. From his methods applied in other domains of science one would expect, without further evidence, that in his anatomical studies also he would apply the methods of personal observation and experiment. Leonardo's more immediate predecessors in anatomy were Arabists, and their Anatomies were made to illustrate Avicenna's teachings. His contemporaries, such as Benedetti and Marc Antonio, had caught the spirit of the Renaissance, but it was that of the literary rather than of the scientific Renaissance, and their Anatomies were made to illustrate Galen's teaching; but Leonardo was a forerunner, nay, rather one of the outstanding representatives of the scientific Renaissance, basing his knowledge not on the teaching of others, but on his own observations. He practised the method of personal observation used by Vesalius some thirty years later, but Vesalius completed his work and gave it to the world, while Leonardo's remained uncompleted and hidden away in Melzi's villa at Vaprio.

It was then with knife, saw and chisel in his own hands that Leonardo made the anatomical preparations that were recorded by his facile pencil. His ingenuity in invention suggests an inquiry as to whether he may not have improved upon the methods of dissection commonly employed, or invented special methods for the solution of special problems. The earlier writers speak of maceration and mum-

[2] This statement is contained in a manuscript in the Bibliotheca Nazionale at Naples, entitled *Itinerario di Monsignor R^mo et Ill^mo il Cardinal da Aragona mio Signore, incominciato dalla città di Ferrara nell' anno del Salvatore 1516 del mese di maggio et descritto per me, Dom. Antonio de Beatis, Clerico melfictano.* Attention was first drawn to the passage referring to Leonardo by G. Uzielli (*Richerche intorno a Leonardo da Vinci*, Roma, 1884) and the portion containing the statement mentioned above has been quoted by Solmi (1910) and Bottazzi (1907).

mification as suitable methods for the study of certain parts. Thus Mondino after mentioning the "simple parts" says—

"I shall not give a detailed anatomy of them because their anatomy does not show perfectly in a dissected body, but rather in one macerated in running water."

So too, Guy de Chauliac recommended for the study of the bones, cartilages, joints, the larger nerves, tendons and ligaments, bodies that had been dried in the sun, decomposed in the earth, or macerated in running or boiling water, and Berengario taught that the union of the nerves with the spinal cord could only be observed in bodies macerated in water, confessing at the same time that he had never himself observed the union; he also recommended the use of bodies that had been boiled for the study of the muscles. Leonardo had apparently made trial of the maceration method, but found it very unsatisfactory when employed for the study of the nerves. He says—

"And I remind you that the anatomy of the nerves will not give you the situation of their branches, nor in what muscles they branch, by means of bodies macerated in running water or lime water; because, while their origin remains to you without as well as with such water, their branchings by the current of the water come to unite, just as flax or hemp, hackled for spinning, make themselves into one bundle, so that it is impossible to discover again into what muscles they enter or with what or how many branches they penetrate the said muscles." (QI, 2.)

He makes no other mention of the application of this method, not even in connection with the preparation of the bones, although it is evident from his figures that he used some form of maceration for these and did not rely upon mummified preparations as was the custom of mediaeval anatomists, whose manuscript representation of the skeleton are manifestly drawn from desiccated preparations.

Holl (1905) has suggested that in the preparation of the blood-vessels Leonardo made use of injections, basing his suggestions on the appearance of the vessels in the drawings. A conjecture based on such evidence alone necessarily rests on a very insecure foundation, for an artist would naturally represent tubes with flexible walls and known to be filled with fluid as if they were cylindrical in form. It seems probable that if Leonardo had employed some method of injection to distend the blood-vessels he would not have failed to give a description of it, and nowhere in his notes is there even a mention of it. The art of injecting the blood-vessels did not come into general use until after Harvey's discovery of the circulation of the blood in the seventeenth century, though sporadic instances of its employment are recorded long before that time. Thus Galen mentions the inflation of the cerebral vessels as a means of facilitating their study, and M. Medici, without vouching for the accuracy of the statement, quotes from the advocate Alessandro Macchiavelli (*uomo d'altre parte eruditissimo*) to the effect that Alessandra Giliani of Persiceto made dissections for Mondino with surpassing skill, and injected the blood-vessels with various colored fluids, the injection quickly hardening to a permanent mass.

But even if evidence is lacking that Leonardo used injections in the study of the blood-vessels, he did employ the method for another purpose, namely, to obtain a clear idea of the ventricles of the brain by injecting them with melted wax. His description of the operation is as follows:

"Make two air-holes in the horns of the greater ventricle and take melted wax with a syringe, making an opening in the ventricle of memory (*i.e.* the fourth ventricle), and fill through this opening the three ventricles of the brain. And then, when the wax has solidified, dissect the brain and you will see the form of the three ventricles distinctly. But first place slender tubes in the air-holes, so that the air that is in these ventricles may escape and give place to the wax which enters the ventricles." (QV, 7.)

That Leonardo actually made such an injection is shown by the legend placed below one of the drawings on the same folio:

"Form of the sensus communis. Injected (*gittato*) with wax through the bottom of the base of the skull by the opening *m*, before the skull was sawn."

In this case, however, the injection was made through the floor of the third ventricle instead of through the fourth as was prescribed in the directions for the operation.

This method of demonstrating the form of the cerebral ventricles has frequently been used in recent times, but Leonardo was the first to employ it. It is a method that must be used only with great caution, as the roofs of the third and fourth ventricles may readily be ruptured before the injection of the lateral ventricles is completed, and this seems to have happened with Leonardo's preparation, for his figures give an entirely erroneous idea of the form of the third ventricle, and there is no indication of the prolongation of the lateral ventricles into the temporal lobes. But even with these and other serious defects, his figures based on the method correct fundamental misconceptions evident in his earlier figures of the brain, and credit should not be witheld from Leonardo for his ingenuity in devising so novel a method and for his skill in carrying it out, even though the results were only partially successful.

Nor was this the only instance in which Leonardo's inventive genius led him to anticipate a method which was later made successful. His problem was to evolve a method by which the structure of the eye might be demonstrated without the loss of its humors and the consequent distortion of the parts. To accomplish this, he recommends placing the eyeball in white of egg and then boiling the whole; then when the white of egg had coagulated the eye might be cut across transversely, and nothing lost from the lower half (K. 119). This seems to be an anticipation of the modern method of imbedding tissues for the preparation of microscopically thin sections and, indeed, in the early days of this process, albumen was used by Calberla as the imbedding material. But Leonardo's process lacked one of the essential features of the modern treatment in that he probably did not allow the albumen to thoroughly penetrate the eyeball that was to be studied, and so give it a uniform consistency. Indeed, the thorough permeation of an entire eyeball is a matter of some difficulty and without it the use of the albumen could be of but slight advantage. At all events it yielded Leonardo no important results, since his ideas as to the structure of the eye show no advance upon the erroneous views held by his predecessors. Nevertheless he was moving along the right path and his method, though crude, was no more so than the early methods of imbedding for section-cutting, employed more than three centuries later.

A third anticipation by Leonardo of a modern technique was his suggestion of the use of transverse sections for the study of the gross anatomy of the limbs. On QV, 20 (fig. 10) there is a sketch of a leg in which there is indicated a number of planes, three in the thigh and four below the knee, in which the limb might be transected, and beside this there are two sketches showing the leg divided through these planes, the structures cut across being represented in outline in certain of the sections and, finally, the upper surface of one of the sections, the third of the thigh, is shown with the cut structures outlined and lettered. Unfortunately no text accompanies the drawings and there is no explanation of the lettering employed. Perfect accuracy can not be claimed for the lettered drawing, for while the section of the femur (*d*), the vastus lateralis (*a*) and medialis (*e*), probably both heads of the biceps (*b* and *c*), the sciatic nerve and the femoral artery can be identified, uncertainty remains as to the other structures represented. On QV, 19 there is a pencil sketch of the leg with planes for section represented in ink, three in the thigh and three below the knee, and again beside it is a figure showing the structures cut at the middle plane of the lower leg. The structures are lettered, but again there is no text to explain the lettering and again uncertainty exists as to what several of the structures represent, the figure being inaccurate. Leonardo had from his dissections a knowledge of practically all the muscles of the leg, but he evidently was not sufficiently familiar with their relations throughout their courses to identify them with accuracy in sections of the limb. So far as can be judged from his manuscripts he did not employ the method extensively and used it apparently only in connection with the lower limb. It was an experiment performed with knife and saw on material which lacked the previous preparation employed

Fig. 10. Transverse sections of the leg. (QV, 20.)

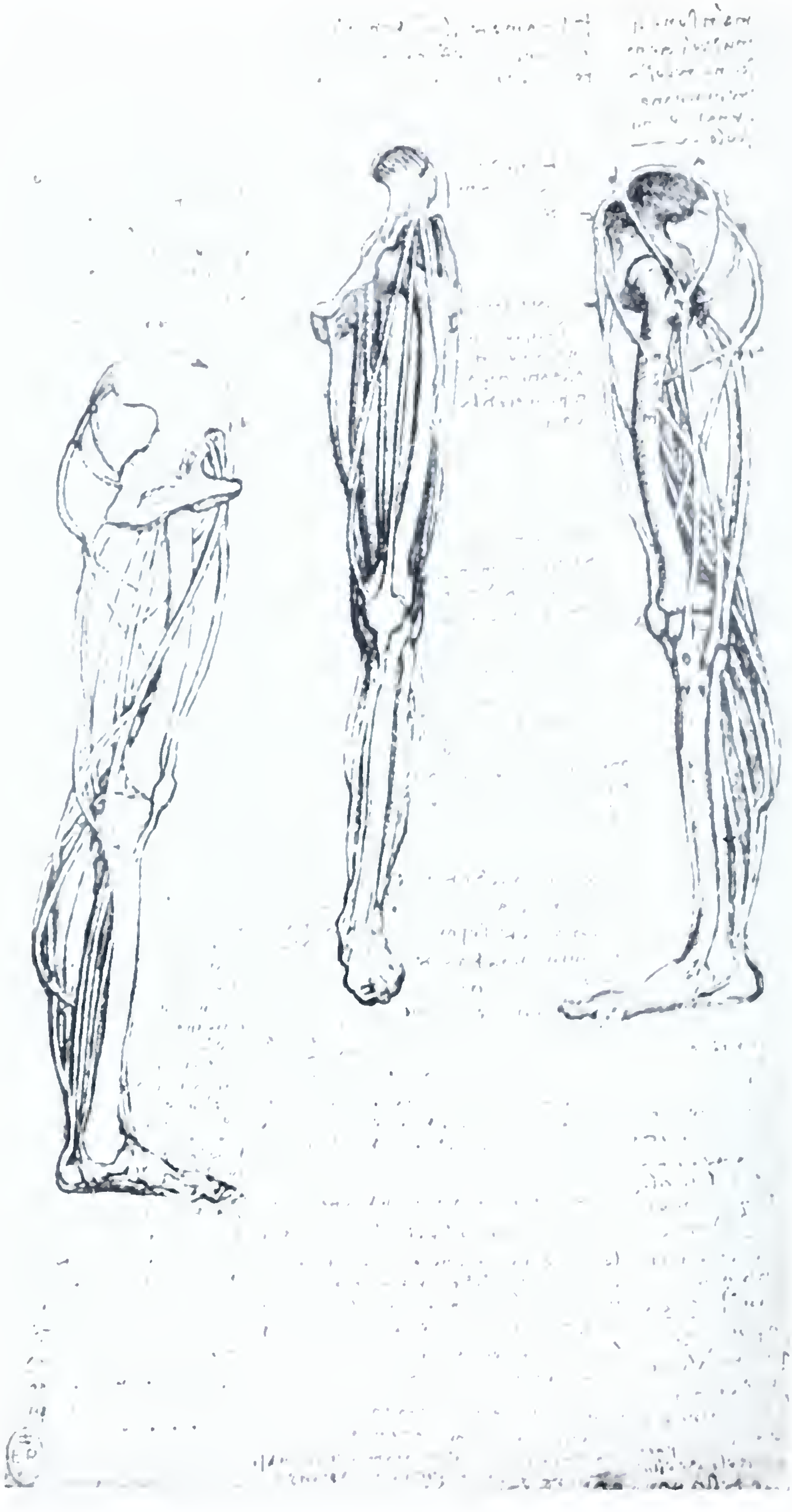


Fig. 11. Figures in which the muscles of the leg are represented by cords or wires. (QV. 4.)

in the present-day applications of the method, and the cut structure could not have had that smoothness of surface and sharp definition necessary for their ready identification. At all events it may be supposed from the limited use he made of it, that he found the method unsatisfactory, and it is only in recent times that it has been elaborated so as to become a recognized and valuable method in the study of anatomy.

Leonardo's deep interest in the mechanical principles involved in natural phenomena found for him a fruitful field for study in the action of muscles and in the movement of the blood in the heart. So clearly did he perceive the necessity for a correct understanding of such principles in the investigation of muscle action that he intended to preface the account of the muscles in his projected book with a treatise on the elements of mechanics and their applications (AnA, 10). Structure and function were for him correlated phenomena, the study of one necessarily involving that of the other. A muscle was an organ intended for the movement of a part, it served a definite purpose and it could not be properly understood until its purpose was determined. So he notes that one must remember to make sure of the origin of each muscle by pulling upon its tendon (AnA, 18), and that for each muscle there must be given the reason for all its offices, in what manner it acts and what moves it, etc. (AnB, 27). Pulling upon the tendon was an obvious procedure for determining the effect of the contraction of the muscle and was that recommended by Galen. But Leonardo desired a method that could be illustrated, and devised the plan of representing the muscles by means of threads (fig. 11).

"You will never avoid confusion in the representation of the muscles and of their positions, origins and insertions if you do not first make a representation of the slender muscles using threads, and thus you will be able to represent one over the other as Nature has placed them; and thus you will be able to name them according to the member which they serve, as the motor of the end of the great toe or of its middle or first bone, etc. And granted that you have such knowledge you will represent along side of this the true form and size and position of each muscle; but remember to place the threads which indicate the muscles in the same position as is the central line of each muscle and so the threads will represent the form of the leg and their distance will be quickly known." (AnA, 18; *cf.* AnA, 4v.)[3]

In another passage (QV, 4) he suggests the use of copper wires instead of threads, and from this it might be suggested that he contemplated the preparation of a model in which the muscles would be represented by wires attached to the skeleton and "bent into their natural form." It is doubtful, however, that he really made such a model;

[3] The last sentence of this paragraph *"e la lor distanzia spedita e nota"* is somewhat obscure. Probably it means that the relative positions of the muscles will be readily perceived.

he probably used the threads in his drawings merely to represent the muscles diagrammatically, so that their action and relations to one another might be more clearly perceived. This view is indicated by a passage (AnA, 10) in which he states that he uses threads to represent the muscles rather than lines, to show which muscle goes over and which goes under the other, "which thing would not be possible with simple lines."

The method is used in the representation of quite a number of the muscles, one of the most interesting cases of its employment being in the comparison of the hip and thigh muscles of a man and a horse (QV, 22) (fig. 12). Unfortunately the representations are inaccurate in some details, but it is noteworthy as a study of corresponding muscles under different mechanical conditions. It was one of Leonardo's maxims that "Every muscle uses its power along the line of its length" (QIV, 6), and the use of cords or wires was useful in determining that line. It must be remembered that for Leonardo the question of muscle action seemed much less complex than it does today. For him it was a question of the action of the individual muscles, not of muscle groups, and under such circumstances the use of the method might be of advantage, while for present purposes it can have only a limited value.

From the deep interest shown by Leonardo in problems connected with the movements of the heart and of the blood within it, one might expect that his inventive ingenuity would have led him to devise methods for rendering these movements apparent. And such was the case. He pondered much over the nature of the eddies and whirlpools that must be formed within the cups of the semilunar valves, when these were brought together by the reflux of the blood on the completion of the contraction of the ventricle. There are several sketches representing theoretical possibilities for these eddies (fig. 48), but these did not satisfy; the eddies could not be actually observed in the heart and Leonardo proposed to make a glass model of the basal portion of the aorta in which the course of the blood could be seen. On QII, 12 there is a sketch of a longitudinal section through a cylinder which becomes somewhat bulbous in its lower part, very much as the proximal portion of the aorta is represented in other drawings. Within the figure is written:

> "Form of plaster (*gesso*) to be inflated and a thin glass within it and then break it from head to foot in *an*" and below this the passage continues—"But first pour the wax into the gate of an ox's heart, so that you may see the true form of this gate."

It is difficult to obtain from these statements a clear idea of what Leonardo was planning, but apparently he proposed to make first a wax cast of the cavity of the aorta in its ascending portion and to use this cast to prepare a plaster model of the vessel. A lining of thin glass

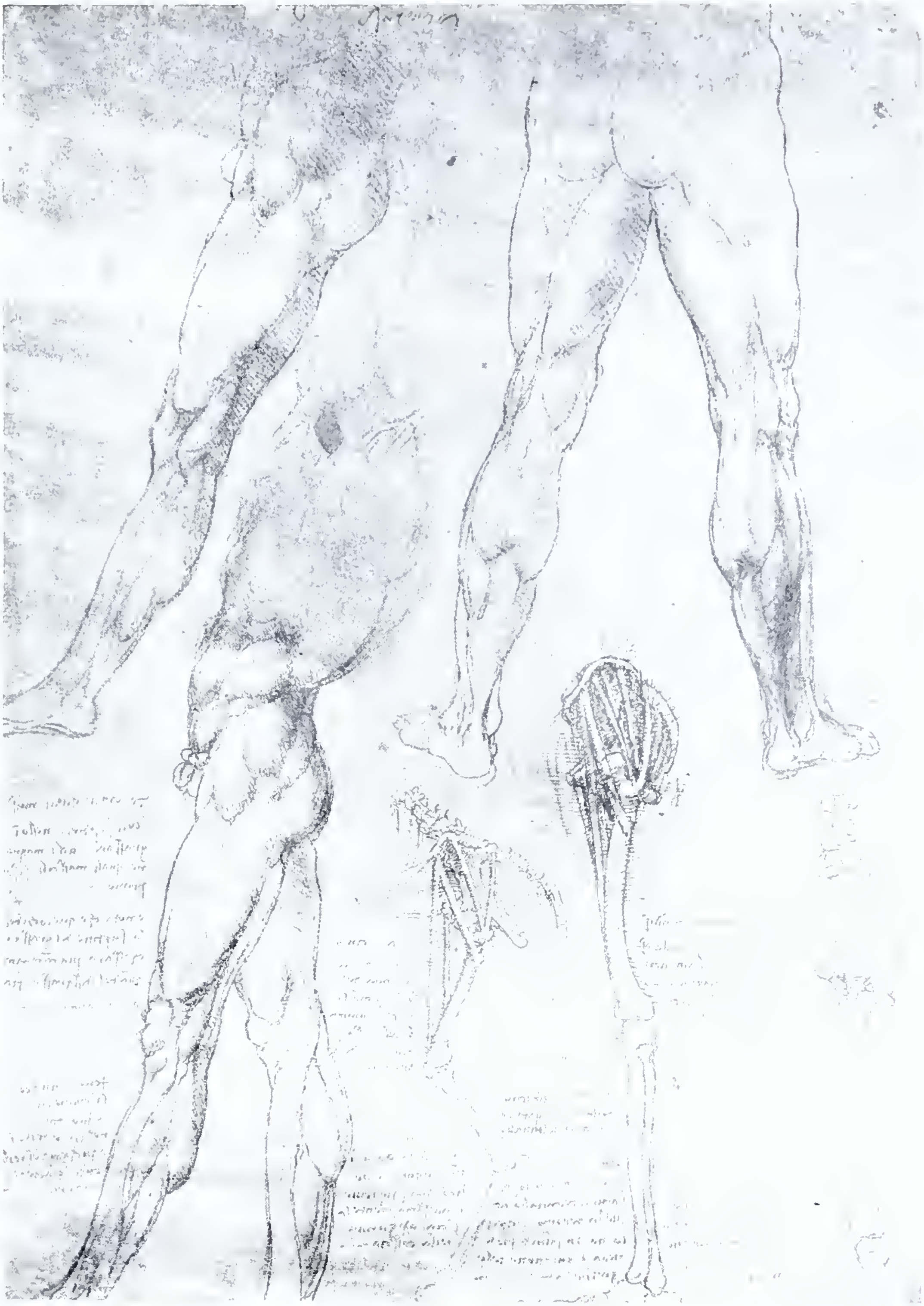


Fig. 12. Figures of surface anatomy of the leg with a comparison of the hip muscles of a man and a horse, muscles being represented by cords or wires.

was then to be blown into this model, and when the plaster was broken away the glass tube might be used to observe the currents of blood. On QII, 6v, there is again mention of a glass by which might be seen "what the blood does in the heart when it closes the valves of the heart," but no further details as to its preparation and use are given. But on QIV, 11v there is a memorandum, referring to the movements of the blood, "Make this experiment (prova) in glass and move within . . . membrane," a sentence whose obscurity is increased by the illegibility of a word, but which seems to imply that Leonardo was planning to attach a membrane to the inside of the glass to represent one of the semilunar valves. There is no evidence that the suggested model was ever constructed, no mention of results obtained by its use.

In connection with his studies of the heart-beat, Leonardo made use of another experimental method or rather adapted the method employed by the Tuscan farmers in slaughtering their pigs (QI, 6). The animal was tied to a board, back downward, and a drill (*spillo*), such as was used to pierce wine casks, was driven through the chest wall into the heart. The point where the drill pierced the chest wall served as a fulcrum and, as the heart contracted, the point of the instrument moved upward and the handle was depressed and *vice versâ* as the heart passed into diastole, the range of motion of the handle indicating more or less accurately the extent and direction of the movements of the organ.

The history of the use of this method in modern times has been told by van Leersum (1913), who shows that Leonardo had anticipated its use by modern physiologists by over three centuries. Schiff, substituting a needle for a drill, used it in 1849 in connection with his studies on the nerve control of the heart, and Rudolf Wagner used it in 1854 as a method unusually favorable for counting the heart beats and for determining the intensity of the heart's contraction. Later it was used by Moleschott and others, and more recently J. Berry Haycroft (1891) developed from it the more complicated, but more accurate, cardiograph.

In his investigations of the phenomena of vision Leonardo was continually resorting to experimentation, testing the effects of sudden illumination, studying the phenomena revealed by the pin-hole camera, etc. But these observations may be more appropriately considered later. One other experiment only need be mentioned here, that of pithing a frog.

"The frog suddenly dies when its spinal cord (*midolla della sciena*) is perforated; and before that he lives without head, without heart or any interior (organ) or intestines or skin. And it seems therefore that here is situated the foundation of motion and life." (QV, 21v.)

Also on the recto of the same folio it is stated that the frog will live for some hours if deprived of its head, heart and all the intestines, but if the spinal cord be pricked the animal "suddenly twitches and dies;" "All the nerves of the animal arise here (*i.e.* from the spinal cord), and this nerve being pricked it suddenly dies." Leonardo thus demonstrated a very important fact. A frog deprived of his brain becomes a purely reflex organism, without volition but capable of responding to certain stimuli in an unvariable manner. It would therefore seem to be still alive. But destruction of the spinal cord means destruction of the reflex centers and the animal lies flaccid and inert, apparently dead, but not really so. For death is not a sudden but a gradual process, and if Leonardo had varied his experiment or carried it further he would have found that the heart would continue beating and the muscles would contract if their nerves were stimulated for some time after the brain and spinal cord had been destroyed.

These examples will suffice to show that Leonardo approached his anatomical problems with originality and with ingenuity of method. But anatomy, being so largely a science of observation, did not give full scope to these characteristics; they are more clearly manifested in other fields of his activities, in his studies in hydraulics, for instance, and in his numerous mechanical devices. It was his fertility of invention that rendered his search for knowledge so productive and contributed to making him the greatest genius of the Renaissance.

CHAPTER VIII

GENERAL ANATOMY AND PHYSIOLOGY

In Leonardo's time a cleavage between anatomy and physiology, between the study of structure and function, did not exist. As an artist he was interested in form and as a student of mechanics he was interested in function, but the two could not be separated; there was no question as to whether form determined function or function determined form; each organ was believed to be designed and created for a special purpose and to be perfectly adapted to perform that purpose. The extreme teleology of Aristotle and Galen had been accepted with satisfaction by the Arabs, and the mediaevalists received it without question because it was in harmony with the teachings of the Church; and so, for Leonardo, the teleological view of Nature was the only one available. "The Author" he says "does not make anything superfluous or defective" (QII, 3), and again "Nothing is superfluous and nothing lacking in any kind of animal and product of Nature" (QI, 4v), to which dictum he adds the qualifying phrase "unless the defect comes from the manner in which it acts," apparently referring to the abnormal action of a pathological organ rather than to a defect in a normal one. "The *anima* can never be affected by the corruption of the body, but acts in the body like the wind which produces the sound of the organ, in which, if one of the pipes is injured, the wind can not produce a good result in the pipe" (Tr. 71). The same idea of perfection in form and function is seen in the statement that "Nature is said always to produce its effects in the easiest way and in the shortest time possible" (QI, 4).

With such beliefs, the dissociation of form and function was hardly possible. It did not take place until much later and may be traced back to the formulation of Cuvier's theory of types. For while Cuvier fully recognized the interdependence of structure and function and made it the basis of his investigations, his theory of types led to the development by Serres and Geoffroy St. Hilaire of the doctrine of unity of plan, according to which "Nature tends to repeat the same organs in the same number and in the same relations, and varies to infinity only their form." And so morphology became divorced from physiology, probably to the detriment of both, by becoming a search for homologous parts throughout the animal kingdom—form, structure and relations being the only criteria for homology, since function was dependent upon form.

But all this developed three centuries after Leonardo's time; he, like his contemporaries, followed the teaching of Galen, and not only in this particular, but also in his general conception of the phenomena of life. The naïve monistic materialism of the early Greek philosophers soon gave place to a dualism that has persisted even until today, a recognition of force or energy as something apart from matter, though acting on it. A lump of clay was mere matter, a living body was matter energized by a vital force, the *pneuma*, an imponderable, unsubstantial something, derived from the air in respiration and elaborated by the heart, whence it was distributed throughout the body. Some such concept was inevitable. How else could the characteristic phenomena exhibited by living organisms be explained, how else the difference between living and dead bodies, in the days when chemistry did not exist? As Sir Clifford Allbutt has pointed out, the pneuma of the ancients was their substitute for oxygen; it played in the animal economy essentially the same rôle as that element, though, since it was a mere concept and not a demonstrable entity, its mode of action necessarily remained obscure. It was the vital spirit, disturbance of which produced disease and failure of which was death. Its recognition goes back at least as far as Hippocrates and, as has been said, it is with us today, even though oxygen may have robbed it of some of its powers and properties.

Leonardo does not use the word pneuma; it disappeared from use with the disappearance of the Greek language in western Europe. Instead he uses such terms as *vento, spiritus* and *anima*, the last having sometimes a special significance, corresponding to the psychic pneuma of Galen, mediating consciousness and the idea of individuality, though hardly with the theological attributes usually attached to the word soul. Thus in AnB, 2 there is a passage headed "How the five senses are officials of the soul (*anima*)" in which one finds the following:

> "The seat of the soul is in the judicial part (of the brain) and this seems to be in the place where all the senses come together and which is termed the sensorium commune (*senso commune*). It is not everywhere in the body as some have thought, but all in this part; for if in all parts it would not be necessary for the instruments of sense to make a concourse in a single place." . . . "As the sensorium gives to the soul and not the soul to the sensorium, when the sensorium, the official of the soul, is wanting there is wanting to the soul in such a life the knowledge of the office of the sense, as is seen in mutes and in those born blind."

Nor do *vento* and *spirito* always have the meaning of pneuma; *vento* is also employed in the more usual sense of wind and *spiriti* may denote the "spirits of the vasty deep," with which the necromantists claimed to have dealings but of whose existence Leonardo had serious doubts (AnB, 28v, 31v and 31).

What Leonardo's concept of the pneuma or anima may have been, whether he regarded it as peculiar to living organisms or as identical with the forces acting on non-living objects, is of interest. To the Ancients it was undoubtedly a peculiar vital force, derived from the air drawn into the lungs and elaborated by the innate heat implanted in the left side of the heart. Galen recognized three varieties of *pneuma*, the psychic, elaborated in the *rete mirabile* of the brain; the spiritual, distributed from the left side of the heart by the arteries; and the animal, distributed by the veins and having its origin in the liver, and, in accordance with this idea the mediaeval anatomists, such as Mondino, named the contents of the three *ventres* of the body respectively the *membra animata*, *spiritualia* and *naturalia*. To this arrangement and to the principal involved in it Leonardo apparently subscribed, for in a sketch showing the general arrangement of the organs (QIV, 3) the thorax is labeled as the receptacle for the spiritual organs and the abdomen as that for the material organs, and in other drawings (QIII, 3v; QV, 1 and 20v) he indicates the diaphragm as the separation between the spiritual and the material parts.

But there are indications that Leonardo did not accept the classical tradition in all its details. He was so far advanced toward the modern scientific viewpoint as to refer, when possible, explanations of phenomena to the action of known physical forces, rather than to seek them in hypothetical, unknown agencies. He enunciates his *credo* in this respect in the following words:

"Weight, pressure and accidental movement, together with resistance, are the four accidental powers in which all the visible works of mortals have their existence and their end." (SK, II, 116v.)

In accordance with that belief he dismisses the idea of innate heat, so greatly stressed by the ancients, and assigns the warmth of the heart to the—

"rapid and continuous motion of the blood producing friction on the cellular walls of the upper ventricle, as well as by its general motion. Thus the blood is heated and subtilized so that it can penetrate the pores and give life and spiritus to the members." (QI, 4.)

That he regarded the pneuma as merely a special manifestation of one or more of the physical forces mentioned in the passage quoted above (SK, II, 116v) is not so clear, but it may be noted that his definition of force applies equally to the concept of the pneuma. This definition is as follows:

"Force I define as a spiritual power, incorporeal and invisible, which, with brief life is produced in those bodies, which, as the result of accidental violence, are brought out of their natural state and condition." (B, 63; *cf.* A, 34v.)

It may be, however, that he regarded the pneuma as one of the forms of "accidental violence" that produced force.

As regards the constitution of matter he accepted as fundamental the four elements of Empedocles: fire, earth, air and water.

"Man was termed by the ancients a microcosm (*mondo minore*) and assuredly the epithet is well taken. In effect man is composed of earth, water, air and fire; the body of the earth is the same." (A, 55v.)

He also accepted the Empedoclean theory of two forces, love and discord, attraction and repulsion, acting on these elements—

"since one sees water expelling the air and fire that have entered from the heat in the bottom of the cauldron and escape by the bubbles at the surface of the boiling water. Also the flame attracts the air and the heat of the sun draws up the water in the form of a moist vapor, which then falls again as inspissated and heavy rain." (QI, 1.)

It is strange that Leonardo nowhere suggests the possibility of these elements being composed of lesser particles, the atoms imagined by Democritus, accepted by Plato and made popular by Epicurus and Lucretius. He knew of Epicurus, quoting with disapproval his idea that the sun was no larger than it seemed to be (F. 5), but of Lucretius he makes no mention, although the *De rerum naturâ* was first printed in Brescia in 1473, and again in Verona in 1486. He did, however, know of the "elements" recognized by the alchemists, inflammable sulphur, volatile quicksilver and incombustible and stable salt, but his disapproval of the alchemists and all their works (AnB, 31v) led to a rejection of their theories. Thus he says (CA, 76v):

"The lying interpreters of nature assert that quicksilver is a constituent common to all metals: they forget that nature varies its constituents according to the variety of the things it desires to produce in the world."

The concluding sentence of this statement might be taken to indicate recognition of a multitude of elements, but it may merely refer to varying admixtures of the four classical elements.

Leonardo's outlook was so sane, so scientific, that it is almost a relief to find in his note-books some traces of the mysticism so prevalent in his day. One such trace is to be found in his acquiescence in the idea that man is a microcosm, similar in all essential members to the macrocosm. The idea is an old one, tracing back in its fuller development to the Neo-platonists of the third and fourth centuries, who taught that man was composed of the same elements as the rest of the cosmos and was endowed with a portion of the world-soul which pervaded all things; materially and spiritually he was therefore a miniature cosmos, subject through his moiety of the world-soul to all the influences affecting the greater cosmos. The inherent mysticism of the idea appealed to the Arabian commentators, and during the Middle Ages was made familiar by the writings of Hildegarde of Bingen and later by the teachings of Grosseteste and Albertus Magnus, the Doctor Universalis. It gave a foundation for the belief of astrologers in the influence of the stars in their courses on the lives of man, a belief that lingered, nay flourished, long after Leonardo's time.

He, however, was not interested in the astrological bearings of the idea, it was the structural analogies of the parts of the human body and those of the earth that appealed to him. The opening sentence of a passage in which he declares his belief in the microcosm idea has already been quoted (p. 96); in the continuation of that passage (A, 55v) he compares the bones which are the framework and support of the flesh to the rocks which are supports for the soil; the respiratory movements of the lungs are likened to the ebb and flow of the tides, which are the breathing of the world; the veins, arising in a pool of blood (the heart), spread their branches throughout the body, just as the ocean fills the body of the Earth with infinite veins of water. Only tendons (*nervi*) are lacking in the Earth, since tendons produce movement and the Earth is stable without movement; "but in all other things man and the Earth show a great similarity." In the Leicester Codex (fol. 34) he gives a somewhat more detailed comparison that it is worth while to transcribe.

> "Consequently it may be said that the Earth has a vegetative soul and that its bones are the series of conglomerations of rocks which make the mountains; its cartilages are the tufas; its blood are the veins of water; the lake of blood contained within the heart is the ocean; its breathing is the increase and diminution of the blood through the pulse and so, in the Earth it is the ebb and flow of the sea; and the heat of the world-soul is fire that is infused throughout the Earth and the seats of the vegetative soul are the fires, which, in different places of the Earth breathe in hot springs, in sulphur mines and in volcanos, as at Mongibello in Sicily and at several other places."

These are passages in which the idea is stated most completely, but there are allusions to it in others. Thus in QI, 2 he speaks of fifteen figures illustrating the cosmography of the "minor mondo" in the same order as was employed by Ptolemy in his Cosmography, and in CA, 171, he again draws comparison between the veins and the rivers and streams of the Earth, pointing out, however, in still another passage a difference, in that—

> "The origin of the sea is the reverse of that of the blood, for the sea receives into itself all the rivers, which are totally produced from the aqueous vapors that have ascended into the air, while the sea of blood is the source of all the veins." (AnA, 4.)

It is noteworthy that in none of these passages is there any suggestion of astrological implications; they are merely expressions of fanciful structural analogies.

With the doctrine of the four elements, that of the four humors with their definite qualities was so closely linked that it is a natural inference that Leonardo gave it credence also. And yet one finds but little reference to it in the note-books; he mentions the humors collectively only, not individually.

"The cause that in all the kinds of animate bodies moves the humors against the natural tendency of their weight is undoubtedly that which moves the water contained within the terrestrial veins." (CA, 171.)

Of course he knew of the blood, phlegm and yellow bile, and there is indirect evidence that he also accepted the existence of the more elusive black bile, since in more than one drawing he represents a direct communication between the liver and the spleen (*e.g.* QIII, 10v) (fig. 52), apparently based on the Galenic theory that the black bile, elaborated in the liver, passed to the spleen and thence to the stomach.

The chief interest that lay in the doctrine of humors was the part it played in the etiology of disease. In the normal body they were in a proper balance, but if from any cause any one of them should be produced in too great abundance or in a lessened quantity disease resulted. It was a plausible and consistent theory, and since the qualities of the humors, hot, cold, moist and dry, were known, the therapeutic methods that should be employed were indicated. Leonardo, however, when he writes of the cause of disease does not refer it to a dyscrasia of the humors, but of the elements.

"It is necessary to understand what sort of thing is man and what life is, what health is and how an equality, a concordance of the elements maintains it and how discordance of them threatens and undoes it" (CA, 270). . . "Medicine is the readjustment of elements that have become disequalized; disease is the discordance of elements that are united in the living body." (Tr. 4.)

The practical difference is slight, for the qualities of the humors were also those of the elements. However, the etiological significance of the humors was a matter pertaining to medicine and Leonardo's anatomical studies were pursued for the benefit of art and science, rather than for practical medicine. Indeed like Montaigne a few years later, he had but a poor opinion of the methods and practise of physicians.

"Endeavor to preserve your health," he said, "and this you will succeed in doing so much the more, the more you keep away from doctors. For their mixtures are kinds of alchemy, the books on which are not less numerous than those that exist on medicine." (AnA, 2.)

And still more harshly he comments:

"Every man desires to gain wealth that he may give it to the doctors, the destroyers of life; therefore they ought to be rich." (F, 96.)

After Aristotle's time it was customary in anatomical treatises, after referring to the elements and the humors, to describe the body as composed of similar and dissimilar parts, the former corresponding approximately to what are now termed tissues, the latter to organs or members. If a lump of fat were divided into two parts, each resembled the other and was still fat, whereas if a foot or hand were divided, the two parts did not resemble each other. Hence the terms similar and dissimilar. The similar parts were structural units of a higher grade than the elements or humors; as Avicenna puts it, the members (*i.e.* similar parts) were formed by commixtion of the humors, the humors by commixtion of foods and foods by the commixtion of the elements.

Aristotle and Galen mention a number of these similar parts but differ somewhat in their enumeration, for while Aristotle includes such substances as milk and semen, which Galen omits, the latter adds the crystalline and vitreous humors of the eye and also the proper substance of such organs as the stomach, intestines and uterus. Avicenna materially reduces the number, omitting such obvious items as fat, skin and nails, mentioning only bone, cartilage, nerve, tendon (chorda), ligament, arteries, veins, membrane (*panniculus*) and flesh (*caro*). The distinction of tendons and ligaments is not very clear and he apparently recognizes two kinds of flesh, that forming the substance of muscle and that filling spaces not occupied by other material, meaning thereby glandular tissue, such as that of the thyroid and pancreas.

Leonardo does not discuss the similar parts as such, but in his account of the structure of muscles (QII, 18v) he mentions certain of them in a manner distinctly reminiscent of Avicenna; certainly in this case his source was Avicenna rather than Mondino, since the latter author while mentioning the existence of similar parts, purposely omits an enumeration of them, since they could not be demonstrated in an Anatomy. The *similares* mentioned by Leonardo are bone, cartilage, nerve, veins, arteries, these incidentally, and tendons (corde), ligaments, membranes (*panniculi*), flesh, pellicles and fat, but when one attempts to gain a clear idea of what these terms denoted difficulties are encountered. Leonardo was approximately one hundred and fifty years before Leeuwenhoek and Malpighi and the application of the microscope to anatomy, and had therefore to rely mainly on form, color and consistence for the distinction of the various tissues and, further, his notes were recorded at odd times over a long period of years, allowing of uncertainty in the use of the terms employed.

Notwithstanding Galen's attempt to correct Aristotle's confusion of nerve and tendon it reappears in Avicenna and is even more marked in Leonardo's notes, in which tendons are usually indicated by *corde*, but sometimes by *nervi*, and, conversely, nerves are sometimes termed *corde*. Thus on AnB, 2, he says—

"The *nervi* with their muscles serve the *corde* as do the soldiers their leaders (*condottieri*); the *corde* serve the *senso commune* as the leaders do the captains; and the *senso commune* serves the *anima* as the captains do their lord."

The point of this is lost unless one translates *nervi* as tendons and *corde* as nerves.

The definition of the term panniculi (membranes), "joined to the flesh and interposed between the flesh and the tendon (*nervi*); usually they are joined to the cartilage" (QII, 18v), is not clear, but in other passages (AnA, IIv, 18) it is evident that it denotes the periosteum or (AnA, 18) the capsular ligaments of the joints. It would seem, then, that it denoted any connective tissue membrane and might include three varieties, tendinous, nervous and composite, the latter consisting of tendon, nerve, muscle, vein and artery. But here, again, Leonardo's definitions do not clearly define; perhaps a tendinous *panniculo* was one in which the fibers were clearly arranged in bundles, and a nervous one in which they were not. The composite variety seems to indicate the platysma, but the term pellicle apparently denotes the same combination of parts. Furthermore, while the articular capsules are sometimes described as membranes, they are also termed ligaments (AnA, 15v), the aponeuroses of the abdominal muscles are termed cartilage (AnB, 15), and cartilage itself is said to be "indurated tendon or hardened bone" (QII, 18v). It would seem that Leonardo had an inkling of the fundamental relationships of all the varieties of connective tissue and was groping for a method of expressing them.

The opening chapter of Avicenna's Summa on the muscles reads as follows:

"God in his wisdom therefore controlled it by giving it strength (*grossitiem*) which he produced by a commingling of fibers (*villi*) in a substance composed of these and of ligaments, and the meshes of these he filled with flesh (*caro*) and this itself he covered by a membrane (*panniculus*), and in the middle he placed a perpendicular like a tendon (*chorda*) of the substance of nerve. And from this, when all was done, there is a member composed of nerve and ligament and the fibers of these, of the filling flesh and the covering membrane. And this member itself is a muscle."

Leonardo's conception of flesh was undoubtedly the same as Avicenna's, but his statement of it is obscured by an interchange of the words "muscle" and "flesh." He says, "Flesh is composed of muscle, corda, nerve, blood (*i.e.* veins) and artery" (QII, 18v), and if "muscle" be substituted for "flesh" and "flesh" for "muscle" the agreement with Avicenna is complete.

Fat is mentioned as a substance occurring beneath the skin and filling up the depressions between the muscles. It is said to be of a spongy or viscous consistency and to contain little vesicles full of air, which condense or rarefy according to the increase or rarefaction of the muscle substance (G, 26).

So much for Leonardo's ideas concerning the basic structural constitutents of the body. They were essentially those of Galen as transmitted by Avicenna, but showing here and there indications of independence, originality and imagination. The dissimilar parts or organs, formed by the conjunction of various *similares*, will be considered in succeeding chapters, but the general question as to their arrangement in the body may be considered here. The extreme teleology of the mediaeval anatomists demanded a purpose in all things. That the animal, spiritual and natural parts should be located respectively in the head, thorax and abdomen seemed quite reasonable, but why, Leonardo asks "is man divided by the brain, rectum, the fork (of the legs), lips, nose, penis and anus and lung, but not by the stomach and bladder (gall-bladder)" (QI, 13), that is to say, why should the stomach and gall-bladder be placed asymmetrically in the body, while the other organs named are symmetrical? The answer to the question is partly to be found on QII, 15, in a passage headed "The balancing of the weight of the right and left side," in which it is held that the heart is inclined to the left in order that it and the spleen may together balance the liver on the right, the stomach on the left is balanced by the cæcum, the duodenum on the right balances the ileum on the left, while the jejunum and rectum are placed in the middle line.[1] The explanation seems somewhat lacking today, even with our imperfect knowledge of developmental mechanics, but it was no doubt acceptable in the early part of the sixteenth century.

Leonardo's general physiology was even more purely Galenic than his anatomy. Wastage of the body substance was continually going on. Food underwent a concoction in the stomach whereby it was converted into chyle, which was carried to the liver and there was subjected to a second concoction. This converted it into blood, with the separation of certain impurities, yellow and black bile, and the excess of water, this last passing to the kidneys. From the liver the blood passes to the heart, whence it is distributed to the various parts of the body for their restoration, a portion of it, however, being subtilized into pneuma (*anima*) by the heat developed by the pulsation of the heart. This passed through minute pores in the septum of the ventricles and was distributed to the body by the arteries. The lungs served to moderate the heat of the heart. Quite a plausible and consistent theory when one makes allowance for ignorance of the circulation of the blood and of the chemical processes involved in metabolism.

[1] In this passage Leonardo becomes confused in his use of the terms "right" and "left," placing the cæcum and duodenum on the left. Correction has been made above.

The philosophic side of Leonardo's mind found interest in the idea of the continual destruction and repair, death and rebirth of the tissues of the body, and he comments upon it at some length in a passage (AnB, 28) headed "How the body of animals continually dies and is born again." He compares the life of the body to the flame of a candle—

"formed by the nourishment given to it by the fat of the candle, which life is thus continuously renewed by very rapid aid from beneath, in proportion as the upper part is consumed and dies, and in dying becomes changed from radiant light to dingy smoke. And this death goes on as long as the smoke continues; and the period of duration of the smoke is the same as that which feeds it, and in a moment the whole light dies and is entirely regenerated by the movement of that which nourishes it. And its life receives from it also its ebb and flow, as the flicker of its point serves to show us."

So, he continues—

"The flesh of animals is restored by the blood, which continually is generated from their nourishment, and this flesh unmakes itself and returns by the meseraic arteries and passes to the intestines, where it putrefies by a putrid and puant death, as is shown by their expulsions and vapors; just as does the smoke and fire given for comparison." . . . "Man and the animals are merely a passage and channel for food, a tomb for other animals, a haven for the dead, giving life by the death of others, a coffer full of corruption." (CA, 76v.)

But why, except for accident and disease, should not the restoration of the wasted tissues go on indefinitely? Why should "the old who enjoy good health die through lack of nutrition" (AnB, 10v)? Seeking an answer to this question Leonardo seizes the opportunity for making an autopsy of a centenarian, who—

"did not feel any failure in the body except weakness, and thus sitting on a bed in the hospital of Santa Maria Nuova of Florence, without any movement or sign of any accident, he passed from this life." (AnB, 10v.)

And he found that—

"The veins of the aged acquire great length and so become tortuous, those that are wont to be straight, and they become so thick in their wall that they close and prevent the movement of the blood. And from this comes death in the aged, without illness." (AnB, 11v.)

He figures the tortuous vessels and compares them with the straight vessels of a child (fig. 50), giving the first record of a case of arteriosclerosis and the first foundation for the aphorism that a man is as old as his arteries.

Life then is a question of nutrition.

"We support our life by the death of others. In a dead thing there remains insensible (?*sentato*) life, which, united to the stomach of the living, takes again sensitive and intellectual life." (H, 89.)

This statement might be justified by an appeal to the teachings of modern chemistry, but from Leonardo it is mere speculation. He was, however, groping for an explanation of life more fundamental, more satisfying than that which made it merely a question of nutrition, and in his gropings he suggests possibilities, whose full significance, far beyond the knowledge of his day, is interesting in the light of modern mechanistic theories. "Where there is life there is heat and where there is vital heat there is movement of the humors" (CA, 171), and he carries this idea back to its source in the sun by the statement that "all vital principle descends from it (*i.e.* the sun) since the heat there is in living creatures proceeds from this vital principle" (F, 5). But more startling, because so modern, is the assertion that "Motion is the cause of all life" (H, 141).

CHAPTER IX

LEONARDO'S CANON OF PROPORTIONS

It was Leonardo the artist rather than Leonardo the anatomist who was dominant in an endeavor to formulate a canon of proportions for the human body. An anatomist in determining the relative proportions of different parts of the body would be seeking for the structural and physiological adaptations underlying these proportions, and of this there is nothing in Leonardo's treatment of the subject; the artist, on the other hand, would be working more empirically, seeking merely to establish a standard for the more accurate portrayal of the human form. This was evidently Leonardo's purpose, and, furthermore, as will be shown later, he evidently approached the study of proportions purely from the standpoint of the artist.

Cantor in his lectures on the history of mathematics[1] states that Giotto had written on the proportions of the body and that such studies had also been ascribed to Piero della Francesca and to Ghirlandajo, but there is no evidence that Leonardo was influenced by any of these. He was, however, indebted to the Roman writer Vitruvius,[2] who, in the reign of Augustus, wrote a treatise on architecture in which he advocated the observance of a definite symmetry in the various parts of an architectural design, and advanced in support of this idea the fact that such symmetry occurred in natural objects. As proof of this he gives the proportional lengths of several parts of the human body, pointing out, for example, that the length of the body is eight times the height of the head from the point of the chin to the vertex and six times the length of the foot. He says—

> "Therefore if it is agreed . . . that a correlation of proportional parts may be found between the individual members and the whole aspect of the body, it follows that we should admire those who, building temples to the immortal Gods, have so ordered the parts of their work that, individually and in general, their distribution is made harmonious in proportions and symmetries."

An edition of the *De architecturâ* was published in Rome in 1486 and another in Florence in 1494 and either of these may have been consulted by Leonardo. He undoubtedly knew of the work of Vitruvius, for there is a memorandum that he had borrowed a copy of it and there is a folio in the Royal Gallery at Venice with drawings by Leo-

[1] Cantor, *Vorlesungen über Geschichte der Mathematik*, Bd. II, Leipzig, 1900.

[2] Marcus Vitruvius Pollio, *De Architecturâ*, Ed. by A. Choisy, 4 vols., Paris, 1909.

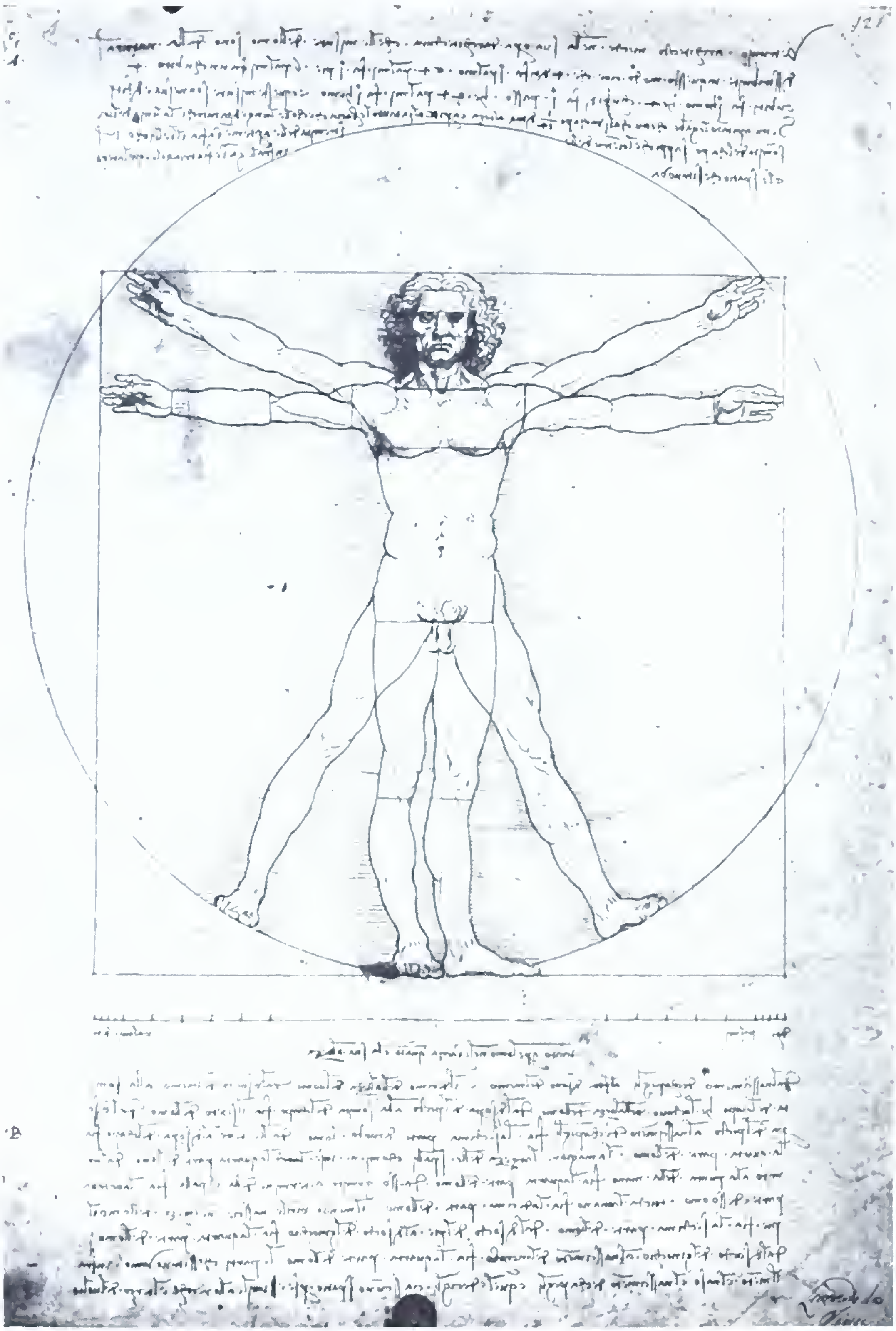


Fig. 13. Figure of a man inscribed in a circle and in a square. Drawing in Royal Academy, Venice (Anderson).

nardo, showing the figure of a man inscribed within a square and also within a circle (fig. 13). These figures are evidently illustrations of two of Vitruvius' proportions, namely, that in which he states that in a man standing erect with the arms stretched horizontally, the distance between the tips of the fingers will be equal to the height of the body and the figure may therefore be inscribed in a square, and, secondly, if a man lie supine with arms and legs abducted, a circle drawn with the umbilicus as a center will touch the tips of the fingers and toes. Memoranda accompanying the figures mention other proportions recognized by Vitruvius, and it is further noteworthy that the figures were reproduced in an edition of the *De architecturâ*, edited by Jocundum and published in Venice in 1511, as well as in some later editions.

It is possible that Leonardo may have begun his studies of proportions early in his career, while he was still a pupil of Verrocchio; it is even possible that he had studied a Vitruvian manuscript prior to his exodus to Milan in 1483, for in his letter to Ludovico Sforza, he boasts of his skill as an architect. But these are mere conjectures; it is more likely that he seriously took up the study of proportions only after he had taken residence in Milan and after the establishment of his friendship with Luca Pacioli. The association with Pacioli has already been mentioned (p. 56), but it may be recalled that in 1497 Pacioli had written his *De divinâ proportione* in which he advocates the use of the "divine proportion" in architectural designs, and also, like Vitruvius, considers certain proportions of the human body and, further, the symmetries of the five regular solids. These last and their modifications are illustrated by numerous figures that were drawn by Leonardo and, further, the book contains two outline drawings of heads, through which lines are drawn indicating their symmetry and the proportions of their parts. These also may reasonably be attributed to Leonardo and further evidence of his collaboration has been found in the picture in the book of an arch on the bases of which there are on one side the letters MA and on the other LV; these have been interpreted as MAgister Leonardus Vincius but, as Solmi (1919) has pointed out, may be as well interpreted as MAgister LUca. However, even without this third item, the evidence that Leonardo collaborated with Fra Luca in the *De divinâ proportione* is sufficiently authentic and is the first definite indication that he had become interested in the study of bodily proportions.

The book though written in 1497 was not published until 1509, a delay which may have been partly caused by Leonardo's dilatoriness in his artistic work, but more probably by the exodus of the two friends from Milan in 1500, shortly after the city had been taken by the French. It does not seem improbable that the illustrations were completed in Florence during the residence there of Pacioli and Leonardo after their visit to Venice, when, as is known from a reply to an inquiry of Isabella Gonzaga, Leonardo was too much interested in mathematical studies to find time for his art. But, be that as it may, the book was not published until after Leonardo had returned to Milan in 1506 and had become the guest of the Melzi in their villa at Vaprio.

Leonardo's memoranda concerning proportions are scattered through his various manuscripts, but several folios of QVI are almost exclusively devoted to such memoranda, arranged in a more or less tabular form. At the time these folios were written he must have been actively engaged in the study of proportions, and if an approximate date could be assigned to them it would indicate whether his special interest in this line of studies antedated his association with Pacioli. Fortunately there is a clue to their date. Folios QVI, 10 and 11, both of which are devoted to lists of proportions, have the heading *el treço,* which Professor Lesca has plausibly interpreted as meaning that the measurements recorded were made on a man from Trezzo, that is to say from the village of Trezzo sul' Adda, not far from Vaprio, and well known to Leonardo in connection with his plans for the extension of the Martesan canal to Lake Como. If this identification is correct the folios were probably written during the early months of 1507, when Leonardo was residing at Vaprio, or later in that year, or during 1508 when he was busy with his plans for the canal.

The probabilities then are in favor of the view that the stimulus to intensive study of the bodily proportions came from Pacioli. He had cited a number of them, largely those of Vitruvius, in his book and Leonardo had drawn figures to illustrate those of the head. It seems likely that it was this task, undertaken to oblige a friend, that aroused Leonardo to a more thorough and extensive study of proportions. It is noteworthy, however, that the proportions given by Pacioli do not all correspond with those in Leonardo's notes. Thus, both authors divide the distance from the roots of the hair to the chin into three equal parts by two horizontal lines (fig. 14), one passing through the eyebrows and the root of the nose and the other through the lower edge of the nasal septum (these are Vitruvian proportions), and the lower of these thirds is again divided by horizontal lines passing through the mouth and through the labiomental groove between the mouth and the chin; while the other two thirds are each divided into only two equal parts. But Pacioli added another principle, which is shown in the illustration, but is not made use of by Leonardo. It is to the effect that if lines are drawn from the external occipital protuberance to the extremities of a line touching the forehead and lips and representing the length of the face, the result will be an equilateral triangle. It is strange that Leonardo, after having drawn a figure illustrating this proportion, should make no mention of it in his notes; indeed he very rarely uses angles or triangles (fig. 16), his measurements being mostly linear, vertical, transverse, or occasionally sagittal.

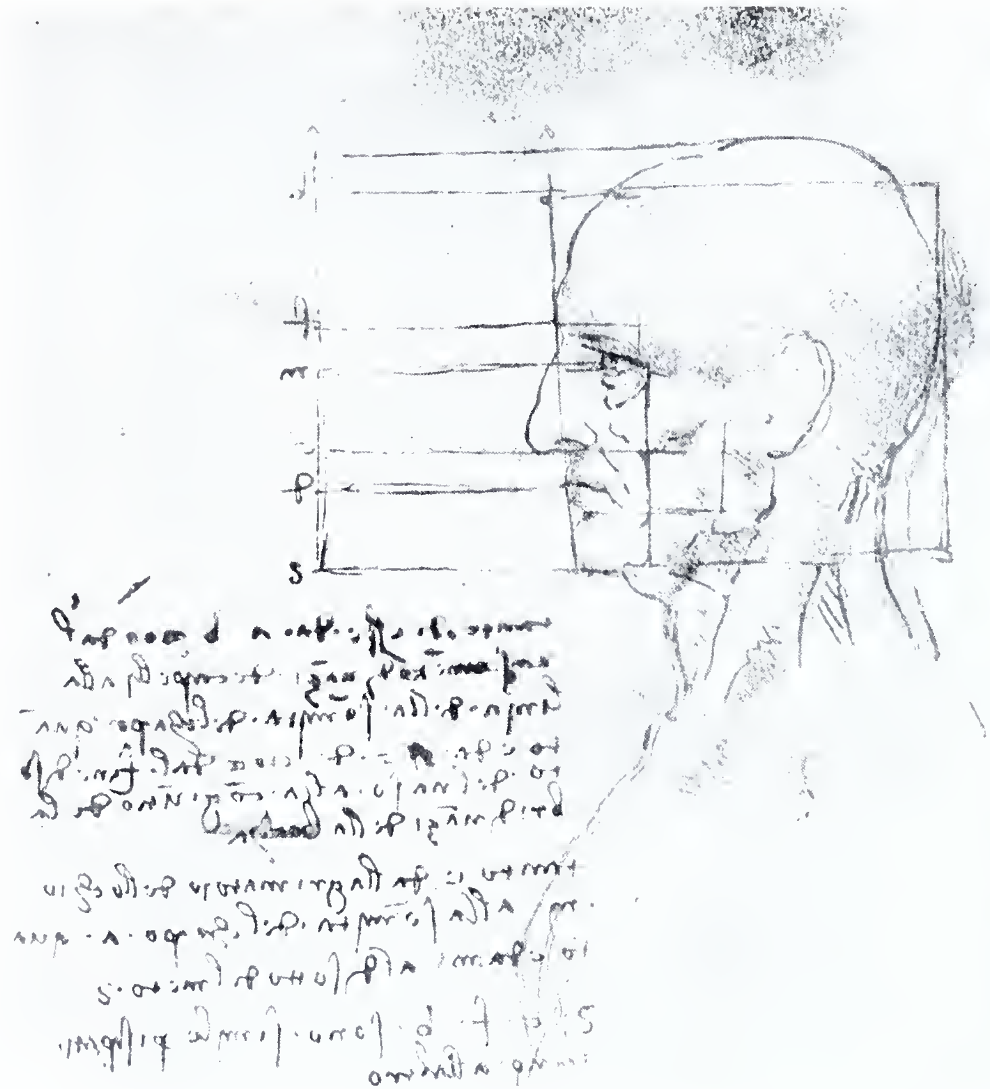


Fig. 14. Figure illustrating proportions of the head. (QVI, 1.)

Fig. 15. Figure showing lines of measurement used in determining proportions of leg. (QVI, 11v.)

Fig. 16. Figures illustrating proportions of the face and eye. A drawing in the Royal Palace, Turin (Anderson).

Again, Pacioli in his description of the man inscribed in a circle, states that the circle not only touches the tips of the fingers and toes, but also the top of the head, erroneously modifying the statement of Vitruvius, which may be translated—

"If a man is placed supine with his hands and feet spread out and his umbilicus is taken as a center of a circle, by describing the circle the digits of both hands and feet are touched by the line."

Leonardo, in his notes on the folio bearing his illustrations of the man inscribed in a circle and in a square, specifies more clearly than Vitruvius the position of the limbs necessary in order that they may touch the circle. He says—

"If you open the legs so as to reduce your stature by one-fourteenth, know that the center of the extremities of the opened limbs will be the umbilicus and the area between the legs will be an equilateral triangle."

This note was probably written in 1509 or 1510, since the accompanying drawings were published in the Vitruvius of 1511; if before that date, surely Leonardo would have noticed and corrected his friend's error.

It would seem then that when Leonardo drew the illustrations for the *De divinâ proportione* he was merely illustrating Pacioli's views; he had not yet seriously undertaken the study of the proportions of the parts of the body, but when he did so later he went into the question far more thoroughly than Pacioli had done and found it necessary to differ in some respects from the proportions laid down by that author. Thus Pacioli, as has been stated, divided the distance from the edge of the nasal septum to the chin into three equal parts, and since that distance equalled one-third the height of the face, each of the parts would equal one-ninth that height. Leonardo, however, in QVI, states that the distance from the mouth to below the chin equals one-fourth the height of the face (QVI, 4 and 9) and that the distance from the mouth to the labiomental groove, *i.e.* the height of the lower lip, is one-third that distance and therefore one-twelfth the height of the face instead of one-ninth. If then the distance from the nasal septum to below the chin is one-third the length of the face, the height of the upper lip must also be one-twelfth that length. In other words, the distance from the labiomental groove to below the chin is twice the height of either lip, instead of equal to it as Pacioli would have it, and is therefore one-sixth the length of the face (QVI, 4) instead of one-ninth. In passing it may be noted that on that very same QVI, 4 Leonardo also states that the height of the upper lip is one-seventh the length of the face, a proportion irreconcilable with those given above. Is it a variation or an error, for Leonardo sometimes nodded?

Leonardo's proportions have been thoroughly collated and classified by Professor Favaro (1917), who, to coördinate them, chooses the height of the lip as a modulus, this being one-twelfth the length of the face. The distance from the roots of the hair to the vertex is one-sixth greater than the length of the face (QVI, 11v) and since the height of the head, from the vertex to below the chin, is one-eighth the total height of the body (QVI, 10), the modulus is one one-hundred-and-twelfth of the total height. Leonardo, however, makes use of no definite unit of proportion or modulus, but expresses his proportions sometimes in terms of the total length, sometimes in terms of the length of the face and, more frequently, in those of the height of the head. In the case of the limbs the length of one part may be expressed in terms of another, as for example, in the statement that the length of the arm from the shoulder to the tip of the middle finger is equal to the length of four hands (QVI, 12), or that the distance from the anterior superior spine of the ilium to the ground is equal to the length of four feet (QV, 4). A good example of his method is shown in figure 15. Here the leg is shown in side view, crossed by lines lettered and representing diameters at various levels. The accompanying text states that the knee is halfway between the anterior superior spine of the ilium and the sole of the foot; the diameter through the buttocks is equal to one-eighth of that distance and to the distance from the anterior superior iliac spine to the gluteal fold; the diameter of the calf is one-quarter the distance from the knee to the sole; the diameter of the leg a little above the malleoli is one-sixth the knee-sole distance; and so on. Occasionally the lengths of the parts of one limb are expressed in terms of the parts of the other, as when the distance from the shoulder joint to the flexed elbow and from this to the tip of the thumb are each made to equal the distance from the middle of the knee to the ankle joint (T.P, c167.).

And so Leonardo proceeds from region to region, head, neck, trunk, limbs, determining the distance from point to point and comparing it with some other known distance, and, considering the multiplicity of the proportions recorded by him and the variability that occurs in the various parts of the body, it is a wonder that there are not more discrepancies to be found in his statements. Some do occur, for, as pointed out by Favaro, the distance between the vertex of the head and the upper border of the forehead is in QVI, 1 made equal to the length of the upper lip; in one of the Venetian folios it is given the value of one-fifth the height of the head, as is also the distance from the lip fissure to below the chin, which according to the QVI proportions would make it three times the height of the upper lip. And again from the statement on QVI, 11v, that the length of the head is one-sixth greater than the height of the face, one would conclude that the forehead-vertex height was twice the height of the upper lip. These discrepancies are partly due to the fact that in the Venetian folio fifths were the units into which the height of the head was divided, while in QVI the length of the face was divided into sixths, and partly, perhaps, to a recognition of the variability of the height of the forehead and of the vaulting of the skull.

The obvious object in formulating a canon of proportions is the determination of what may be regarded as the dimensions of a standard or typical member of a given race of the genus *Homo*. But no individual of that race will conform to the standard in every particular, there will always be variations or departures from it. Leonardo was too good an artist, too sure in his perception of relative dimensions, too keen an observer to fail to appreciate these individual variations; in fact an examination of his own drawings and writings will show that he did appreciate them. And he says—

"If nature had only one set standard for the proportions of the various parts, the faces of all men would resemble one another to such an extent that it would not be possible to distinguish one from another; but she has varied the five parts of the face (this is the Vitruvian division) in such a manner that although she has made an almost universal standard as to their size, she has not observed it in the various conditions to such an extent as to prevent one from being clearly distinguished from another." (CA, 119v.)

And in another passage (G 5v) he condemns those "who study only the measurements and proportions of the nude figure and do not seek for its variety." It is possible, accordingly, that some of the discrepancies to be found in his proportions may be due, as has already been suggested, to his recognition of variations. Indeed, in one case, that of the foot, he is willing to modify the actual proportion in order to satisfy an ideal standard of beauty. In one passage the length of the foot is said to equal the height of the head (QVI, 5) and the height of the head is taken as one-eighth the total height (QVI, 10), but in another statement the foot length is said to be one-fourth the distance from the anterior superior spine of the ilium to the ground (QV, 4), a proportion which would make it one-seventh the total height. This is greater than the QVI, 5 proportion, but less than that given by Vitruvius, who makes the foot enter only six times into the total height. Comparing his proportion of one-seventh to the Vitruvian one-sixth, Leonardo expresses his preference for the one-seventh, because such feet have a tendency toward the small side and the beauty of the leg lies in a small rather than a large foot. Favaro (1917) in his resume of Leonardo's proportions expresses them in centimeters on the assumption that the total height is 168 cm. (5 ft. 7.2 in.). On this basis the length of the foot, according to the three proportions mentioned would be 21 cm. (8.4 in.), 24 cm. (9.6 in.) and 28 cm. (11.2 in.).

Leonardo gives no data as to the proportions of the female form; those recorded refer almost exclusively to the adult male body in the erect position and in such a posture that the ear orifice, the tip of the shoulder and the great trochanter are cut by the same frontal plane (QVI, 11). A few statements are made, however, as to proportions in other postures (fig. 17). Thus it is stated that a kneeling man loses one-third of his height and that in that position the umbilicus is the mid-point of the height (QVI, 8), whereas in the erect position the mid-point is at the symphysis pubis (root of the penis). In the sitting posture the distance from the seat to the vertex (sitting height) is made equal to half the total height *plus* the length of the scrotum (QVI, 8). Certain proportions of the limbs when in a condition of flexion are also recorded.

And, finally, there are a few scattered statements as to the proportions of a child. It is noted that with a child's head in profile a circle may be described, with its center at the ear opening, to cut the middle of the forehead and touch the tip of the nose, the tip of the chin and the prominence of the larynx, all these points being therefore equidistant from the ear opening (A, 2v). The umbilicus is found to be the mid-point of both the length and breadth of the child's body (QIII, 8v), a condition which is correlated with the importance of the umbilical vein during fetal life. An appreciation of the greater relative size of the child's head is indicated by the statements that while in the adult the width across the shoulders was equal to the height of two heads (QVI, 8), in the child it is equivalent to only one head (Ash, 28v). A few data regarding the proportions of the limbs of the child are also given (TP, 167 and 169), but they do not differ essentially from those of the adult.

Fig. 17. Proportions of the human body in standing, kneeling and sitting postures. (QVI, 8.)

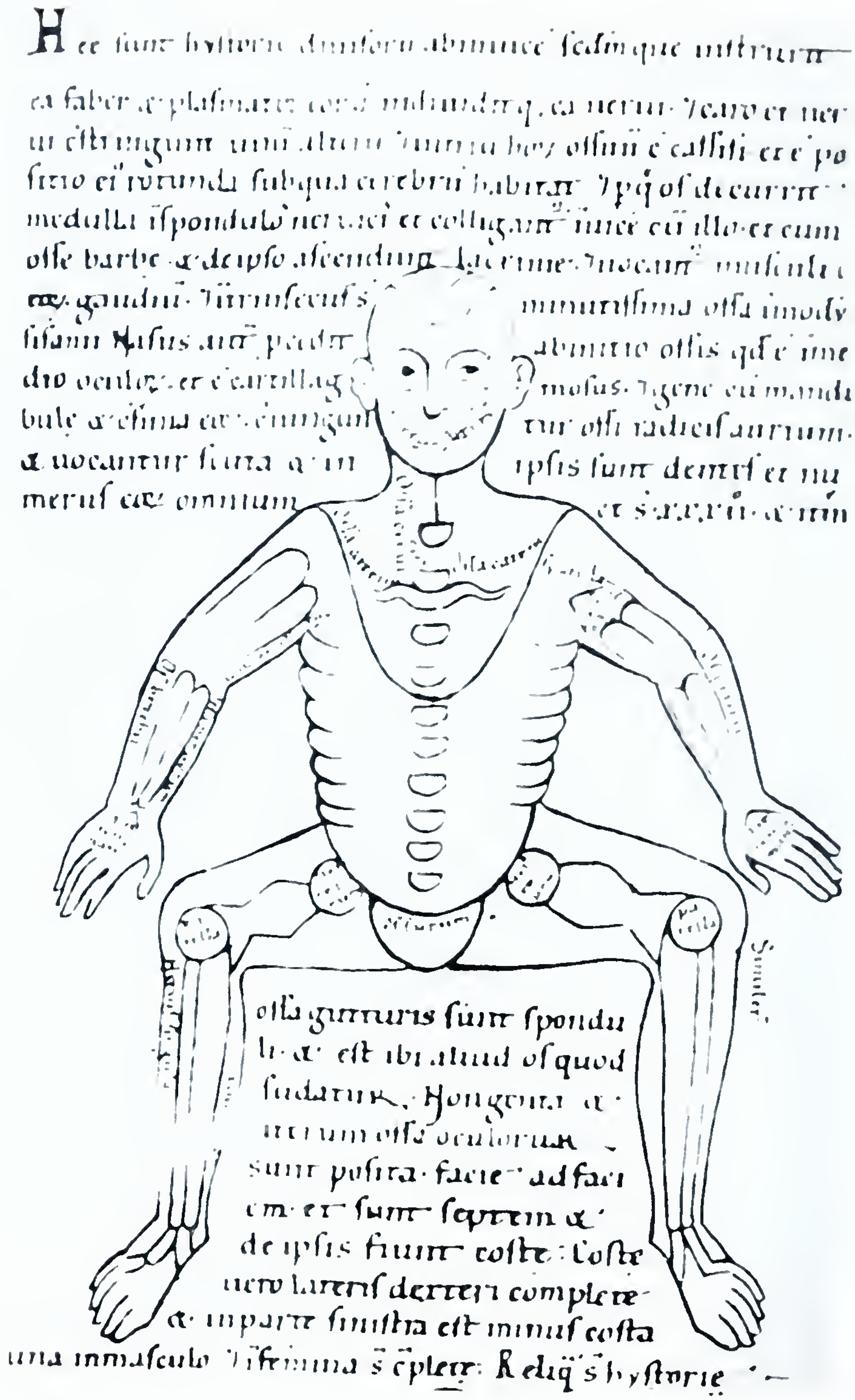


Fig. 18. The bone man from the Prüfling Five-Figure Series (1158). From Sudhoff, Studien, Heft 1, pl. 14, 1907.

CHAPTER X

THE SKELETON

In no department of anatomy does Leonardo's accuracy of observation and portrayal stand out more clearly and more certainly mark the initiation of a new period in the history of descriptive anatomy, than in his studies of the skeleton. Conventionalism reigned in osteological illustration before his time; he it was who first portrayed the parts of the human skeleton in the form and proportions that Nature has given them.

The researches of Professor Karl Sudhoff have brought to light a number of manuscript representations of the human skeleton dating back at least to the middle of the twelfth century, and if to these are added the printed illustrations of the latter part of the fifteenth century, one obtains an excellent idea of the state of osteological knowledge in the pre-Vincian period and a basis for an estimate of the value of Leonardo's work.

The early illustrations may be arranged in three groups, that is to say, three types of representation of the skeleton may be recognized, each of which is to be found, with more or less modification, in various manuscripts or prints. The oldest of these types, so far as they are known, is that contained in the Five-Figure Series (see p. 41) and of these the oldest known example is in a manuscript of the Munich Hofbibliothek (No. 13002) written by a monk of the abbey of Prüfling, near Regensburg, in the year 1158.[1] The figure (fig. 18) has the crouching posture characteristic of the Five-Figure Series and, like the other illustrations of the series, is highly conventionalized and inaccurate. One may note especially the indication of sutures in the cranium and the curious device employed to represent the full complement of teeth; the insufficient number of vertebræ; the diagrammatized sacrum; the crenulations of the sides of the body to represent the ribs; two bones, apparently, in the upper arm; no indication of the os innominatum; the trochanter, termed *vertebrum*, represented as a distinct bone; and the remarkable arrangement of the bones of the foot. Sudhoff is undoubtedly correct in supposing that such illustrations were made by persons with no intimate knowledge of the objects they were portraying, copying unintelligently an earlier drawing, and he is

[1] K. Sudhoff, *Tradition und Naturbeobachtung in den Illustrationen medizinischer Handschriften und Frühdrucke vornehmlich des 15 Jahrhunderts*, Studien zur Gesch. der Medizin., vol. 1, 1908.

also correct in supposing that what is represented is based upon what might be revealed by a *lemur* or desiccated cadaver rather than an osteological preparation.

Four[2] other representations of this type are known. The Munich manuscript No. 17403, written at the Monastery of Scheyern by the Monk Konrad *circa* 1250 (Sudhoff, '07), shows a figure practically identical with the Prüfling one, although the accompanying text differs somewhat, and a strong resemblance is shown by the bone-man of a manuscript of the Bodleian Library (Cod. e Mus, 19)[3] of about the middle of the fourteenth century, though here the cranial sutures and the teeth are omitted, a single bone is shown in the upper arm and the abdomen shows a highly conventionalized representation of the stomach, liver and intestines. The bone-man of the Ashmolean Cod. 399,[4] dating from 1292, closely resembles the Prüfling figure, differing from it in a fearsome expression of the countenance and in the fact that seven ribs on one side and six on the other are clearly represented as curving toward the median line, though no sternum is shown nor are the ribs attached to the vertebræ. Finally in the library of the Prince von Lobkowicz at Raudnitz, Bohemia, there is a manuscript[5] with a figure practically identical with that of the Ashmolean, though with a much milder facial expression. The date of this mansucript is 1399, a century later than that of the Ashmolean.

The illustrations of the second type are also parts of series which in their general conventionalism and posture are very similar to the Five-Figure Series just considered. They differ, however, in certain particulars, the differences being especially noticeable in the cases of the osteological figures. Four of the six known figures illustrating this type are in Persian manuscripts dating from the fourteenth century, but these need not concern us here except to note that they indicate an oriental origin for these series. They had, however, reached the western world at an early date, for Professor Sudhoff has brought to light two European examples of them, also belonging to the fourteenth century.

One of these was found in Ms. D II. 11 of the Library of the University of Basel[6] and is accompanied by text written in the Provençal dialect; from it (fig. 19) the characteristics of the type may be perceived. The most striking peculiarity is that the skeleton is represented as seen from

[2] Sudhoff lists five, *i.e.* six, in all, but one of these, the Dresden Cod. 310, will be considered later.

[3] K. Sudhoff, *Drei weitere anatomische Fünfbilderserien aus Abendland und Morgenland*, Arch. für Gesch. d. Medizin, vol. 3, 1910.

[4] K. Sudhoff, *Weitere Beiträge zur Geschichte der Anatomie im Mittelalter, III.* Arch. für Gesch. d. Medizin, vol. 7, 1914.

[5] K. Sudhoff, *Abermals eine neue Handschrift der Anatomischen Fünfbilderserie*, Arch. für Gesch. d. Medizin, vol. 3, 1910.

[6] K. Sudhoff, *Ein Beitrag zur Geschichte der Anatomie im Mittelalter*, Studien zur Gesch. d. Med., Heft. 4, 1908.

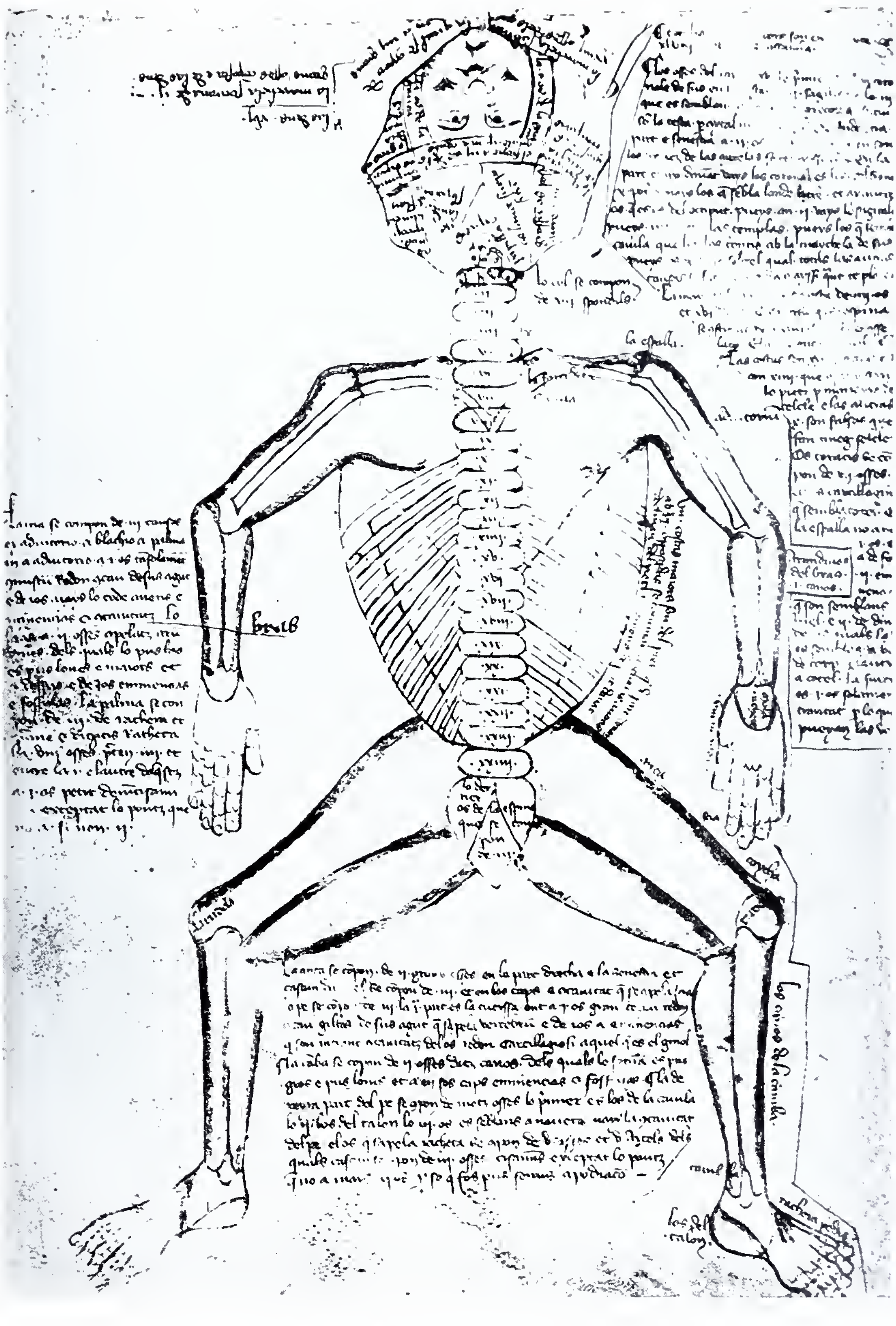


Fig. 19. Skeleton from a provençal manuscript in the University Library, Basel, Codex D II, 11 (End of thirteenth century). From Sudhoff, Studien, Heft. 4, pl. 1, 1908.

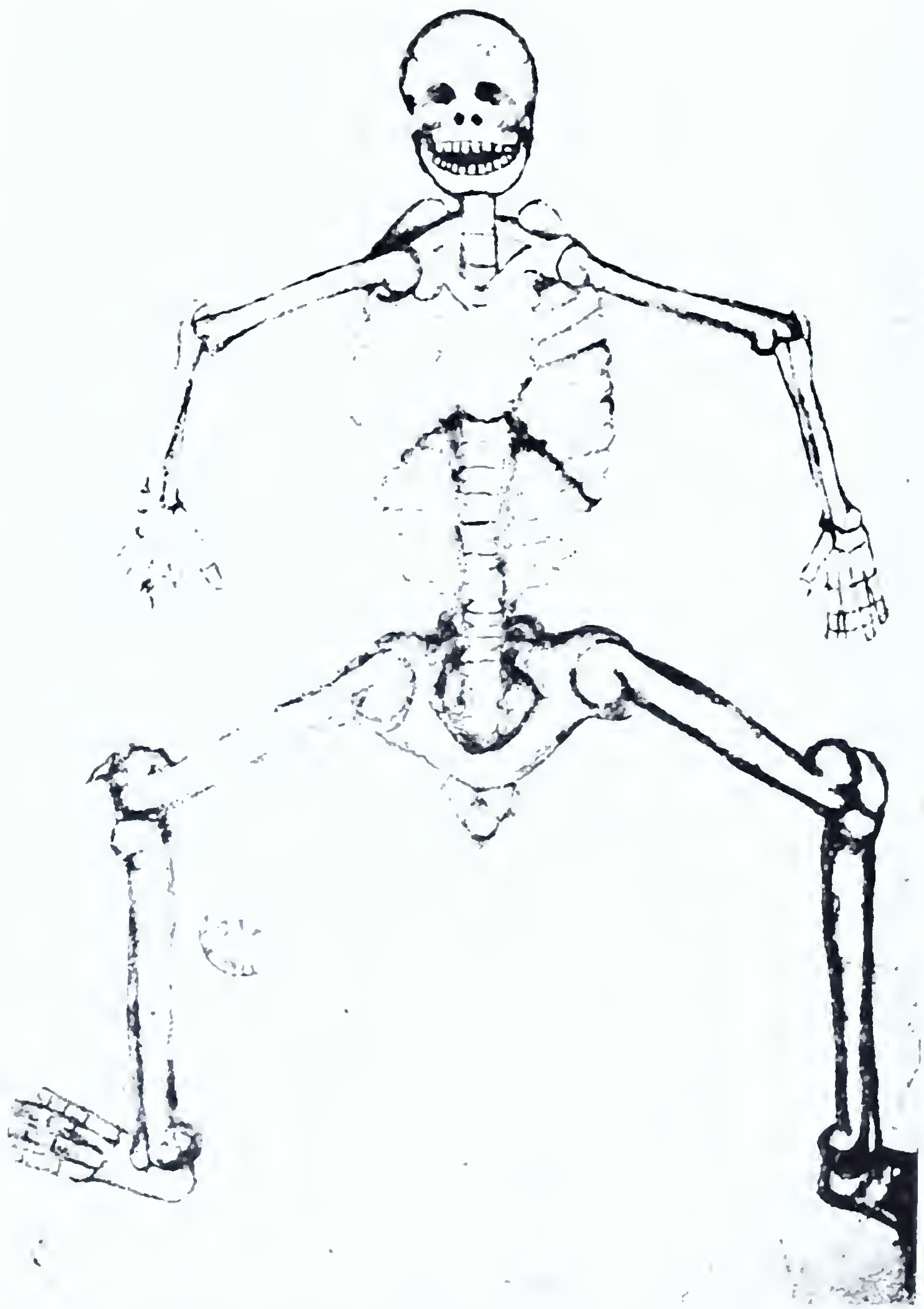


Fig. 20. Skeleton from Dresden Codex No. 310 (1323).
From Sudhoff, Studien, Heft. 4, pl. 6, 1908.

behind and the face is bent upward as if hinged upon the frontal bone. The bones of the cranium are much more fully, if still highly diagrammatically, indicated than in the type I figures, the legends mentioning the upper and lower maxilla, the cheek bone, the frontal and parietals (*os lande* i.e. *laudæ subpositum*); the occipital (*papillus* = *paxillus capitis*) and the mastoid process. A series of twenty-four vertebral bodies succeeds, of which seven are assigned to the neck and the series ends with a sacrum said to be composed of three bones. Thirteen pairs of ribs, each attached to a vertebral body are shown, but the uppermost is attached to the tenth vertebra and consequently the last three have their attachment to as many lumbars. The clavicle is shown, but no scapula, notwithstanding that the view is from the back; the humerus is shown as a slender bone, while the bones of the forearm are stout; the carpus is indicated and transverse lines on the digits indicate the phalanges. There is no os innominatum, but one finds the label *anca* (ilium) some distance down upon the thigh and *scia* (acetabulum) still farther down, while *coxa* (femur) is just above the knee, and the bone itself is not represented. The patella is shown and the two bones of the crus, but the bones of the foot are treated as sketchily as those of the hand. It would seem that the figure was copied from an earlier drawing by one unfamiliar with the parts he was endeavoring to represent.

What is probably on the whole a more accurate copy of this or another earlier original is a pen drawing in the Munich Ms. No. 13042, also of the fourteenth century (Sudhoff, '07, '08). The face is here indicated by three rhombs and an oblong, standing for the eyes, nose and mouth, the ribs are correctly represented as to number and attachment to the vertebræ, the scapula is indicated, as also the os innominatum, the only particular in which there is less accuracy than in the Provençal figure being the omission of the two bones of the forearm. But in addition to its greater accuracy this figure presents one peculiarity that is especially noteworthy, that is the absence of the crouching posture, so characteristic of the illustrations belonging to the Five-Figure Series. In this it forms a connecting link with the illustrations to be described as type III.

Before considering these, however, mention should be made of a fourteenth century osteological figure that can not readily be included in any of three groups. This is the single illustration of the Dresden Ms. No. 310, dated 1323 (fig. 20), which has been regarded by Sudhoff (1908) as an example of the Five-Figure Series, the other illustrations of the series being omitted. This is probably correct, since the posture of the figure is altogether characteristic and the accompanying Latin text is evidently the original, or a copy of the original, from which the osteological part of the Provençal text was translated. But the details of the illustration are quite different from both those of the Prüfling series and those of the Persian series. The actual skeleton is figured and it is viewed from in front. The mouth with its batteries of teeth recalls that of the Ashmolean figure, but there the resemblance ceases; no details of the cranial bones are shown, but the coronal suture is represented. The vertebral column resembles that of the Provençal figure; there are twelve pairs of ribs, the upper nine of which are represented as curving around toward the ventral surface and the uppermost five pairs (according to the text there should be seven) are attached to the sides of a broad sternum. This is the earliest representation of the sternum, although it had been described centuries earlier, and it is noticeable that it is shown as a single bone although the text describes it as composed of seven bones.[7] The ossa innominata are shown, but they articulate with the upper lumbar vertebræ and are quite distinct from the sacrum. The text gives a much fuller description of the parts of the skeleton than does that of the Prüfling set and it would seem that the author had endeavored to give a representation of the parts described while adhering to the conventional five-figure posture.

The beginning of the fourteenth century witnessed the introduction of a new type of osteological illustrations, the earliest of which are, with good reason, supposed to be reproductions of figures which Gui de Chauliac informs us in his *Chirurgia* were used by Henri de Mondeville in his lectures on anatomy at Montpellier. They occur in Ms. français No. 2030 of the Bibliothèque Nationale and have been reproduced by Sudhoff (1908). The manuscript or at least the anatomical portion of it is dated 1314, but if the figures are really miniature reproductions of the charts used by de Mondeville, their originals must date a decade earlier. There are altogether twelve figures, four of which are especially interesting as showing attempts at portrayals of the skeleton. Unfortunately these, like the others, are too small to reveal many details and, furthermore, they have the appearance of being drawn from desiccated bodies rather than from skeletal preparations, except that the skull shows clearly the principal sutures. One of the figures is represented as seated, recalling somewhat the five-figure posture, but the other three are shown standing erect. One figure is seen from behind and shows the vertebral column and the scapulas, indications of the ribs occurring below the latter. In the front views the clavicles are shown and below them are two areas, indistinctly outlined, which seem to indicate areas where the pectoral muscles might in a dried cadaver conceal the underlying ribs. Below these areas ribs are sketchily shown, much as they were in the Five-Figure Series. The abdomen is opened, but appears merely as a blackened area; the ossa innominata are not separate from the femora, and do not meet ante-

[7] This is a tradition that comes down from Galen and was adopted by the Arabians, *e.g.* Avicenna.

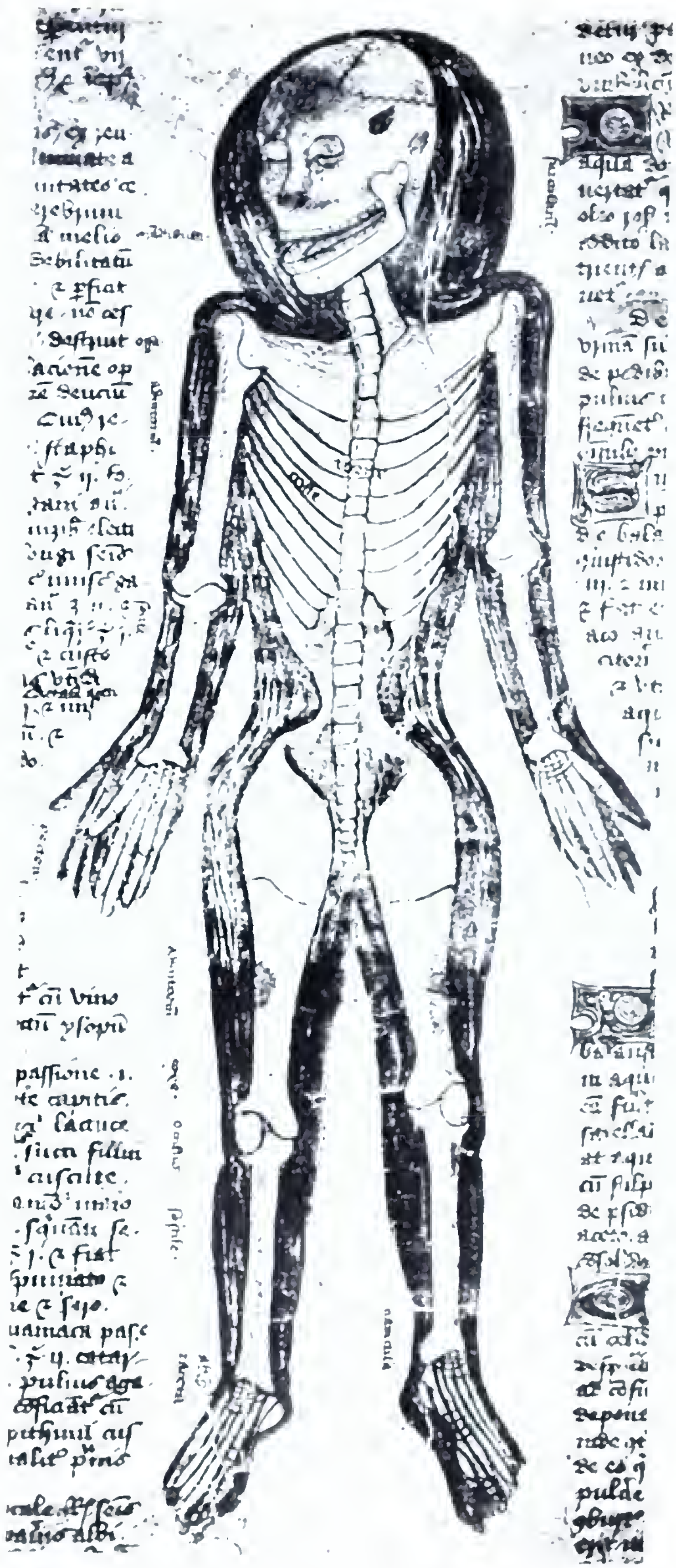


Fig. 21. Skeleton from the *De arte phisicali* of John Arderne (circa 1412). From Sudhoff, Studien, Heft 8, pl. 3, 1915.

riorly; the patella is indicated in the seated figure, but not in the others; and the bones of the forearm, crus, manus and pes are not shown.

Notwithstanding their imperfections, these figures seem to have served as types for a long series of representations which, gradually improving in detail, are to be found in manuscripts and, later in prints, through the fourteenth and fifteenth centuries. One of the earliest of these has been found, again by Sudhoff (1908), on the verso of the last page of a translation of the anatomy of Rhazes contained in Ms. No. 3599 of the Bibliothèque Mazarine (Institut de France). This looks much more like an actual skeleton, but, strange to say the skull shows no sutures. A manubrium sterni and twelve pairs of ribs are represented, and again the abdomen is solid black. The innominates are clearly shown, but they fail to meet ventrally, allowing the sacral vertebræ to be seen; the two bones of the forearm are shown, but no patella. The posture is identical with that of the erect de Mondeville figures.

The Guido de Vigevano figures of circa 1345, reproduced by Wickersheimer from Ms. 569 of the library of the Chateau de Chantilly (see fig. 2), need merely mention. They show the Mondevillian posture, but being obviously drawn from *cadavera exsiccata* they show little osteological detail. The ribs and clavicles are crudely represented, the latter being shown perforated,[8] but beyond these there is nothing noteworthy. Of great interest is a figure in a manuscript epitome of John Arderne's *De arte phisicali et de cirurgia* in the Royal Library of Stockholm (fig. 21). It dates probably to 1412 and has been reproduced by Sudhoff[9] and also by Sir D'Arcy Power in his translation of the manuscript.[10] It is distinctly reminiscent of the de Mondeville figures; indeed it suggests an attempt to combine in one figure both the ventral and the dorsal views of de Mondeville's skeleton, for the vertebral column is shown throughout its entire length in the ventral midline, the clavicles and the ventral ends of the upper seven ribs articulating with it; below, it lies within the pelvis and gradually tapers to a series of coccygeal vertebræ, those of the sacrum being represented as quite separate from one another. The cranium shows the coronal and sagittal sutures, but they are decidedly askew, imparting thereby a decidedly rakish appearance to the figure. The clavicles are massive bones, but show no indications of a perforation; their massiveness sug-

[8] The text of the Dresden Codex, C 310, describes the clavicle thus: Furcula est unicum os perforatum per quod foramen ascendunt venæ. The idea is no doubt borrowed from Avicenna.

[9] K. Sudhoff, *Weitere Beiträge zur Geschichte der Anatomie im Mittelalter,* Arch. für Gesch. der Med., vol. 8, 1915.

[10] Sir D'Arcy Power, *De Arte Phisicali et de Cirurgia of Master John Arderne,* Research Studies in Medical History No. 1, From the Wellcome Historical Medical Museum, 1922.

gests the idea that again they represent the clavicles *plus* the pectoral areas of the de Mondeville figures. The innominate bones are shown very crudely; they are rounded off above without any indication of the iliac portions and they fail to meet in a ventral symphysis. A single bone only is shown in the forearm and crus; the femur is very massive and shows no indication of either head or trochanter; the patella is distinct; and the carpus and tarsus are roughly indicated, the calcaneus, however, being plainly shown.

Another skeletal figure of this type occurs in an illustrated manuscript copy of certain works of Gui de Chauliac belonging to the City Reference Library, Bristol, England. It dates back to about 1430 and has been reproduced by Dr. Singer (1916). One of the illustrations represents a surgeon demonstrating a skeleton to a pupil. The skeleton is recumbent and clearly belongs to the type now being considered, resembling closely the Stockholm figure. It may be noted that it represents the clavicle distinct from the pectoral areas.

Again the type is shown in Ms. français No. 19,994 of the Bibliothèque Nationale in a skeleton drawn by one Etienne Beludet in 1454 and reproduced by Sudhoff (1908). The cranial sutures are shown and seven cervical vertebræ; the upper thoracic vertebræ are hidden by a broad area which is labeled *ossa thoracis* and bears the numbers 3, 4, 1, 5, 7. This area recalls the clavicles of the Stockholm figure, greatly exaggerated and, as has been suggested, probably represents the clavicle *plus* the pectoral areas of the de Mondeville figures. Below the areas are twelve ribs on each side, represented in the usual manner, and in the middle the vertebral column which bears the legend *spondilia 12*, some confusion having evidently taken possession of the artist's mind as regards the number of vertebræ. No sacrum is shown, but there are three coccygeal vertebræ (*ossa caude*). The innominates have the form of those of the Stockholm figure, no iliac portions being indicated, but each bone consists of two parts, *osscie* (= ischium) and *os pectus* (= pubis), the latter uniting ventrally in a symphysis. In the forearm two bones are shown, and a label calls for four carpal bones (*ossa rachete*) though none is shown. On the femur the trochanter (*vertebrum*) is indicated by a legend; the patella (*occulus genu*) is represented; there are two bones in the crus; and a rude attempt is made to show four tarsal bones (*ossa rachete*) in addition to the calcaneus. Evidently the artist knew his Avicenna better than he did his skeleton.

An interesting figure, with curiously complex affinities, is that reproduced by Sudhoff ('08) from a manuscript in the Bibliothèque Nationale, Ms. lat. No. 7138. It probably dates from the earlier part of the fifteenth century and accompanies a text consisting of material partly from William of Saliceto and partly from Avicenna. The skull, slightly turned toward the right, recalls that of the Stockholm figure, although the sutures, including even the metopic,[11] are shown in greater detail; the thorax is practically identical with that drawn by Beludet (Ms. franç. 19,994), the enormous *ossa thoracis* bearing the numerals 1 to 7; each innominate consists of two parts, the *os pectinis* and the *scia aut ancha,* but instead of being rounded off above it is prolonged upward to meet the ribs, the iliac portion (*ancha*) being thus indicated; the arrangement of the *ossa caude* so as to form a triangle and the representation of the upper portion of the femur as a distinct bone (*vertebrum*) recall the osteological figures of the Persian Five-Figure Series; the hand and foot resemble those of Beludet's figure, but the number of carpal bones is correctly given in a legend and the calcaneus is represented as a composite bone and is designated talus (*tallis*). Add to these complexities a trace of Salernitan influence in the statement in a legend of the total number of bones and blood-vessels in the body[12] and one obtains an idea of the interestingly composite character of this illustration.

The art of printing was invented in 1448, and it was not long thereafter before printed treatises of a medical character began to appear. At first these were of a popular nature, such as the Purgation Calendar published by Gutenberg in 1457 and the Bloodletting Calendar published in Mayence in 1462, and with them appeared loose leaves printed on one side with an illustration showing more or less of the anatomy of the human body, indications being given of the parts especially influenced by the various signs of the zodiac, forebears of the Farmer's Almanacs, so widely distributed a generation ago. Somewhat more technical than these is a loose-leaf illustration, the *Anathomia ossium corporis humani,* printed at Nuremberg in 1493[13] and drawn by one Richard Helain who announces himself as a Parisian and a *doctor artium et medicinæ.* The figure (fig. 22) shows a skeleton in the erect position and lacks any astrological significance; the various bones have pennon-like labels attached, recalling those of the Beludet skeleton but differing somewhat in the names they bear, a larger proportion of them being Arabic. The nomenclature, indeed, follows closely that of Avicenna.

The figure too differs much from that of earlier representations of the type, while still showing sufficient similarities to warrant its inclusion therein. The skull is quite similar to the other illustrations, but shows clearly the mandible as composed of two distinct bones, a belief dating back to Galen and stated in the text or legends of earlier illustrations, even if not portrayed. The ribs, correct in number, are still shown without any intercostal spaces, but a sternum is present. The

[11] This is also shown in the figure from Ms. français 19,994.

[12] This same influence is seen in the texts of the Dresden Codex, C 310, and the Provençal Ms.

[13] The date printed on the illustration is 1293, but the figure 2 is evidently an error.

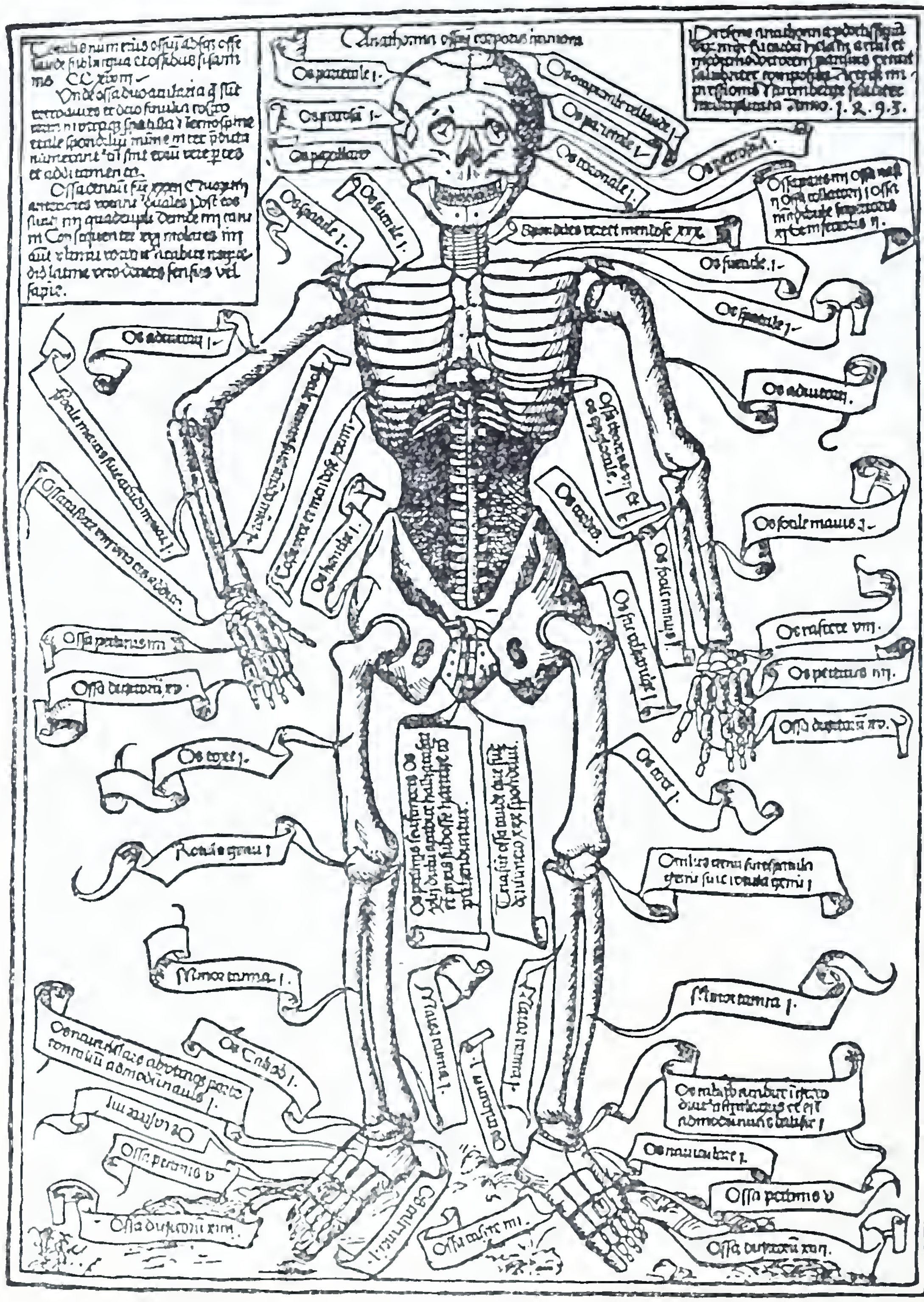


Fig. 22. Skeleton by Richard Helain (1493).
From Sudhoff, Archiv, vol. 1, p. 57, 1907.

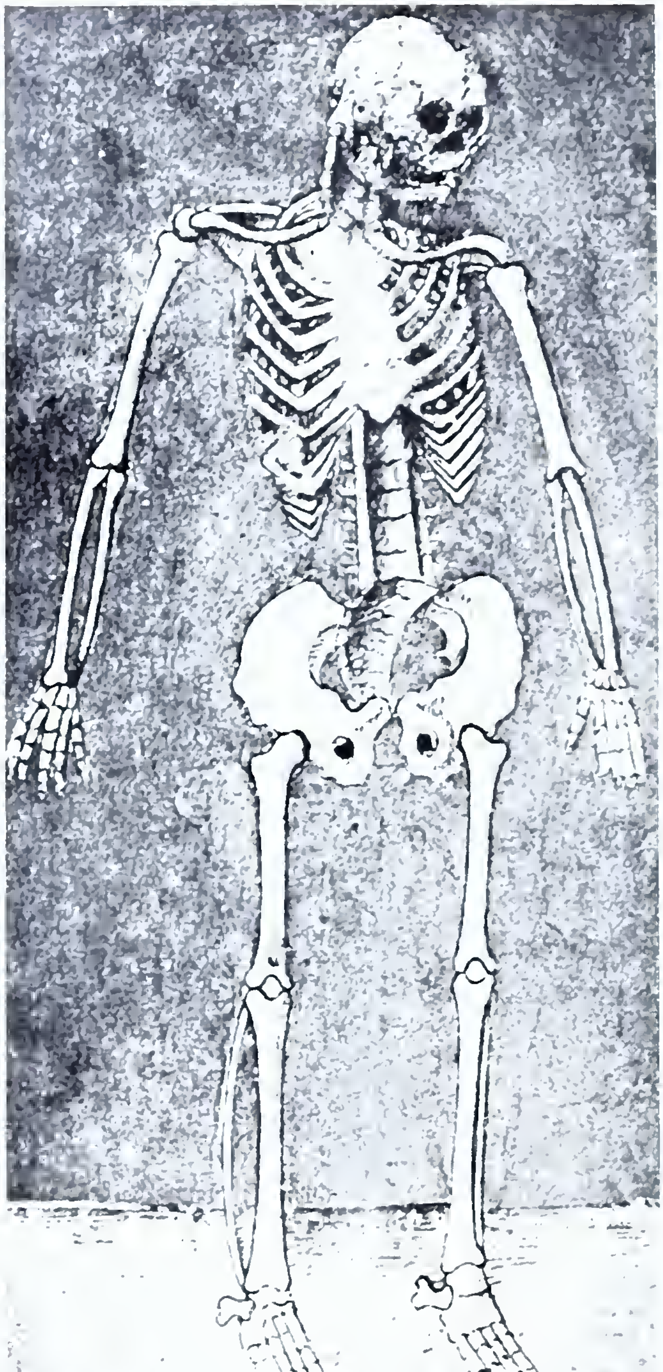


Fig. 23. Skeleton from British Museum Additional Ms. No. 21618. From Sudhoff, Archiv, vol. 8, p. 140, 1915.

region of the abdomen is deeply shaded and shows in the mid-line twelve ribless vertebræ, and between the innominates ventrally the sacrum is shown, without any particular relation to the rest of the vertebral column; a label gives the number of *ossa caudæ* as three, and since the total number of the vertebræ is given as thirty, the implication is that the sacrum represents only three bones.

The clavicles are shown and the acromion processes, and there is an attempt to indicate the eight carpal bones (*ossa rascete*). The treatment of the innominates is remarkable. There is a very feeble attempt to represent the concave form of the ilia and these and the ischia form a single bone, the *os scie vel hanche*, those of the two sides being curiously continuous across the mid-line in front of the vertebral column. More ventrally still is a bridge-like structure between the two bones, probably representing the pubis and termed in the attached label *os pectinis vel femoris*, *halhafacar* (*al harcafa*) and *pyxis*, all but the first being terms used by Avicenna, although he applies *al harcafa* to the ilium and *pyxis* denotes the acetabulum. The obturator foramen is distinctly represented. The patella is shown, and in the tarsus three of the bones receive special names, the talus (*os cahab*), the calcaneus and the navicular, the remaining four being grouped together as *ossa rascete*.

Notwithstanding its many inaccuracies and imperfections this figure is unquestionably an advance upon those so far considered. It is not a copy of any of these, though manifestly influenced by them, but is drawn by one who had actually seen a skeleton and who knew his Avicenna and endeavored to harmonize experience and authority. Being printed it was accessible, and it was later copied with more or less modification for other publications, as for instance in the *Kalendrier des Bergiers* of 1495, where the astrological element again comes to the fore, and in the *Buch der Wund-Artzeny* of Hieronymus Brunschwig, published at Strassburg in 1497.

But anticipating Helain's figure by nearly half a century and practically contemporary with Beludet's drawing is an illustration in the Additional Ms. No. 21618 of the British Museum which has a note much more modern than any of the other pre-Vincian osteological illustrations. It dates back to 1452 and precedes a German translation of the Surgery of Bruno of Pavia, who, according to Gui de Chauliac, made summaries of Galen and Avicenna and of the operations of Albucasis. We are again indebted to Sudhoff for a reproduction of it (1915). The figure (fig. 23) is evidently drawn directly from the skeleton, conventionalism being almost discarded and an attempt made to represent the bones as they really are. The skull and the neck region are somewhat blurred, but the clavicles and scapula and the long bones of the limbs are for the first time represented with a fair amount of accuracy. The ribs, too, are much more true to Nature, the intercostal spaces being shown, and while the sternum and vertebræ are greatly exaggerated in width, the sacrum is shown with something of its true form, and an attempt is made to indicate its curvature. The innominate bones are somewhat crudely drawn, but are more accurate in their relations than those of the Helain figure; indeed, it is only in the portrayal of the hands and feet that this drawing is surpassed by the later one.

Such were the osteological illustrations of the times preceding Leonardo, and it is with these that his must be compared in order that a just appreciaton of their merit may be had. Leonardo has left no drawings of the complete skeleton, but every part of the skeleton is figured and the figures demonstrate clearly his wonderful accuracy of observation and his quite as wonderful accuracy of delineation. They form a remarkable contrast to the works of his predecessors, the only figure which at all approaches his being that in the Additional Ms. 21618 of the British Museum, and even this falls far behind.

The nearest approach to complete skeletons are four drawings in the Uffizi Gallery of Florence, if they are really the work of Leonardo as Holl and Sudhoff (1914) believe them to be. Two inscriptions, one on the recto and the other on the verso, claim them as Leonardo's and in execution the drawings bear out the claim. The inscriptions, however, are not in Leonardo's handwriting, nor do the labels attached to one of the figures and reading from left to right appear to be. The shading, too, seen in one of the figures is right-handed. These discrepancies, if so they may be termed, are, however, of less significance than the evidence from the drawings themselves. They are on a single, soiled and mended folio, two on the recto and two on the verso, and represent the greater part of the skeleton from in front and from the left side, from behind and from the right side; the skull and the left arm are omitted in all of them and the feet are indistinct. But whether or not these drawings are accepted as Leonardo's, there are others in Anat. A (AnA, 8v and 13) which show his conception of the parts of the axial skeleton (fig. 24), even though none are so inclusive as the Uffizi drawings; they reveal an accuracy of delineation hitherto unknown and, what is more important, accurate observation almost free from influence of dogma.

The number of vertebræ was generally accepted by the mediaeval anatomists as thirty, this being the number given by Avicenna, before him by Galen and after him by Mondino. They also recognized seven of these as cervical, twelve as thoracic with a corresponding number of rib pairs and five as lumbar; the sacrum, however, was supposed to represent only three vertebræ and the coccyx another group of three. Leonardo, however, boldly discarding tradition, figures and describes the total number as thirty-one, recognizing that the sacrum represents not three but five vertebræ (AnA, 8v) and reducing the number of

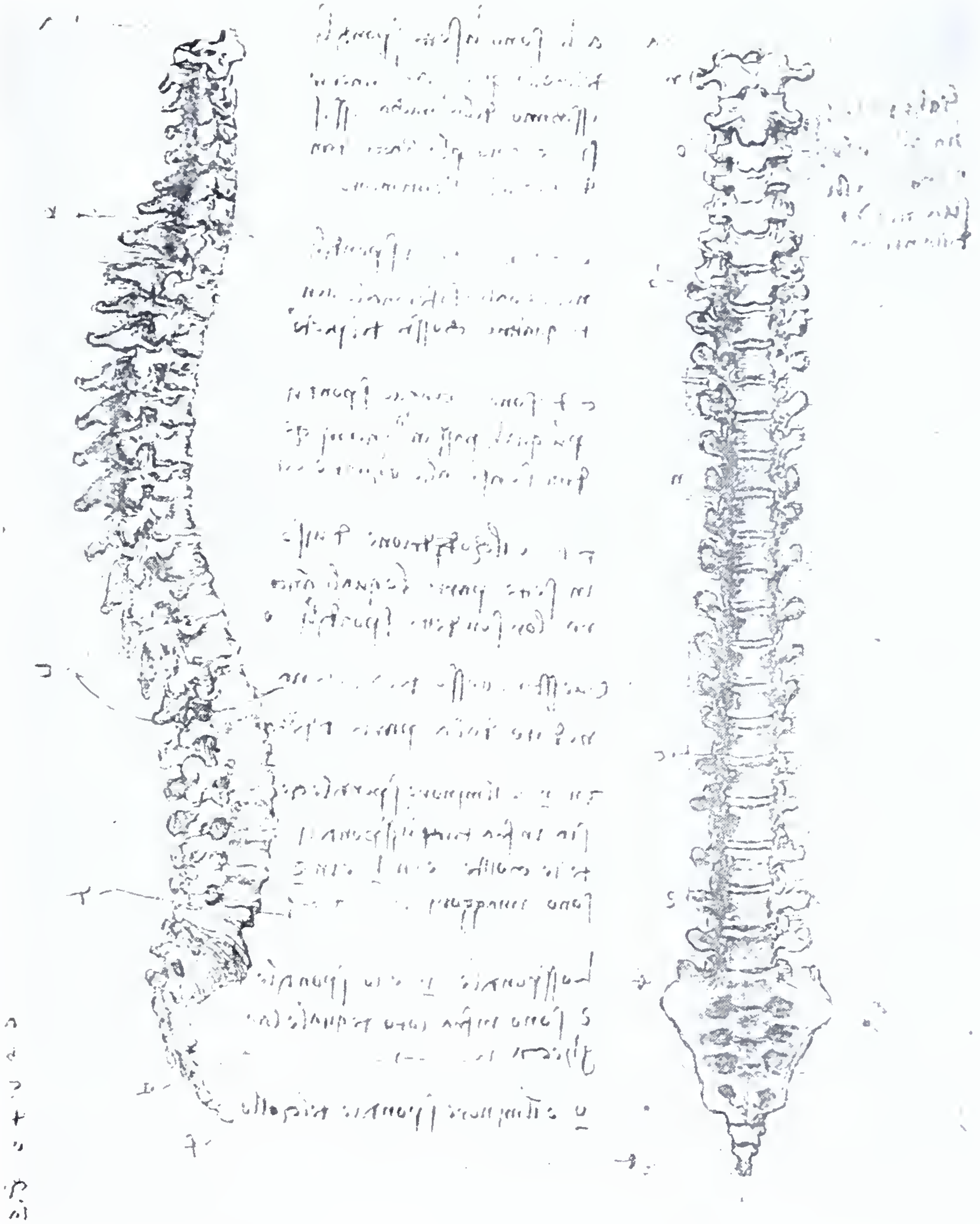
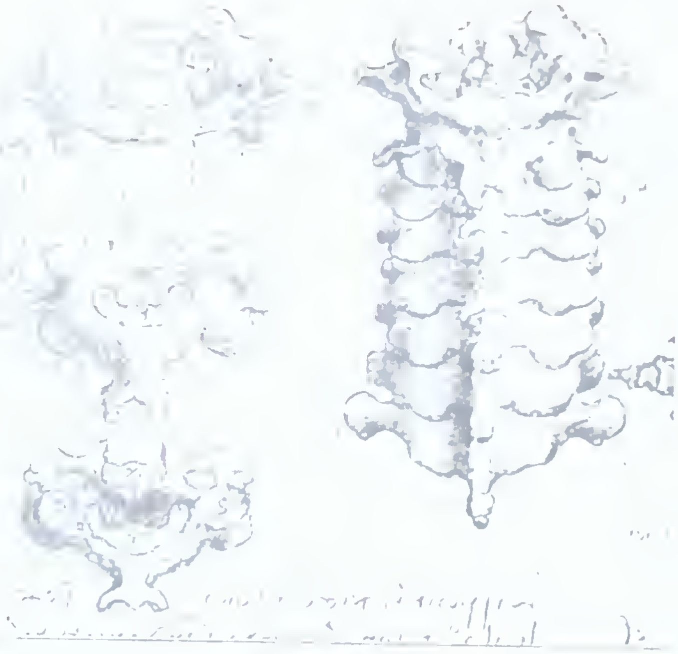


Fig. 24. The vertebral column by Leonardo. (AnA, 8v.)



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26

Fig. 25. The cervical vertebræ. (AnA, 8v.)
Fig. 26. Skull cut to show frontal and maxillary sinuses. (AnB, 41v.)

the coccygeal to two. The great variability of the latter sufficiently explains the number assigned to them; much more important is the fact that Leonardo was the first to perceive the correct number of vertebræ in the sacrum and to represent it accurately.

But still more important is the fact that he was the first to represent correctly the curves of the spinal column, the tilting of the sacrum whereby the weight of the trunk is brought directly over the lower limbs, and the tilting and curvature of the ribs so essential for the correct understanding of the mechanics of respiration. In short he was the first to perceive the static and dynamic conditions demanded of the skeleton by the erect posture, and not only so, but he anticipated by several centuries the final recognition of the correct position of the pelvis by Naegele and the brothers E. F. and W. C. Weber.[14] Not even Vesalius, who effected a revolution in the science of anatomy and indirectly in the science of medicine, approaches Leonardo in the accuracy in this respect of his representations of the skeleton. As Holl (1914) has said, in speaking of Leonardo's drawings of the skeleton—

> "They have life, if such an expression may be used, while Vesalius simply assembled the bones of a man without respect to the natural conditions in the living body; Vesalius' skeletons if they came alive could neither walk, nor stand, nor breathe."

Leonardo, however, was not infallible, as a glance at figure 23 will show. A spinous process, without a corresponding vertebral body, is interposed between the spines of the second and third thoracic vertebræ. He also represents (AnA, 13) eight true ribs, instead of the usual seven, but eight occasionally occur, and he shows the sternum as composed of six sternebræ together with the xiphoid process (*pomo granato*), an incomplete surrender to tradition which required as many parts to the sternum as there were attached costal cartilages (Avicenna).[15]

It is a little surprising that Leonardo with his predilections for mechanical studies did not give special attention to the first two cervical vertebræ. They are, it is true, figured separately (AnA, 8v) (fig. 25), together with the third vertebra, and the drawings are very accurate, all the important parts being shown and designated by letters; but the text gives no interpretation of the lettering, it merely states that these two vertebræ differ from the rest. Elsewhere Leonardo speaks of the various movements of the head (AnA, 4 and AnB, 32) and evidently appreciated the occurrence of lateral inclination of the head at the occipito-atlantoid articulation, but he does not refer to the loca-

[14] See C. Langer (1867).

[15] It may be noted that the Uffizi drawings also show eight pairs of true ribs, but the sternum is undivided and has no xiphoid process.

tion of the rotatory movements, although one would have imagined that with his knowledge of the conformation of the axis and of its relation to the atlas this would have appealed to him.

Throughout the mediaeval period the description of the bones of the skull had not progressed beyond the stage in which it was left by Galen; indeed, confusion and uncertainty had already appeared with Avicenna and the confusion became worse confounded in later treatises, based on Avicenna without personal observation. Leonardo made no attempt to lessen the confusion; he has left no description or even enumeration of the constituent bones, and yet he undoubtedly possessed a better understanding of the skull and its relations than did his immediate predecessors. He has left two important drawings of the skull which reveal the thoroughness with which he carried out his anatomical investigations. Not content with a mere surface view or with the removal of the calvarium, he shows (AnB, 40) a medial sagittal section of the skull in which the three cranial fossæ are clearly delineated and also the frontal and sphenoidal sinuses. His penchant for proportion is manifest, the entire skull, including the mandible, being enclosed within a quadrangular area, bisected by a horizontal line which in modern parlance might be termed the glabella-lambda line. The lower half of the area is again bisected by a line that passes through the anterior margin of the foramen magnum and two vertical lines are shown, one passing through the posterior part of the body of the sphenoid and the other through the anterior margin of the foramen magnum. Where the anterior vertical line crosses the glabella-lambda horizontal, Leonardo locates the sensorium commune. It is to be noted that as a rule Leonardo represents the skull in its natural position, in some cases showing it blocked up behind so that the glabella-lambda line is truly horizontal.

His representation of the frontal and sphenoidal sinuses has already been mentioned; the frontal sinuses are again shown in another figure (AnB, 41v) and in this the maxillary antrum is also well shown (fig. 26). He describes the latter (AnB, 40) as having a capacity equal to that of the orbit which lies above it, and regards it as containing a humor which nourishes the roots of the teeth. It receives veins which descend from the brain, passing through the cribriform plate of the ethmoid (*colatorium*), which discharges into the nose the superfluity of the humors of the head. He shows, too, the bony naso-lacrimal duct, "through which the tears ascend from the heart to the eye, passing by way of the nasal canal." Here again is a curious example of the influence of antique tradition.

It seems that the credit for the first representation of the cranial sinuses, except the mastoid, belongs to Leonardo. They were unknown to Galen and therefore to Avicenna. Vesalius mentions them, but the maxillary sinus had to wait until 1651 for its full description

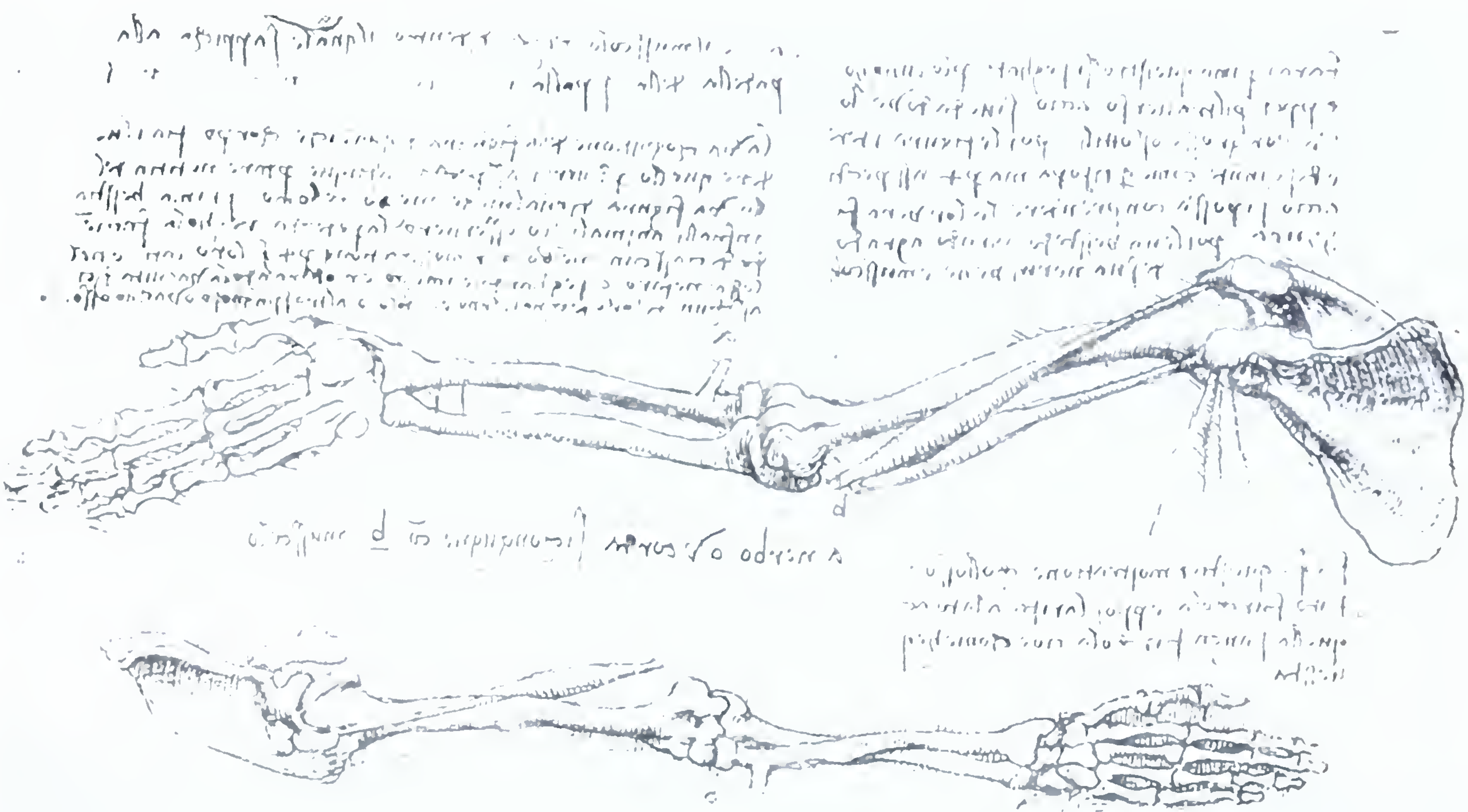

Fig. 27. Bones of arm in supination and pronation, together with scapula and biceps muscle. (AnA, 1v.)

by Highmore, who called it the Antrum, a term previously used for it by Laurentius. The mastoid sinus was observed by Ingrassias (1603).[16]

The skeleton of the limbs was especially attractive to Leonardo, and illustrations of the bones of both the upper and lower limbs are quite numerous, all showing a degree of accuracy in their delineation that stands in marked contrast to what one finds in earlier representations, such as that of Helain (fig. 21). In the upper limb he found special interest in the mechanism of pronation and supination, many of the drawings, such as those of AnA, 1v, showing both the bones and the relations to these of the more important muscles; he is evidently carrying out the plan which he lays down for his illustrations, to represent the bones "so that one may understand their true form, and afterward to cover them gradually with their nerves, veins and muscles" (AnA, 1v). He figures the bones of the limb in pronation from before, from behind and from the side (AnA, 5) (fig. 27) and with great exactness, the upper ends of the radius and ulna (AnA, 1v), correctly demonstrating the behavior of the radius in this movement as a rotation about its own axis above and about the lower end of the ulna below. Leonardo's thoroughness in observation is exemplified by the fact that he recognized the restricting effect on the rotation of flexion of the forearm, stating that in flexion the lower end of the radius revolves through half of a complete revolution, while in extension it makes three-quarters of a revolution (QIV, 14). His statement and figures concerning this movement of rotation are a decided advance on the bald statement of Avicenna that in rotation the radius is twisted as if it came from the inner part and gradually twisted to the outer part, evidently referring to its movement in supination.[17]

Of the scapula (*spatola*) and clavicle (*forcula*), Leonardo gives excellent representations in AnA, 13, but in one figure the right clavicle seems to be turned end for end, and the acromion is shown as a separate bone. Roth (1907) criticizes him for representing the coracoid and acromion processes as distinct bones. In the case of the coracoid one may doubt whether Leonardo intended it to be regarded as separate from the scapula; in some drawings, such as AnA,1v (fig. 16), a line clearly separates it from the upper border of the scapula, but in others, such as AnA, 1v (fig. 18), and AnA, 2 (fig. 25), it is evidently a process of the scapula, and so he speaks of it in the text on AnA,

[16] For an account of the early history of the discovery of the maxillary sinus see W. Tacke (1923).

[17] Leonardo makes the curious statement (AnA, 1v) that the arm is shorter in pronation than in supination and gives a rough diagram to show why this should be so. If one were dealing with rigid bodies and there were no opposing factors his method might be correct, but he apparently overlooks the fact that the plane of the circle, of whose circumference the lower end of the radius describes an arc, is so nearly in the transverse plane of the arm that the displacement would be negligible.

14v, terming it the *punta* or *rostro della spatola.* It may be recalled, however, that the coracoid ossifies from a special center and does not unite with the rest of the scapula until the fifteenth year or even later, and Leonardo may therefore have seen it as an apparently distinct bone.

The acromion is certainly figured as a distinct bone in several drawings, such as AnA 12, fig. 176; 13, fig. 195; 14v, figs. 213, 216 and 218. Here again one has to do with an independent ossification, the acromion remaining cartilaginous until about the fifteenth year, when a center of ossification appears in it, followed by a second about two years later; the two centers soon unite and the bone fuses with the rest of the scapula somewhere about the twenty-first year, though occasionally the union fails to occur. It is quite possible that Leonardo may have been representing what he observed in a young individual, and this possibility is emphasized by the fact that in one passage (AnA, 14v) he speaks of the structure as a cartilage, and in a figure of the scapula of an aged man (AnB, 32) the acromion is shown continuous with the spine. Less probable is the suggestion that in this case Leonardo may have been dominated by ancient tradition, Galen, in the *de ossibus,* stating, but not confirming, the opinion of some writers that in man alone the acromion is a distinct bone, the *os acromiale.* But neither Avicenna nor Mondino, by whom Leonardo would be most likely to be influenced, speak of the acromion as other than a process of the scapula. If Leonardo is to be criticized on the ground of inaccuracy a much better case might be made out from the figure on QII, 5v (fig. 33) in which the scapula is shown without any indication of an acromion process. The sternum too is represented as composed of eight sternebræ and, strange to say, the first pair of ribs is attached to the eleventh vertebra! True, the figure is evidently diagrammatic and drawn to show the supposed actions of muscles rather than osteological details, but still the inaccuracies are glaring. The figure could not have been drawn from a dissection, but seems rather a product of memory, which failed to visualize the parts correctly. Leonardo stands at a disadvantage in that the folios, his *journal intime,* frequently give us his fugitive ideas, premature notions destined to be modified by further observation and reflexion, or even to be discarded.

The figures of the humerus, radius and ulna (*focile major*) are, as a rule, wonderfully true, as compared with the attempts of his predecessors. He nods, however, in one figure (AnA, 5, fig. 78) where he gives the lower end of the ulna the form of that of the radius. He makes a memorandum to inquire into the purpose of the prominences of the bones of the arm (AnA, 5), but mentions only that of the deltoid tubercle of the humerus, incorrectly assuming it to be the origin of the brachialis muscle. But it is in the figures of the hand that his advance over earlier representations is most marked (fig. 28). He figures the

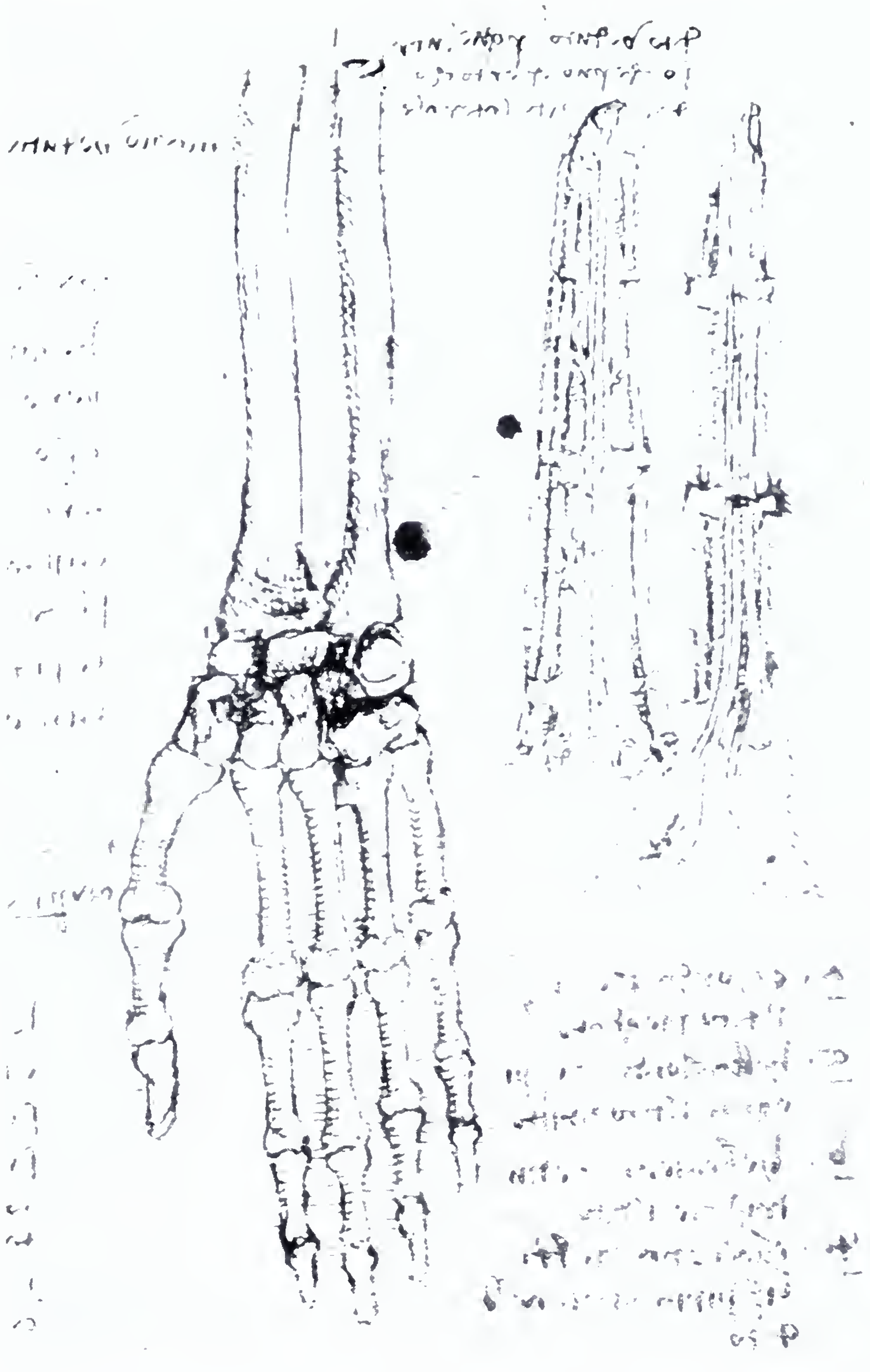

Fig. 28. Bones of hand, with dissection of tendons and ligaments of fingers. (AnA, 10v.)

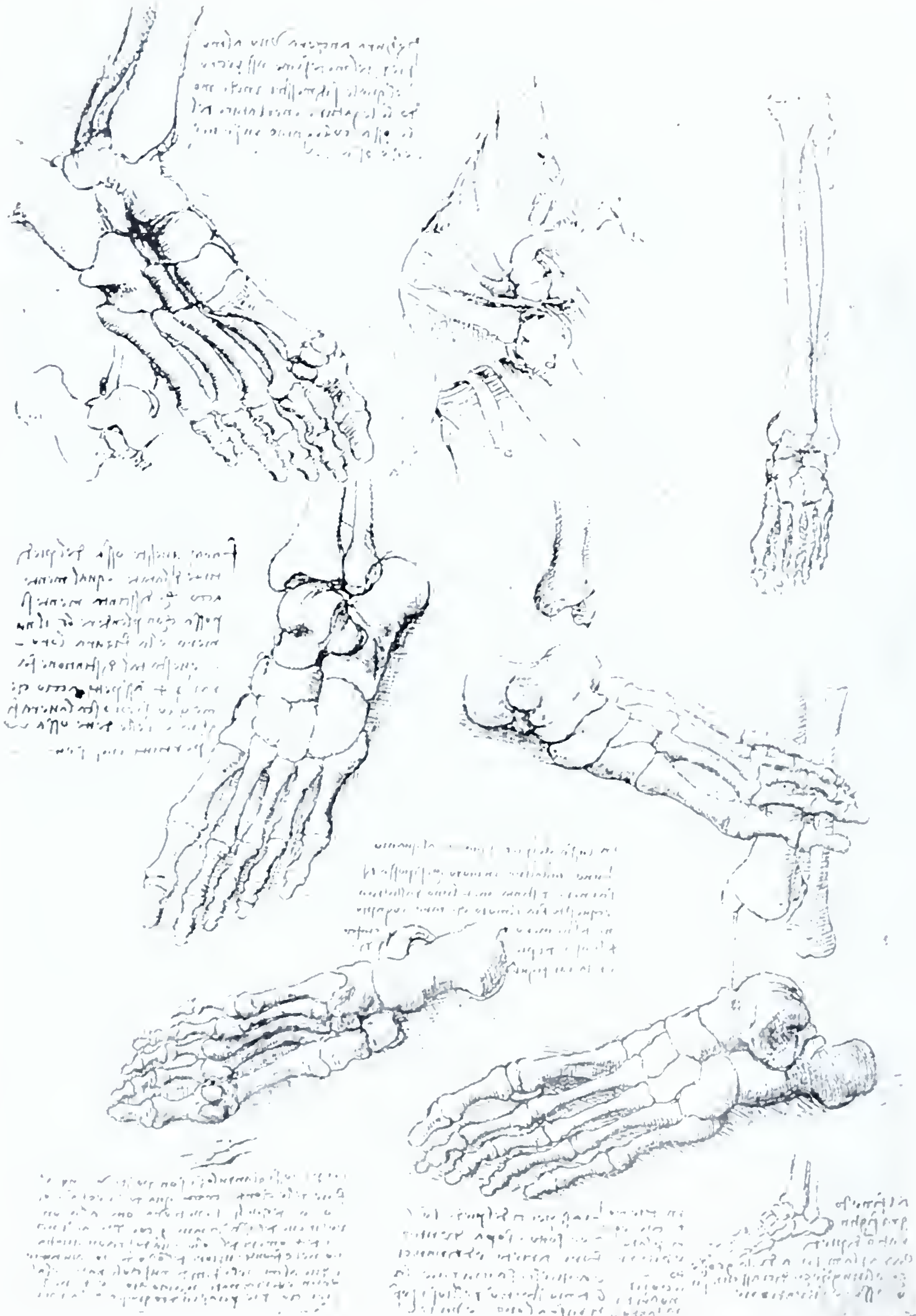

Fig. 29. Various figures of bones of foot with sketch of bones of shoulder. (AnA, 12.)

carpal bones (*rasetta*) for the first time with some approach to accuracy (AnA, 10, 10v), designating them by letters of the alphabet; in the text (AnA, 10v) he terms the trapezium *os basilare* and points out that both the first bone of the thumb and that of the index articulate with it. He follows earlier authors in recognizing only four bones in the metacarpus (*pettine=pecten*), what the text-books of today usually term the first metacarpal being regarded more correctly as a phalanx, each digit thus having three phalanges. He makes no mention of sesamoid bones in the hand.

He figures the innominate bones with remarkable accuracy, giving them, as has been stated, their correct inclination, but of the parts of which they are composed he names only the ileum (*anca*).[18]

The femur (*osso del coscia*), tibia, fibula and patella (*rotula* or *burella*) are represented from various viewpoints and in both extension and flexion (AnA, 9 and 13), and again the accuracy of their representation as compared with earlier figures is most striking. Once again, however, his attention wanders, when in a figure on AnA, 3v, he reverses the positions of the tibia and fibula. The significance of the prominences on the bones interests him here, as well as in the upper limb, and he has a note of inquiry (AnA, 5) as to the significance of the lesser trochanters of the femora, using for them the term *spondyli*, a term recalling *vertebrum* which is applied to the great trochanter in mediaeval manuscripts.

Of the foot he gives a number of illustrations from various aspects (AnA, 3v and 12), the bones for the first time being shown in their true proportions (fig. 29), although there is a decided failure to show the arch of the foot. On AnA, 3v, Leonardo states that the bones of the foot are twenty-seven in number; Avicenna, following Galen, mentions twenty-six. One finds here an example of Leonardo's independence of tradition and reliance upon his own observations—a truly modern attitude. He obtains the number twenty-seven by including the two sesamoid bones beneath the metatarso-phalangeal joint of the great toe. If these be deducted, Leonardo's number becomes twenty-five, one less than that of Avicenna, and it is here that Leonardo's accuracy and independence of authority is shown; for he evidently counts, as he has figured, only two phalanges to the little toe (fig. 29), while Avicenna recognizes three. Three is, of course, the typical number, but the apparent reduction to two, as a result of the fusion of the terminal and middle phalanges, is so frequent that one may feel sure that Leonardo had before him such a condition and drew it as he saw it.

He does not name the bones of the tarsus except in the case of the cuboid, which he calls *os basillare* and notes that the use of each of the prominences on its plantar surface should be described, also "each of

[18] He applies the term *ascia* (ischion) to the great trochanter on AnA, 15v.

its perforations and into how many parts it is divided" (AnA, 3v). The sesamoid bones were known to the older authors, Avicenna, for example, mentioning them and noting their relation to the joint. Leonardo, who terms them *ossi glandulosi* or *ossi petrosi*, has added materially to the appreciation of their true significance, since he defines them as being always situated toward the ends of tendons, where these are attached to the bone (AnA, 12). Furthermore he recognizes as belonging to this category of bones, not only the four associated with the great toes, but also "two in the tendons termed *omeri del collo*, where these join with the upper heads of the bone termed *aiutorio* (*i. e.* the humerus) and two others in the ends of the muscles which arise in the *alchatin* and end in the knee." The *omeri del collo* undoubtedly are the acromial portions of the trapezius muscle and the sesamoid bones in their tendons may be identified with the ununited acromial processes. The sesamoids at the knee joint would seem to be the patellæ, for in a note on AnB, 18v, which shows the muscles of the thigh from in front and from the inner side, it is stated that all the muscles of the thigh reach the knee and are converted first into a nerve (*i. e.* tendon) and underneath this into a delicate cartilage. It is evident that here Leonardo is speaking only of the rectus femoris and vasti muscles, but in the passage quoted above he errs in assigning the origins of all three to the *alchatin*,[19] meaning by that term the innominate bone, even though his figures indicate that the vasti arise from the femur. However, in spite of these slips in memoranda intended for his own guidance, he long anticipated one of the conclusions of modern anatomy in assigning the patella to its proper status as a sesamoid bone.

Naturally Leonardo can have nothing to say as to the minute structure of bone, but he was interested in the internal structure of the various bones and made memoranda to the effect that each one is to be sawn through to show its structure (AnA, 1v and 18; QI, 2), a plan that, apparently, was never carried out. However, he notes (QI, 27) that some are hollow, some contain marrow, some are spongy, some are thick and some are thin and, indeed, that one bone may show all these characteristics at different parts. He describes bone as being of inflexible hardness and destitute of sensation (QII, 18v); its interior is composed of spongy substance, blood and soft fat, and the spongy substance is composed of bone, fat and blood. Cartilage, which invests the extremities of bones is a hard substance like indurated tendon or softened bone, being pliable, unbreakable and acting like a spring. It always intervenes between bone and tendon, because it partakes of the nature of both substances (QII, 18).

[19] There is some confusion in the use of the term *alchatin*. Leonardo uses it or the word *catino* to denote the innominate bone, but in Avicenna it is applied to the lumbar vertebræ.

Nor can Leonardo be said to have added anything to the knowledge of the joints, except in that he has more accurately represented the form of their constituent surfaces. In considering the knee he speaks of its articular capsule, but describes it as composed of as many layers as there are muscles descending to the knee, and on this supposed fact he bases a generalization (AnA, 15; AnB, 18) which gives to the capsules of all joints a similar layered structure. On AnA, 15 he correctly notes the important rôle played by the muscle tendons in maintaining the bones in contact at the joints.

He notes the existence of ligaments extending from bone to bone, but gives them little attention. He represents (AnA, 7v) oblique ligaments extending between adjacent metatarsals and basal phalanges crossing to form a letter x, but these must be regarded as artefacts, perhaps produced by imperfect dissection of the plantar ligaments of the joints. In a curious passage (AnB, 28) he points out that in the joints of the feet and hands a convexity is received into a concavity and explains this fact on the ground that Nature did not desire to make the feet too large which they would have been if convexity articulated with convexity, unless the extra size was compensated for by the digits being all of the same length or else by some having two joints and others one. The significance of these last statements is not clear, but the passage is interesting in revealing Leonardo's belief in the adamantine inalterability of bone; the idea of its plasticity was slow to develop.

One other statement concerning the joints may be mentioned. He notes (Ash^2, 28v; see also TP, 261) that in children the position of the joints is indicated by constrictions, whereas in adults the joints are prominent, and explains this by the flesh covering the bones losing its "superfluity of fullness" as age advances, the skin thereby coming near to the bones; but at the joints there is no flesh, but only cartilage and tendons, and so there is nothing to grow leaner.

CHAPTER XI

THE MUSCLES

Galen in his *De administrationibus* had left a very full, though verbose, account of the muscles as he found them in monkeys, and Avicenna briefly epitomizes his account, by condensation and omission covering in a few pages what Galen had spread over many. In Mondino this condensation is carried to almost complete omission, only two groups of muscles being mentioned, those of the anterior abdominal wall and those of the thorax. Concerning the former, he cites Galen as stating that they are eight in number, *i.e.* the two recti, the two pairs of oblique and the two transversi, and of the thoracic or pectoral he says:

> "This anatomy does not allow you to perceive all the muscles of the chest. All are not to be observed because there are eighty-eight (according to Avicenna there are seventy-eight) of them, but nevertheless you ought to know that some are dilators and some dilators and constrictors."

He then mentions, without description, the two muscles of the diaphragm, two in the neck that dilate the upper part of the chest cavity as the diaphragm does the lower part, and two muscles between each pair of ribs, one with its fibers "latitudinal," while in the other they are transversal. Of the muscles of the limbs he says nothing; indeed in the public Anatomies of his and later times the structure of the limbs received but slight consideration or none at all, these parts being left to the last and the main interest being directed to the anatomy of the three ventres—abdomen, thorax and head, in that order.

And if in pre-Vincian times the muscles had fallen upon evil times so far as their description went, in illustration they were in a yet sorrier plight. The muscle-man of the Five-Figure Series (fig. 30) is naïve in its imperfections and could only make confusion worse confounded. It was not until 1496 that a figure is found worthy of being called a representation of a group of muscles. It is contained in the Venetian edition of that year of the *Conciliator differentiarum philosophorum et præcipae medicorum* by the Averroist Pietro di Abano, whose death in 1316 alone saved him from suffering the extreme penalty for heresy and the practice of magic. The figure (fig. 31) which represents the muscles of the abdominal wall does not appear in the first edition of the book printed in Mantua in 1472, nor in three succeeding editions, but it is found for the first time in the fifth edition, printed one hundred and eighty years after the death of the author. It is clear that Pietro

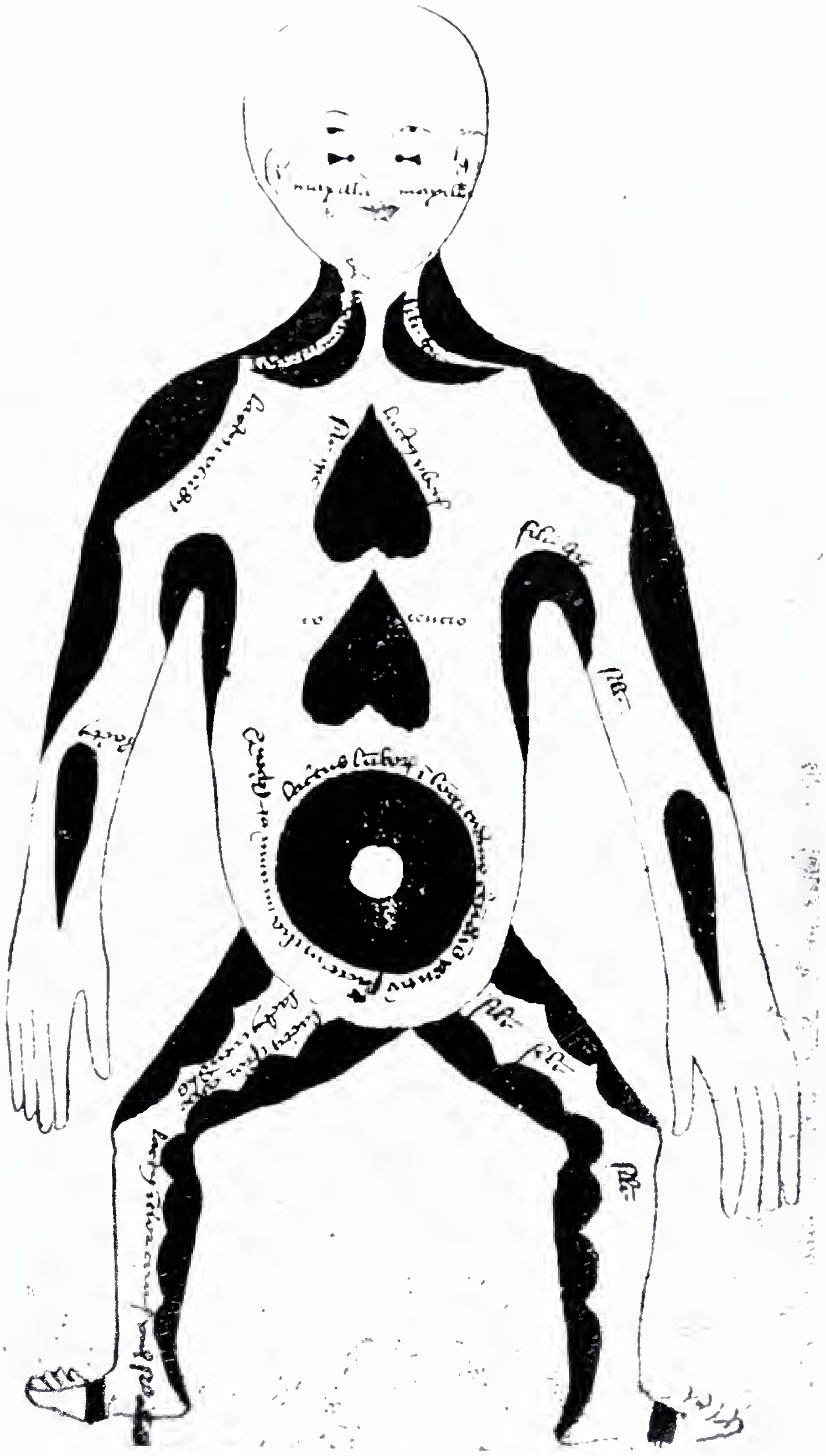

Fig. 30. Muscle man from Raudnitz Five-Figure Series (1399).
From Sudhoff, Archiv, vol. 3, pl. 12, 1910.

di Abano had nothing to do with the illlustration; the publisher of the edition, Octavianus Scotus, was probably responsible for its insertion

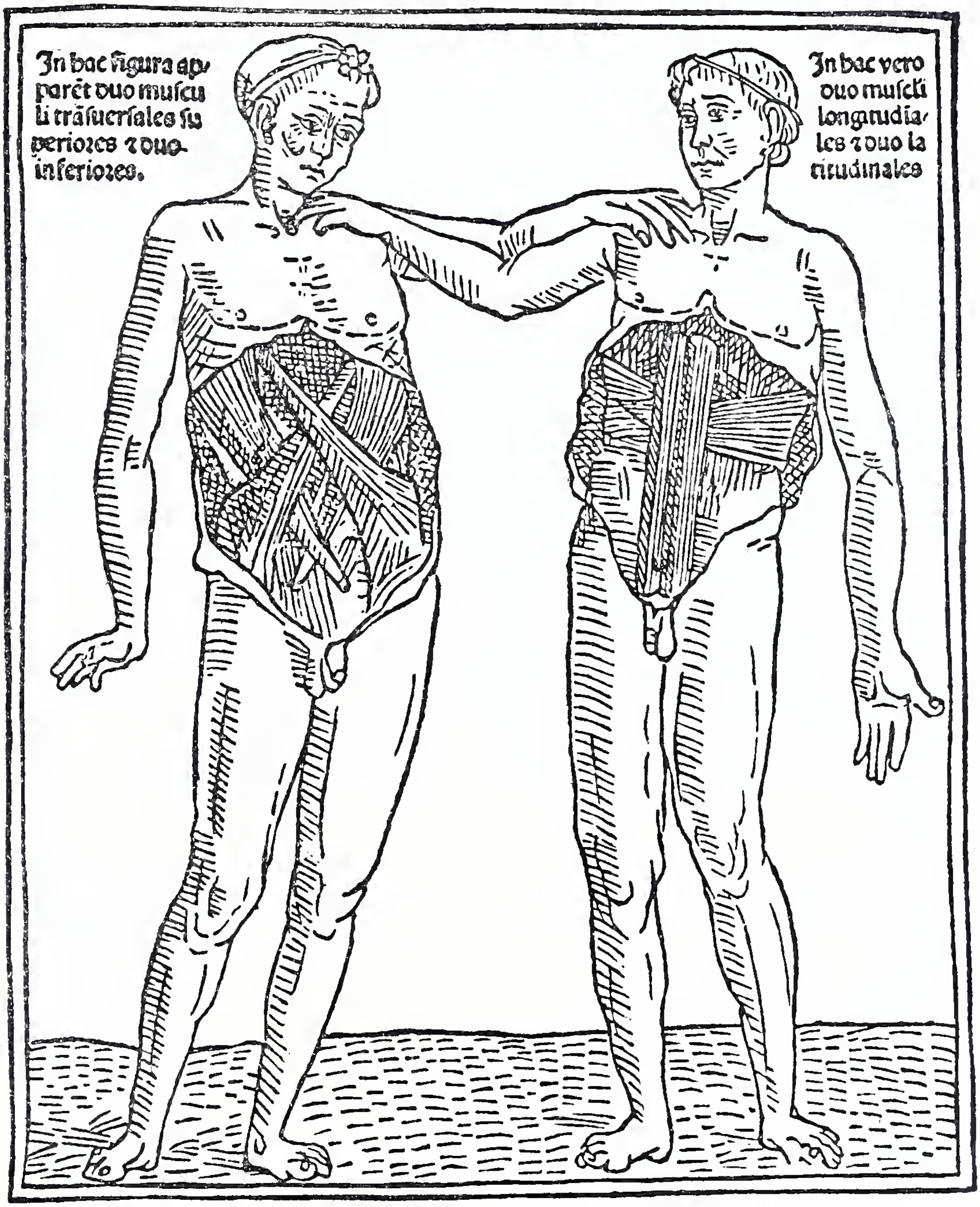

Fig. 31. The abdominal muscles from Pietro di Abano's *Conciliator differentiarum* (1496). From Sudhoff, Archiv, vol. 3, pl. 2, 1910.

and it was evidently drawn by some one who had at least witnessed an Anatomy, but was more influenced by his interpretation of Mondino's statement, with Galen for its authority, than by what he might have observed. The peculiar features of these figures will be discussed in connection with some similar ones by Leonardo.

It was probably the simplicity and conciseness of Mondino's statement regarding the abdominal muscles that led to their representation by a diagram in the *Antropologium* of Magnus Hundt (1501). It is a diagram of extreme simplicity, consisting of a St. Andrews cross imposed upon a St. George. The limbs of the St. George cross represent the longitudinales and latitudinales, while those of the St. Andrews cross represent the transversales (*i.e.* the obliques). This and the figures in the *Conciliator* are the only serious attempts in pre-Vincian times to represent the arrangement and structure of individual muscles.

It must not be forgotten, however, that in Leonardo's time and earlier, the development of Renaissance art had led to an awakening interest in the surface modeling of the human body in rest and in action. In a truly modern spirit, some of the artists, notably Leonardo's preceptor Verrocchio and his contemporary Michel Angelo,[1] endeavored to obtain understanding of this modeling by a study of the musculature underlying the integument, but such studies were solely from the standpoint of the artist and did not lead, as they did in Leonardo's case, to the investigation of the individual muscles. That was a field that, so far as the Renaissance anatomists were concerned, was almost unworked, for Galen's labors in it were practically unknown to them. Berengar di Carpi in his *Commentaria* on Mondino's *Anathomia* had done something, but his work was not published until 1521, two years after Leonardo's death, so that the latter in his abundant myological studies had to rely upon his own observation, with slight assistance from Avicenna.

Leonardo's ideas as to the ultimate structure of muscles have already been considered in the discussion of his definitions of the similar parts (p. 99). On the basis of their form he divides muscles into groups, those that are short and are termed muscles (*s. str.*) and those that are long and are designated *lacerti* (AnA, 15). He also gives a more extended classification based mainly on the form of the tendon (AnA, 13v), recognizing four groups; (*A*) those that begin and end in tendons and of these there are two subdivisions, (*a*) those in which the tendons are dilated and "converted into cartilage" *i.e.* broad and flat, and (*b*) those in which the tendons are round and cord-like; group (*B*) includes those muscles that have tendons at one end only, and of these there are also two subdivisions (*a*) and (*b*) according as the tendon is round or flat; group (*C*) has those muscles that are attached to the bone throughout its whole length; and group (*D*) contains those that arise by tendon

[1] Three drawings of *corpi scorticati* ascribed to Verrocchio have been reproduced by Duval and Bical (*L'Anatomie des maîtres*, Paris, 1890) and one by Michel Angelo, apparently of the same character, is given by Choulant.

and end in flesh, these differing presumably from those in group (*B*) in that the latter begin with fleshy substance and end in tendon.

On QII, 15 there is a more extended description of the various forms under which muscles occur, and the passage is interesting in showing how far Leonardo had carried his studies of individual muscles. Muscles, he says, are of many kinds. Thus, some are without tendons, as the chains of the right ventricle of the heart, etc. (*i.e.* as the moderator bands of the heart), and others are round, as the one that had been previously mentioned, which is detached and does not join itself except by bridles to the member moved by it. Others are large and slender, others large and thick, others long and narrow, others long and thick, some slender and oval, others fish-like, others lizard-like; some twisted, others straight. Some have a tendon from only one part, others on both ends, and others are divided by many tendons, like the longitudinal muscles of the body (*recti abdominis*). Some move the members from either end, some from one end only; some move directly (*dirieto*) on their tendons, others draw the tendons to them. The occurrence of bicipital muscles is also noted (AnA, 11v, and QIII, 9v), these being explained by the suppositions that the parts to which they are attached may require to be moved by two almost similar motions, or that the bicipital condition gives a margin of safety, since if one head be injured the other may still continue to function.

On AnA, 15v there is a sketch showing a muscle with a short, broad tendon above and a rounded one below. At one side is represented a nerve which sends a branch to the muscle belly and, on the other side, an artery and a vein also sending branches to the muscle. All these structures are labeled, indicating their functions; the upper tendon is force (*forza*); the muscle, motion; the nerve, sensation; the vein, nourishment; and the artery, spirit. This might be interpreted as meaning that the muscle acted by virtue of vital spirit conveyed to it by the artery, the nerve being purely sensory. But, as will be shown later (see p. 210) Leonardo used the word *sentimento*, sometimes to imply what would be termed sensation and at other times in the sense of stimulus, and was fully aware that the stimulus to function came through the nerve. This is shown by statements such as "the muscles retract or extend solely on account of the nerve from which they receive a stimulus (*sentimento*)" (AnB, 3v), and many similar passages might be cited. According to the view current in Leonardo's day, the nerves were tubular structures, whence he speaks of them as *corde forata* (AnB, 2), and through their lumina vital spirit could flow to the muscles, whereby an expansion of the muscle, accompanied by a shortening, ensued. He had doubts, however, whether the "air" of the nerves could suffice to render the muscles as tense as they are in full contraction and recalls the case of a stallion, which could scarcely move on account of excessive fatigue, and yet, at the sight of a mare, quickly recovered his forces and overtook the mare, which fled before him (AnA, 18). He doubts if the nerves could furnish enough "air" for so sudden a recovery, but he has no other explanation to offer. He believed, too, that under certain conditions muscles could contract automatically, without stimuli from other officials, *i.e.* from nerves, the *senso commune*, or the soul, and instances as examples—

"the movement of paralytics, of those benumbed by cold, whose head and members move without control of the soul, who can not stop the movements. The same happens in epilepsy and in severed members, such as the tails of lizards." (AnB, 2v.)

On AnA, 15v Leonardo sets forth an important principle in muscle physiology in the statement that when the sartorius and tensor fasciæ latæ (*a* and *r*) contract, the leg is drawn forward and the gluteus medius and anterior part of the gluteus maximus (*b* and *c*) relax, while the posterior portion of the gluteus maximus (*d*) elongates, and he then goes on to note that "this rule is to be described in the action of all the muscles." Thus he establishes a general rule that when a muscle contracts there is a relaxation of its antagonist, an interesting foreshadowing of the law of the reciprocal innervation of antagonist muscles so admirably worked out by Sherrington. Leonardo's rule implies a recognition of muscle tone, as does also his statement that at death all muscles extend in length (QII, 8v); Galen had remarked on it long ago, terming it innate contractility, but it is not mentioned by either Avicenna or Mondino. Naturally its real significance as an effect of the central nervous system was unknown, as was also the mechanism of the relaxation of the antagonist muscle, as an inhibition of its tonus. Such concepts as nerve reflex and inhibition were quite beyond the physiology of the period, they were still far in the future; even though its real significance was undreamt of, Leonardo's observation was an important advance in muscle physiology.

Leonardo was deeply imbued with the prevailing teleological philosophy and seems inclined to believe that each muscle was formed to produce a certain definite movement and that each had a definite antagonist. Thus he states (AnA, 16) that each muscle attached to the spine of a vertebra has an antagonist, and adds a curious explanation of this particular case, namely that the spines of the vertebræ to which muscles passing to the head were attached would break when the head was bent, were it not for the antagonist passing to the spines from below. He does, indeed, recognize combined action of muscles, as when the sartorius and tensor fasciæ latæ flex the thigh or when the hand performs the movement of circumduction, noting, however, in this latter case, that there are four principal movements, namely, what would now be termed flexion and extension, adduction and abduction, and in addition to these an infinite number of secondary intermediate movements (AnA, 14). As a rule, however, he ascribes to a muscle a single definite action which it exercises quite independently of others. There is little suggestion of synergic action.

Holl (1905) has ascribed to Leonardo the recognition of voluntary and involuntary muscles. He uses these terms (AnA, 15v), but of movements and not of muscles and not at all in the sense in which they are applied to muscles today. He is speaking of what may be either the intercostal muscles or the serrations of the serratus anterior and their action in breathing, and states that they have "a voluntary and an involuntary movement, for they are those that dilate and compress the lungs." It is not a question of two different kinds of muscles, but of a group of muscles that at one time may act voluntarily and at another involuntarily.

A few epigrammatic statements scattered through the folios may be quoted as indicating Leonardo's comprehension of the mechanics of muscle contraction.

"It is the function of muscles to pull and not to push, except in the cases of the genital members and the tongue." (AnB, 29.) . . . "The muscles always arise and terminate in bones conjoined one to the other and never in one (and the same) bone, since (then) they could move nothing unless it were themselves, as regards their rarity or density." (AnB, 18v.) . . . "No muscle uses its power in contracting, but always in drawing to itself the parts conjoined by it." (AnB, 38v.) . . . "Every muscle uses its power along the line of its length." (QIV, 6.)

And, finally a passage whose meaning is somewhat obscure—

"A man can draw only his own weight. If he stands in one pan of a balance and puts his shoulders against something solid, he will raise in the other pan as much weight as he has strength." (A, 30v.)

Leonardo has left no systematic description of the muscles, such as is found in modern text-books. Indeed, it seems doubtful, even if he had completed his treatise, whether he would have given such detailed descriptions of the morphology of the muscles as is now customary. His interest lay chiefly in their action, and for an idea as to their form and position he was inclined to rely upon his drawings rather than upon description. Such, at least, is the impression one obtains in studying his statements and this impression is confirmed by what seems to be a preliminary draft of a portion of the anatomy (AnB, 29), in which he gives an account of the muscles moving the lips and cheeks, arranged in a series of paragraphs, each with an appropriate heading. If one may judge from these and similar passages his treatment of the muscles would have been very similar to that of Avicenna, though with somewhat greater detail, with more attention to their action and with the added advantage that the text would have been abundantly illustrated by excellent drawings.

Many of his figures show merely the surface modeling produced by the muscles and are more interesting to the artist than to the anatomist, but in many others the dissection is carried to a greater extent and in some cases the muscles are represented by cords or wires with the object of more readily perceiving their action. A difficulty in the way of concise and lucid description with which Leonardo had to contend was the absence of a definite system of myological nomenclature. Galen had the same difficulty and resorted to the plan of considering the muscles in topographic groups and numbering the individual muscles of each group. There were a few recognized terms in Galen's day such as crotaphitic (temporal), masseter, psoas and cremaster and these he used, but they are not found in Avicenna nor in Mondino, and Leonardo did not know them, or at all events did not use them. Even Vesalius in his *Fabricâ* adopted Galen's device; his older contemporary Dubois (Sylvius) made attempts toward the introduction of a definite nomenclature, as did Riolan later, but it was not until the eighteenth century that a special myological terminology, such as we now possess, was elaborated by the endeavors of Cowper (1694), Douglas (1707) and especially Albinus (1734). Leonardo in many cases met the difficulty by reference to his illustrations in which the muscles were designated by letters of the alphabet, sometimes, however, bestowing a name, as when he speaks of the infraspinatus as *muscolo massimo della spalla* (AnA, 2).

One finds many omissions and numerous errors in Leonardo's myological notes and drawings. The omissions will be pardoned when it is remembered that he passed away with his great plan uncompleted; the errors, too, may be forgiven when one compares his work with that of his more immediate predecessors, and recognizes that he was, in these studies especially, a pioneer. His muscle drawings, sure in touch and as a rule accurate as to form and proportion, can not, indeed, be compared with previous efforts—the contrast is too great. His physiology is undoubtedly ancient, his treatment of his subject rather mediaeval, but his illustrations are altogether modern.

The muscles of the head receive rather scanty consideration, those of the orbit being omitted, while of the trigeminal groups only the temporal, masseter[2] and digastric are indicated (AnA, 13v), the pterygoids remaining unnoticed. The stylohyoid is represented on AnA, 3v. The muscles of expression (the platysma or facialis group) were naturally of interest to him as an artist and he makes a memorandum to "figure the cause of the movement seen in the skin, the flesh and the muscles of the face and whether the muscles have their motion from the brain or not" (AnA, 13v). The platysma itself is not described, unless it be

[2] Piumati identifies this as a pterygoid. It has the direction of the internal pterygoid, but clearly inserts into the outer surface of the mandible, the ramus of which is exposed when the muscle is removed.

in the definition of the term pellicle (see p. 99), but a number of the muscles of the face are shown, some of them being given special names to indicate the expression in which they are active. Thus the frontalis is termed the *muscolo del dolore*, and what seems to be the corrugator supercilii is the muscle of anger, this term being also applied to the zygomaticus minor (AnA, 13v). The zygomaticus major, levator labii superioris, pyramidalis nasi and buccinator are also shown, but strange to say he fails to represent the orbicularis oculi.

The movement of the lips he considers at some length (AnB, 29 and 38v), but it can not be said that he has gained an accurate idea of either their arrangement or action. He starts on the assumption that in man there are more muscles acting on the lips than in any other animal, because in man the lips have more varied movement. He seems to have dimly perceived the orbicularis oris, stating that the muscles which constrict the mouth are "in the lips themselves or rather the lips are the actual muscles which close themselves," but he failed to perceive its true arrangement. He notes that other muscles unite with the muscles of the lips, but of these other muscles he mentions only the lateral ones which antagonize the constricting action of the muscles of the lips. These lateral muscles seem to have been the buccinators. Apparently, however, he recognized the necessity for further observations on the lip muscles, for in addition to the muscles that constrict and extend the mouth he assumes that there are others which protrude the lips and others which restrict them, others that evert them and others that antagonize this movement, others that twist them sideways and others that bring them back into place.

"In fact there may be found as many muscles as there are movements (*accidenti*) in the lips and as many more to counteract these movements, and these I intend to describe and figure in full, proving the movements by my mathematical principles."

Leonardo evidently felt the necessity for a more thorough study of the muscles of expression and makes a further memorandum to—

"Figure all the causes of movement that the skin, flesh and muscles of the face have and whether the muscles receive movement from nerves that come from the brain or not. And thus do first in the horse, which has large muscles and parts very evident." (AnA, 13v.)

But here again the good intentions were never carried out.

From the head-line and opening paragraph of AnB, 28v one is led to expect an extended discussion of the muscles of the tongue. The head-line reads "Of the muscles which move the tongue" and the opening paragraph states that "no member has need of so great a number of muscles as the tongue, of which twenty-four[3] are known without

[3] According to Avicenna there were only nine.

counting the others that I have found." But on reading further instead of the description of these muscles, or even of those Leonardo believed he had discovered, one finds first of all some remarks as to the sensory function of the tongue and a statement that he intends in this place to consider only its movements. Still one may have hopes, but continuing further he speaks of the part played by the tongue, together with the lips and teeth, in producing speech and then goes on to discuss the changes and growth of languages. This leads him on to compare the mutability of human inventions with the permanency of Nature's work; man can only combine the simple products of nature, he can create nothing, "unless it be another self, that is to say his children." This idea leads him on to discuss the futility of the aims of the alchemists for they can not create anything. Gold in the rocks is continually but slowly growing, the tips of its ramifications changing into gold that which they touch, "and note that here there is an anima vegetativa which it is not in thy power to produce." From this he passes on to consider (AnB, 28)[4] how the animal body continually dies and is remade and this leads to an invective against necromancy (AnB, 31v) and this in turn to a consideration of the "spirito," a force united to the body and without which the body can not live (AnB, 31, and AnB, 30v). All this is most interesting, but it is not anatomy. Led by his thoughts far from his starting point he quite forgets it and nothing more is said in this place about the muscles of the tongue.

But he returns to their consideration on QIII, 10, where it is again stated that the tongue has twenty-four muscles,[5] but this statement is modified by the assertion that these twenty-four muscles combine to form the six which make up the substance of the tongue. It would seem that the twenty-four were all extrinsic, for he goes on to make a memorandum to inquire as to how the twenty-four combine to form the six and how they arise, some from the cervical vertebræ in contact with the œsophagus (superior constrictor of pharynx), some on the inside of the mandible (genio-hyo-glossus) and some from the trachea. The movements effected by these muscles, extrinsic and intrinsic, are seven, namely, extension, retraction, attraction, thickening, shortening, dilating and thinning. But of these seven movements three are compound ones and can not be produced except in coöperation with one of the others. Thus it is impossible to extend the tongue without at the same time narrowing it and, similarly, it can not be shortened without thickening it, while dilation involves both thinning and shortening.

The sterno-mastoid and trapezius are represented several times, the former with a pleasing accuracy (fig. 32), the latter not so success-

[4] In these folios Leonardo not only writes from right to left but passes in Semitic fashion from verso to recto.

[5] On QIII, 9v, there are said to be twenty-eight muscles in the roots of the tongue.

Fig. 32. The muscles of the neck and shoulder. (AnA, 3v.)

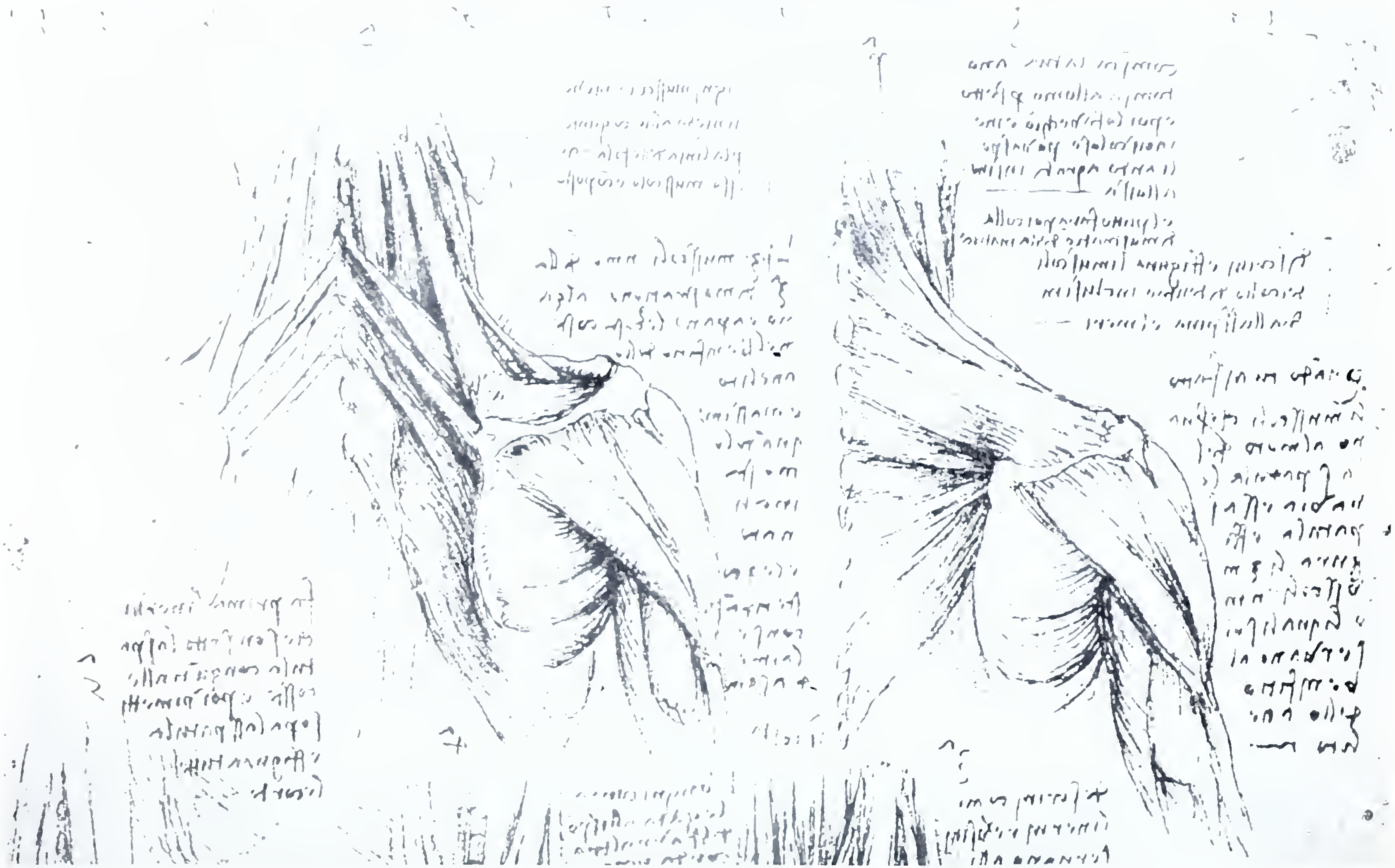

Fig. 33. Two representations of the muscles of the back and shoulder. (AnA, 16.)

fully. Usually only its upper part is represented (AnA, 3v, 4, 4v), but in one figure practically the whole muscle is shown (AnA, 16) (fig. 33), its lower portion in this figure, however, inserting into the vertebral border of the scapula, an error which is emphasized in another figure of the same folio in which the muscle is represented by cords or wires. The mistake is a curious one, since the figure is the first of a series of five designed to show the successive layers of the muscles of the back, and it is difficult to understand how the trapezius could be removed without revealing the true insertion of its lower fibers into the spine of the scapula. In the second figure of the series (fig. 33) the trapezius is removed, showing the inferior belly of the omohyoid, the levator scapulæ and the teres minor, and below the last what may be intended for the teres major, but if so its relations to the scapula are not correctly represented. In the third figure the superior posterior serratus is shown as three separate muscles, instead of a single muscle inserting on the ribs by four digitations, but in the fourth and fifth figures, which represent the true dorsal axial muscles, the identification of the different parts shown becomes difficult. The dissection of these muscles is no easy task, and even Vesalius, thirty or forty years later, was unable to completely unravel their complexities. Leonardo observed that their deeper portions were made up of short slips passing from spinous process to spinous process, and came to the conclusion that each vertebra had ten tendons attached to it, five being antagonistic to the other five (AnA, 16; QII, 5v). He evolves an explanation of this arrangement to the effect that were there no antagonists the spine of the vertebra would be fractured by the great strain to which it was subjected (AnA, 16), since the attachment of the muscles to the spines rather than to the bodies afforded them greater leverage (AnA, 11v).

The mechanics of the movements of the head upon the summit of the vertebral column exercised him not a little, since he seemed to associate with these movements a necessity for a considerable rigidity of the column, inasmuch as the muscles that produced these movements arise from the vertebræ. How the rigidity could be imparted is illustrated by a figure on QII, 5v, in which the muscles are represented by stout cords (fig. 34), and concerning which he writes—

"First you will make the spine of the neck with its tendons, like the mast of a ship with its stays, without the head; then make the head with its tendons that give it movement on its pole."

The cords can not be identified with any actual muscles and the figure must be regarded as a representation of an idea rather than of actual conditions. At first he supposed that the stabilizing muscles passed from the cervical vertebræ to the shoulder girdle, but later, on AnA, 16v, where he returns to the idea of the mast and its rigging, he concludes that—

"The muscles of the shoulder do not aid (in the fixation of the vertebræ), nor those of the clavicle (*forcula*), since the man will relax these muscles arising in the shoulders and *forcula* when he raises the shoulders to the ears and will take away the power of his muscles. And with such relaxation and shortening, movement is not wanting in the neck (head?) and there is not wanting the resistance of the spine in sustaining the head."

Then he proceeds to assign the main stabilizing action to the superior posterior serratus, which he invariably describes as formed of three separate slips (see fig. 35). His earlier notion as to the function of these muscles was that they were elevators of the ribs, acting in respiration (AnA, 16; AnB, 27v), but on AnA, 16v he finds reasons for supposing that they really act as stabilizers of the cervical vertebræ in the facts, firstly, that the ribs are especially strong at the points of attachment of the slips of these muscles, that is to say, in the region of the angles, and, secondly, that the obliquity of the muscles to the ribs places them at a disadvantage as elevators of these parts. Taking this second reason in conjunction with the belief that all parts were perfectly adapted to the functions they had to perform, there would be sufficient reason to doubt the action of the muscles in respiration.

Of the ventral muscles of the neck region a dissection, in which the sterno-mastoid is removed, shows the infra-hyoid muscles (AnA, 3v). The omo-hyoid is figured several times (fig. 31) and in one passage is said to be inserted into the clavicle; on AnA, 15v and 16, however, it is clearly shown to be attached to the upper border of the scapula.

The general mechanism of respiration had been established long before Leonardo's time, and he was familiar with the fact that the capacity of the chest may be increased by muscular action, that with this there is an increase in the capacity of the lungs and, since there can be no vacuum, the air rushes in to fill them (AnA, 16v; QI, 5). Leonardo's problem was the determination of the muscles that were active in enlarging the capacity of the thorax. The intercostal muscles, which he terms the *mesopleuri*, naturally suggest themselves and are represented in a number of drawings, the external and internal muscles, with the correct inclination of their fibers being shown in separate figures (AnB, 27v; QII, 6v), while in another the fibers are represented by cords which form a lattice-like arrangement between the ribs (AnA, 7). In the text (QI, 13v) it is stated that there are twenty of these muscles, which may be interpreted to mean that there are ten sets on each side, those of the eleventh intercostal spaces having been overlooked.

The actions assigned to these muscles are the traditional ones; the external intercostals serve to raise the ribs, thereby increasing the capacity of the chest, while the internal ones—their fibers having a direction at right angles to those of the external—will have a contrary action and serve to depress the ribs. Leonardo notes that the eleva-

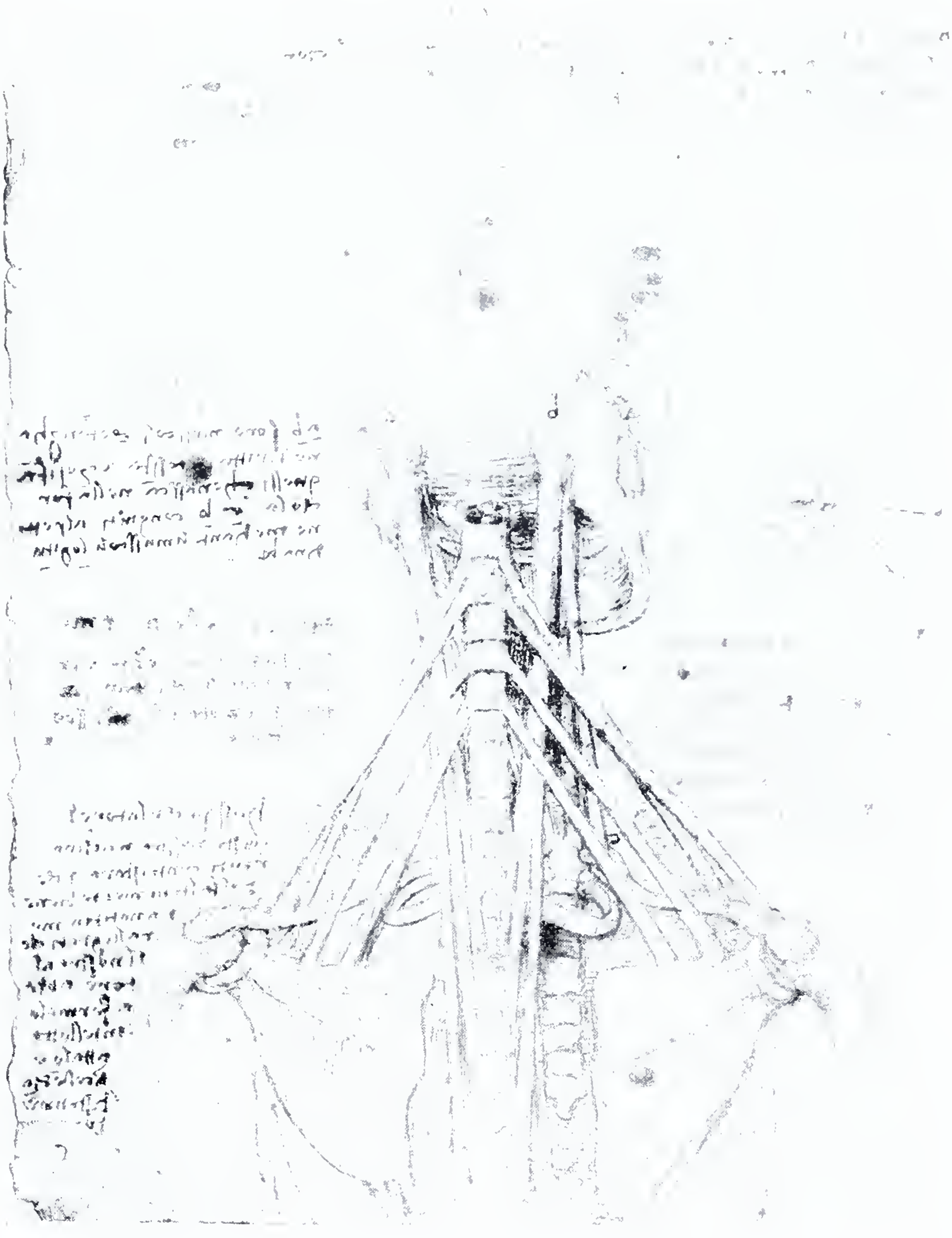

Fig. 34. A cord diagram of the muscles supposed to stabilize the cervical vertebræ in movements of the head. Also a sketch showing the insertions of muscles into the spine of a vertebra. (QII, 5v.)

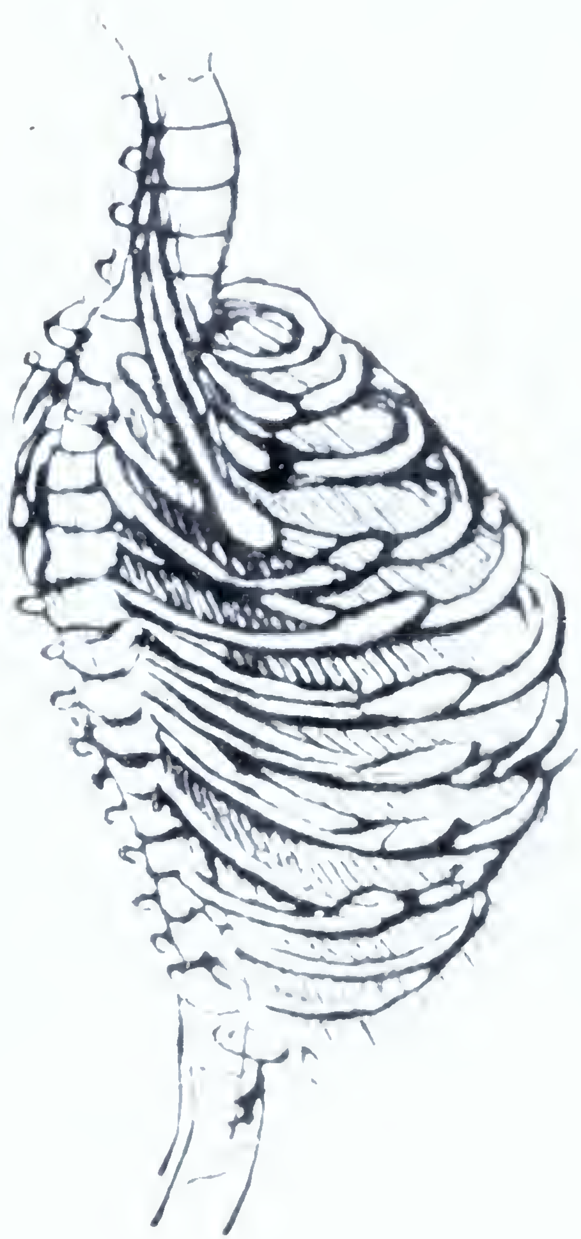

Fig. 35. Diagrammatic representation of superior serratus posterior and serratus anterior. (QO, 8.)

tion of any rib will tend to raise all those below it and, furthermore, that the lower ribs have more motion, successively, than the upper ones (QII, 6v). That the elevation of the ribs will increase the dorso-ventral diameter of the thoracic cavity is clearly perceived by Leonardo and he gives diagrams to illustrate how it is done (QI, 2v), but that it also increases the lateral diameter is not so clearly brought out, although his reference to the movement being through a "curved obliquity" (QII, 6v) is probably a recognition of that fact. One would, however, have expected that Leonardo, knowing as he did the form, position and attachments of the ribs, would have shown greater interest in the mechanical principles involved in this lateral enlargement. When the external intercostals relax, the ribs return to the position of rest by their own weight, provided the body is in an upright position, but if recumbent, then the internal intercostals come into play (AnB, 27v); the elasticity of the costal cartilages, which are bent when the ribs are raised (QII, 6) is not considered.

But while recognizing the action of the external intercostals as elevators of the ribs, Leonardo for a time at least attached much greater importance in this respect to the serratus posterior superior; indeed in one passage (QI, 8) in speaking of the dilation of the chest he mentions only this muscle and the serratus anterior. It is figured and described as three separate muscles (fig. 33), and there is some uncertainty as to the insertion of these, one passage (QI, 2v) stating it to be into the three upper ribs, another (QI, 8) that it is into the second, third and fourth ribs, (fig. 32) and it is figured (QI, 5; AnA, 16v; AnB, 27v) as passing to the third, fourth and fifth ribs. Leonardo evidently mistook the dentations by which the muscle is inserted for separate muscles and overlooked one of them, and a further error is the statement that the muscles are supplied by branches of the *nervi reversivi* (AnA, 16; QI, 2v), by which term the vagi are meant.

The change in Leonardo's views as to the action of these muscles has already been mentioned (p. 138). At first he assumed that their sole action was to elevate the ribs (AnA, 16) and for that reason proposed to term them *li tiranti* (AnB, 27v). Later he argues that they may raise the ribs and also serve in the fixation of the cervical vertebræ, which he believed to be necessary for the proper functioning of the muscles that move the head, and finally he concludes that the latter is their only function (AnA, 16v).

Another muscle regarded by Leonardo as important in respiration is the serratus anterior, concerning which he again falls into grievous error. One is inclined to suppose that in his dissections he did not remove nor look beneath the latissimus dorsi and so failed to see the main portion of the serratus extending backward to be inserted on the vertebral border of the scapula. Only the serrations of the lower portion of the muscle were known to him. Of these he shows five (QI, 5; AnB, 15v; 27v) in most of the illustrations, but on QI, 8 there are six (fig. 33) and on AnA, 15v, seven (fig. 36) and the diagram on QI, 8 indicates that he supposed the serrations to be continued into round cord-like tendons that passed backward to be attached to the vertebral column. This is another case in which Leonardo's conclusions outran his observations, and apparently his conclusions altered with time, for on AnA, 15v he represents the serrations diagrammatically as passing obliquely from one rib to the next over the intervening intercostal space, without any suggestion of their being attached to the vertebral column.[6] The muscles are supposed to dilate the ribs, withstanding the tendency of the diaphragm to draw them inward; hence Leonardo proposes to term them *li dilatanti* (AnB, 27v).

Leonardo believed that if the shoulders were raised by the muscles of the neck, the lowering of the ribs would be prevented and, similarly, if the shoulders were depressed the ribs could not be raised and so, to obviate the difficulties, Nature provided the diaphragm to attend to the necessary increase of chest capacity (AnB, 16v). This is a thick tendinous (nervous) sheet surrounded by muscles (QIV, 2v) which are attached to the costal cartilages or the ends of the ribs (QI, 5); its form is that of a deep spoon (fig. 37) and by the contraction of the muscle the concavity is diminished and to that extent the vertical diameter of the chest is increased. The flattening of the diaphragm can, however, occur only if the lower ribs are fixed or dilated by the serrations of the serratus anterior, the part the diaphragm plays in respiration being thus of a complex character and, to be effective, requiring the coöperation of the serratus. Its return to the vaulted condition is not due to any intrinsic effort. When it contracts, it presses upon the liver and stomach, which lie in its concavity, and through them upon the intestines, which force outward the anterior abdominal wall (*mirac*). When the diaphragm relaxes the muscles of the abdominal wall contract, in turn pressing upon the intestine, stomach and liver, forcing these last against the under surface of the diaphragm and so causing it to become concave. There is accordingly an alternating contraction of the diaphragm and the muscles of the anterior abdominal wall (QI, 6v; QII, 16v). But the diaphragm not only serves in respiration, it has other functions. By pressing upon the stomach it causes the ejection of chyle into the intestine; with the aid of the abdominal wall it expels the superfluities of the intestine; and it serves to separate the spiritual organs from the natural ones (QI, 5v; QII, 16). The action of the diaphragm on the abdominal contents will be considered in the chapter on the digestive organs.

[6] Piumati identifies the muscle slips shown in this diagram as intercostals, but their position and form does not at all correspond with those muscles, while they do with the serrations of the Serratus. The fact that the same sheet has a beautiful *scorticato* showing the serrations is contributory evidence that the diagrams are representations of these.

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Fig. 36. The muscles of shoulder, trunk and leg. (AnA, 15v.)
Fig. 37. Figures showing the form of the diaphragm. (QI, 5.)
Fig. 38. The abdominal muscles. (QI, 5.)

Reference has been made (p. 128) to an illustration of the muscles of the ventral abdominal wall in the 1496 edition of Pietro d' Abano's *Conciliator differentiarum*. The illustration shows two human figures in which the muscles of the anterior abdominal wall have been dissected, one figure showing the two recti (*longitudinales*) and on either side of these the transversi (*latitudinales*). The other figure shows the obliques (*transversales*), the more superficial or external one on each side attached to the iliac crest by a broad origin and passing upward and medially, narrowing as it goes, to cross its fellow in the median line and to be inserted into the ribs of the side of the body opposite to that from which it arose. The deeper or internal muscles have essentially the same form and relations, but are reversed, their fibers running downward and medially. The obliques, therefore, are incorrectly represented in crossing the median line and in the direction of their fibers. In the very crude diagram in Hundt's *Antropologium* (1501) they are again shown as crossing, but the external and internal muscles are not distinguished. Further, Sudhoff has found in a copy of the 1495 edition of Ketham's *Fasciculus* a marginal diagram drawn by a student in 1499 as an interpretation of Mondino's description of the abdominal muscles, and again the obliques cross the median line.

There was apparently, at the close of the fifteenth century, a fairly general belief that the oblique abdominal muscles, being oblique, must necessarily cross the median line, since otherwise they could find no bony parts into which they might insert. Leonardo seemed to have acquired the idea of a crossing in the abdominal muscles, either from his reading or from hearsay, but he applied it to the recti instead of to the obliques. In two sketches (QIII, 7 and QIV, 6) (fig. 38) he shows the two recti crossing the median line and each other a short distance above their attachment to the pubis, so that the muscle attached above to the ribs of the right side inserts into the left pubic bone, concluding from this arrangement that the action of each muscle is to bend the trunk forward and at the same time draw it laterally, or, as he expresses it "the right shoulder inclines toward the left thigh." When, however, the recti are drawn from a dissection, as on AnB, 15, they are represented accurately and with no indications of a crossing, though they are still supposed to incline the trunk laterally as well as to flex it. This last figure also shows each of the muscles divided into four portions by tendinous inscriptions, an arrangement that makes for strength, "for where there is life with thickness there is force, and where there is so much length of movement there it is necessary to divide the motor into several parts." The same muscles and their division by tendinous inscriptions are also considered in TP, 230, and here the number of portions is given as three. That the arrangement conduces to greater strength is again referred to, but it is also pointed out that since each part will furnish only one-third of the entire contraction, there will be less distortion of the anterior abdominal wall and little alteration of the general beauty of the body.

In discussing the actions of the recti (QIV, 6), Leonardo perceived the necessity for antagonistic muscles that would counteract the forward bending produced by them and so allow a purely lateral inclination. Such antagonists he describes and represents in sketches as two muscles on the dorsal surface of the body, said to arise from the ninth vertebra of the back and shown as passing, downward without crossing, to the crests of the ilia. The identification of these muscles is difficult. The sacrospinalis suggests itself, but the insertion forbids its acceptance and it is possible that they are intended for the quadrati lumborum, even though they do not resemble them in form.

But if the identification of these muscles with the quadrati is uncertain there is no doubt that Leonardo observed the psoas. For in speaking of the action of the recti in bending the trunk forward he says "And their assistants (*adherenti*) are the *lonbi*, which are on the side of the spine within" (QII, 16v). There is no evidence, however, that he knew of their relation to the thigh.

The external and internal obliques are indicated in a diagram on QIII, 7, and the serratious of origin of the external muscle are well shown on AnB, 15v. In the text (AnB, 16) this muscle is said to arise from the sixth rib, its serrations alternating with those of the serratus anterior, and below, becoming aponeurotic or, as Leonardo expresses it, "converted into cartilage," it is attached to the ilium and to the pubis. The internal oblique is described as arising from the spinal column opposite the umbilicus and inserting on the eleventh rib and the pubis, in the interval being converted into "cartilage" which covers the rectus; the fan-shaped arrangement of its fibers is distinctly shown in the lower figure on AnB, 16.

But the transversus interested Leonardo more than the obliques, since he believed it to be *par excellence* the muscle that compresses the intestine and so expels its contents. It is partly shown on AnB, 15, on either side of the posterior wall of the sheath of the recti, again spoken of as "cartilage," beneath which it is supposed to pass, being in close contact with the peritoneum (*sifac*), a relation that leads Leonardo to speak of it as the transverse muscle of the *sifac* (QII, 16; QIV, 3), and, going a step farther, to ascribe the act of expulsion from the intestines to the *sifac* (QII, 16).

Leonardo's treatment of the limb muscles is the most satisfactory portion of his myological contribution, but the merit of it does not lie in verbal description, of which there is little, but in the illustrations, many of which are sufficiently accurate in detail and execution to satisfy even modern standards. They form, indeed, a startling contrast to the pre-Vincian attempts and it was not until many years after Leonardo's time that illustrations appeared that could be compared

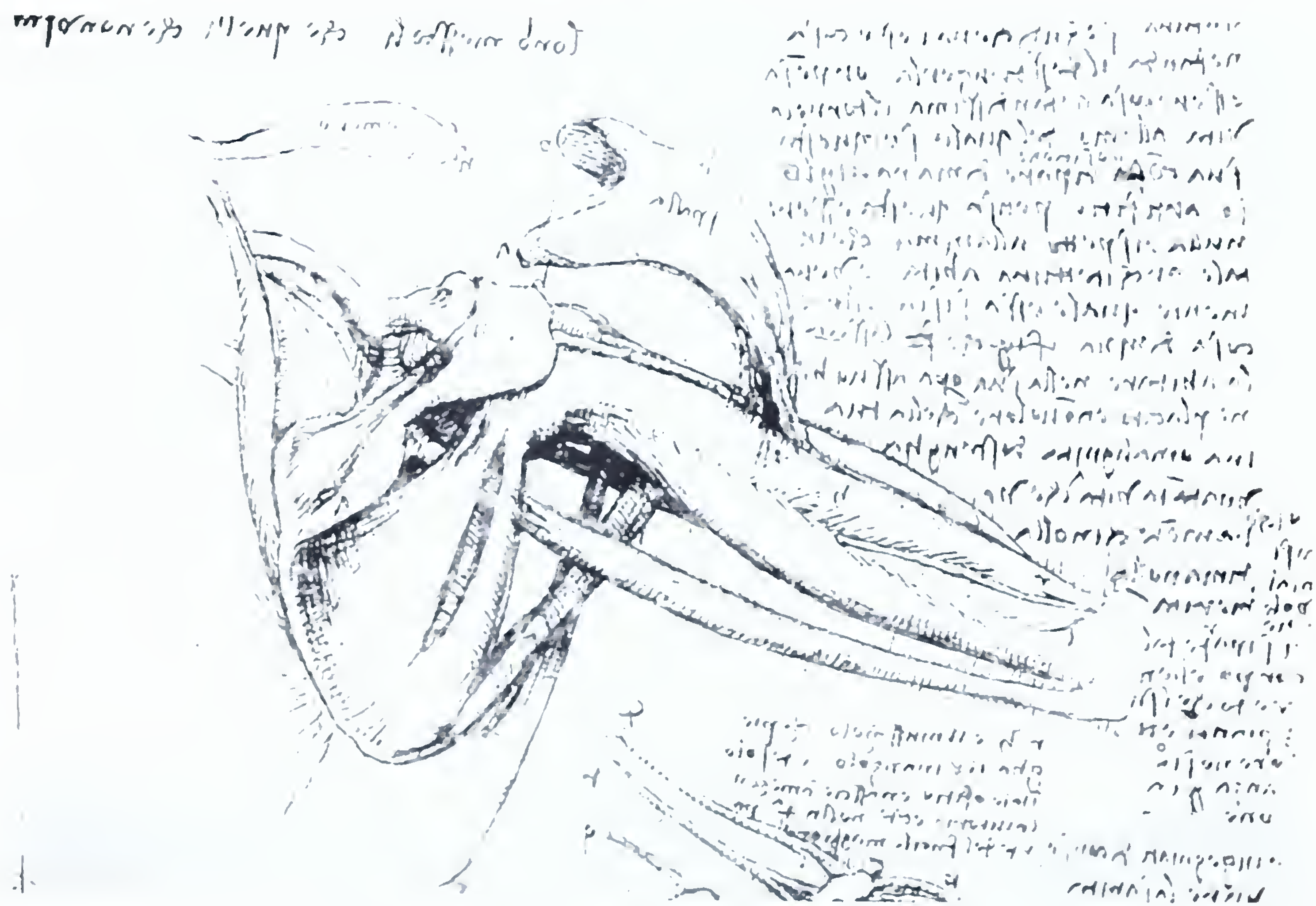

Fig. 39. Scapular and brachial muscles. (AnA, 2.)

with them. From the artist's standpoint attention may be especially called to the figures showing the surface modeling of the neck and shoulders on AnA, 2v; AnA, 4 and 5v, and of the lower limb on QV, 22 and 23.

The scapular muscles receive a good deal of attention, a fact that renders all the more remarkable the failure to perceive the correct attachment of the trapezius and serratus anterior. The muscles of the dorsum of the scapula, together with the teres major and the upper part of the latissimus dorsi are shown in several illustrations (AnA, 2, 4v and 14v) (fig. 39), and on AnA 12 there is a representation of the scapula with the spine cut away to show the tendon and insertion of the supraspinatus. On AnA, 2 the same muscles are represented by cords, and a figure shows the bone tilted so that the supraspinatus and infraspinatus, which Leonardo terms *il massimo*, are seen, while another figure shows the muscles severed and the humerus slightly withdrawn from the glenoid cavity, so that the insertions of the teres minor, supraspinatus and infraspinatus into the tuberculum majus and of the subscapularis into the tuberculum minus are clearly shown. The action of the latissimus dorsi and teres major is stated to be the inward rotation of the humerus (AnA, 4v, 14v) and the latter muscle also serves to adduct the arm (AnA, 14v).

The deltoid appears on a number of folios of AnA (figs. 32, 35, 38 and 39); on 6v and again on 13v it is labeled as if consisting of four separate parts, and on 4v, in which it is seen from behind, there is a gap in the continuity of its origin, the portion arising from the base of the spine being separated by an interval from the acromial portion. To the more posterior portion is strangely attributed the action of rotating the arm inward. The pectoralis major is said to arise from the thorax as far down as the seventh rib, alongside the xiphoid cartilage (*pomo granato*), and at its lower border it is transformed into fascia or aponeurosis (*panniculo, cartilagine*) which covers all the abdomen and terminates below on the pubis. It is regarded as consisting of several muscles (AnB, 16v), an idea which finds expression in figures on AnA, 2v, and AnA, 4v, where it is represented as four separate muscles which reverse their original succession from above downward just as they approach their insertion on the humerus, Leonardo having perceived the curious twist of the tendon of insertion. On AnA, 6 it is represented as a single muscle, although the separation between its clavicular and sterno-costal portions is well marked. Its action is to adduct the arm and it is of large size so that the arm may be drawn with force from the hands of any one attempting to seize it (AnA, 14v). It is represented by cords on AnA, 4v. The pectoralis minor is also shown with a fair amount of accuracy; its origin is not quite exactly given, but its insertion into the coracoid process (*rostro del spatolo*) is correctly shown (AnA, 2v, 4v; AnB, 15v). Its action is to raise the ribs and hence it is one of the muscles of respiration (AnA, 14v). It is represented by cords on AnA, 4v. On AnA, 4 a small muscle is shown extending from the clavicle to a rib. Piumati (AnA) and Holl (1905) identify it as the subclavius; it may be this muscle, but the drawing makes it seem to be on the upper rather than on the under surface of the clavicle.

Of the muscles of the upper arm the biceps, which is termed *il pesce del braccio*, receives the most thorough treatment. It is represented together with other muscles of the arm on AnA, 9v, 13v and 14v; it is figured alone on QII, 19, and in five figures on AnA, 1v the origins and insertions are clearly and correctly shown (fig. 27), as they also are in a sketch on QIII, 9v. Figures showing the origin also occur on AnA, 2, 4v and 14v. Leonardo attributes to it as its main function the supination of the forearm, its action as a flexor manifesting itself only when the supination is complete (AnA, 9v; QIII, 9v). This view of its function is interesting, since it is only in recent years that the supinating action of the biceps has been given the recognition it deserves. Leonardo seems to regard it as the sole agent in supination, apparently overlooking the supinator, through failure to remove the superficial extensors. The origin of the biceps by two heads is naïvely explained by the supposition that it is double above, so that if one head fails the other may act (QIII, 9v; AnA, 11v). The coracobrachialis is represented in a figure on AnA, 4v, but receives no mention in the text. The brachialis is the important flexor of the forearm (QIII, 7v, 9v; AnA, 2, 9v) and is a strong muscle since it must support great weights; its insertion into the ulna (*fucile maggiore*) precludes it from any share in supination (AnA, 2). The triceps is recognized as the extensor of the forearm (AnA, 9v); its insertion is accurately represented, but only two of its heads, the long and the external, are shown (AnA, 2).

The superficial muscles of the forearm are well shown in a number of figures (AnA, 6, 6v, 9v, 12v, 13v, 14v) (fig. 40) but no dissection of the deeper ones, except the pronator quadratus, was made, and special mention in the text is made of only a few. The tendons of the long flexors were, however, dissected out and the palmar muscles were studied. The pronator teres attracted attention as the antagonist of the biceps, it being noted that the latter muscle can not act, that is to say in supination, if the pronator teres keeps its power (QIII, 9v). The pronator quadratus is figured (AnA, 10) (fig. 41) and described as a strong fleshy muscle passing from the radius to the ulna, but in TP, Ch. 218, it is termed a tendon (*corda*); its sole purpose is to keep the two bones from separating. The relation of the tendons of the flexor sublimis and flexor profundus are worked out (AnA, 10) (fig. 41), one figure showing the deep tendons passing to the fingers, another both superficial and deep tendons together with the tendon sheaths, and in a

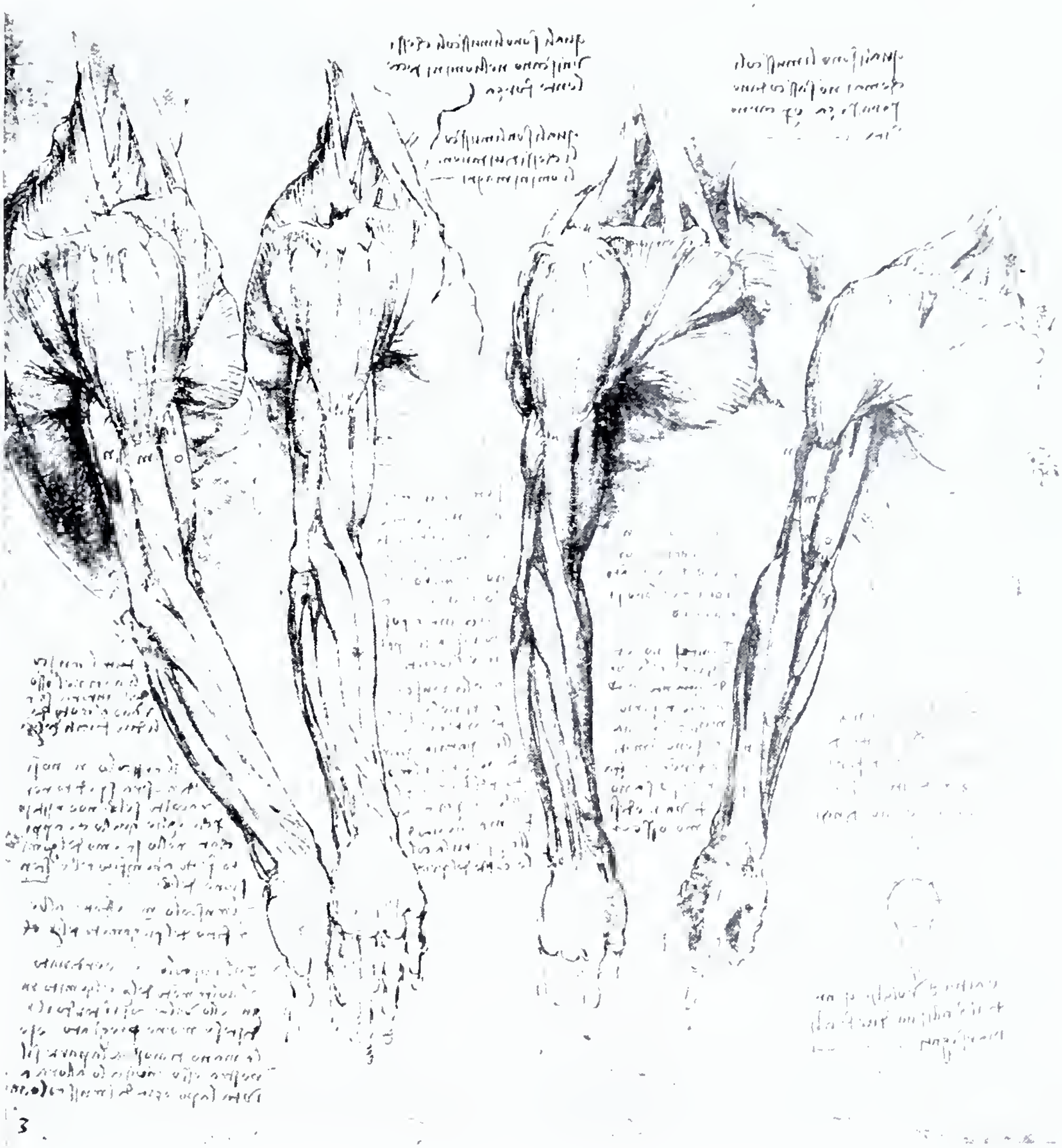

Fig. 40. The muscles of the arm and forearm. (AnA, 9v.)

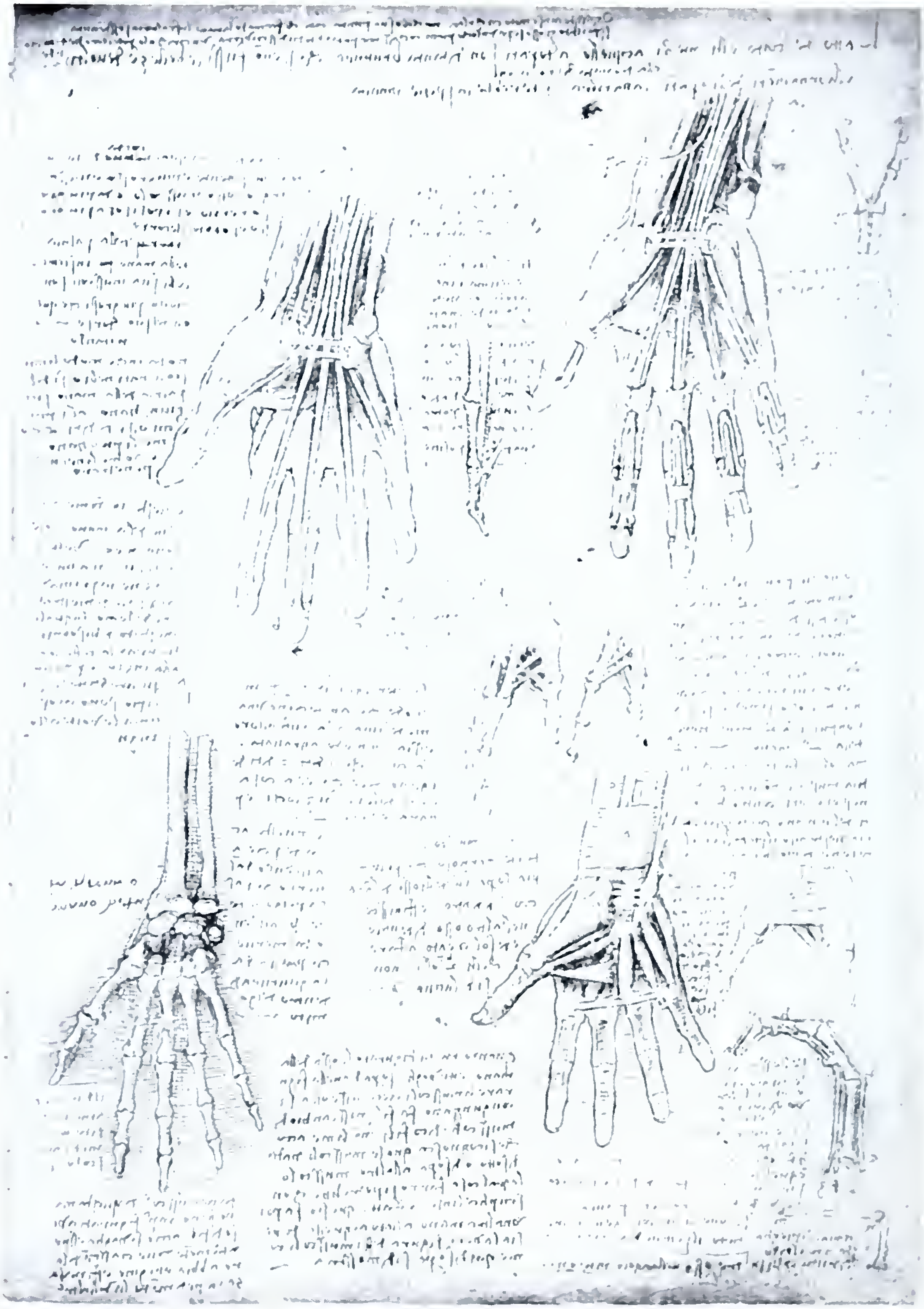

Fig. 41. Dissections of muscles, tendons and ligaments of hand and fingers. (AnA, 10.)

third figure the tendon of the profundus is shown perforating the corresponding one from the sublimis. It is noted that the tendons of the flexors are stronger than those of the extensors and also that the long flexors are able to flex the middle and terminal phalanges; it is queried, without an answer, as to how the flexion of the basal phalanx is brought about.

In the dissection showing the long flexor tendons in place (fig. 41) the lumbricales are shown, and in addition there is on the same folio a representation of a dissection of the palmar region in which the long tendons and lumbricales have been removed, so that the deep muscles, as well as those of the thenar and hypothenar eminences, are shown. Unfortunately no mention of any of these muscles is made in the text; Leonardo makes a memorandum that they are to be represented as cords in order that their relations and action may be readily seen, but apparently this illustration was never made.

As with those of the arm, the muscles of the lower limb are shown chiefly as surface modeling (fig. 12) or in *scorticati*, comparatively little dissection being done upon them. Indeed, if one may judge from what Mondino says, the limbs received very scant treatment in the "Anatomies," and it is all the more to Leonardo's credit that he should have considered them as fully as he did. Admirable representations of the muscles of the lower limb from the front are given on AnA, 3, 7, 15, 15v and on QV, 3 and 23; from the side on AnA, 9, 11v, 15v (fig. 36), and from both the side and back on AnB, 19, 19v; QV, 3 and 22. Figures in which certain of the muscles are represented by cords are given on QV, 4 (fig. 11). It will be recalled, also, that it is in connection with the lower limb that Leonardo suggests the possibility of studying anatomy by means of sections, giving representations of the surface of certain sections (QV, 19 and 20) (fig. 10). Two of these, one from the thigh and the other from the crus, have the different muscles labeled with letters, but unfortunately no text accompanies the figures. The outlines of the muscles shown are not quite accurate; in the thigh section the vastus medialis and intermedius, together with the rectus tendon, are unlabeled and the semimembranosus and semitendinosus are not separated, while in the crural section the soleus is represented as three muscles and no separate tibialis posterior and flexor longus hallucis are shown. The figures are more interesting as suggesting the possibilities that lie in the method of study, than as exact anatomical illustrations.

The glutei are noted as being the largest and most powerful muscles, whose strength is shown in the lifting of weights (AnA, 6v), but only the maximus and medius are shown, the former labeled as if two separate muscles (AnA, 15v). The tensor fasciæ latæ (fig. 36) is also shown and is figured separately, rather diagrammatically however; it is said to connect with the vastus lateralis below (AnA, 15) and also with the ligament that binds the knee, *i.e.* the ilio-tibial band. No dissection of the deeper portions of the gluteal region is shown and hence the gluteus minimus and other muscles of this region receive no recognition. The tensor fasciæ latæ and sartorius act in drawing the thigh forward (AnA, 15v) and also in effecting abduction and adduction (AnB, 18), and when they contract the gluteus maximus relaxes and the medius elongates; furthermore the tensor is said to produce an internal rotation and the sartorius an external (QV, 4). The glutei and the other two muscles are represented by a string figure on QV, 22.

The rectus femoris and the vasti are shown in the front views of the thigh, and on AnA, 9 it is stated that the patella is in relation to the rectus, here termed *pesce di coscia*, to the muscles on either side of this, *i.e.* to the vasti, and to the patellar tendon that is attached to the tibia. The sartorius is well shown on AnB, 20, in a leg flexed at the knee. On QV, 15 is a representation of a dissection in which the rectus and sartorius have been removed, exposing the vastus medialis and intermedius, and a memorandum suggests the removal of the tensor fasciæ latæ to see what lies below it, but there is no indication that this idea was carried out. Curiously, there is no satisfactory figure of the hamstring muscles; apparently their relations were not understood, for on AnA, 9 the bones of the leg are shown both extended and flexed, with two cords attached, the one to the condyle of the tibia and the other to the head of the fibula. They might be supposed to represent the semimembranosus and the biceps, but the one is attached above to the lesser trochanter and the other to the greater one. They are supposed to rotate the crus to one side or the other when the leg is flexed at the knee, but when it is extended they will merely press the tibia more firmly against the condyles of the femur.

The gastrocnemius and tendo Achillis are well shown on QV, 22, and it is noted that the two heads of the gastrocnemius, regarded as separate muscles, and the soleus, also regarded as two muscles, unite to be attached to the tendo Achillis (AnA, 11), and Leonardo inquires why Nature did not make of them a single muscle, but does not answer the inquiry. The conjoint muscle is regarded as that which draws the heel upward and so raises the body upon the toes, and he calculates that when the body is so raised one half its weight is borne by the balls of the toes and one half by the muscle in contraction (AnA, 9 and 11v).

The deep muscles of the calf were not exposed, but their tendons as they pass behind the internal malleolus are well shown (AnA, 11 and 11v) (fig. 42) as well as the distribution to the digits of the flexor longus hallucis and flexor longus digitorum, the connection between the former and the tibial tendon of the latter being emphasized. Similarly, only the superficial muscles of the extensor surface of the crus are shown, but the tendons of all are shown. In AnA, 7v the tendons of the three peronei are seen in one figure and in two others the tendon of the

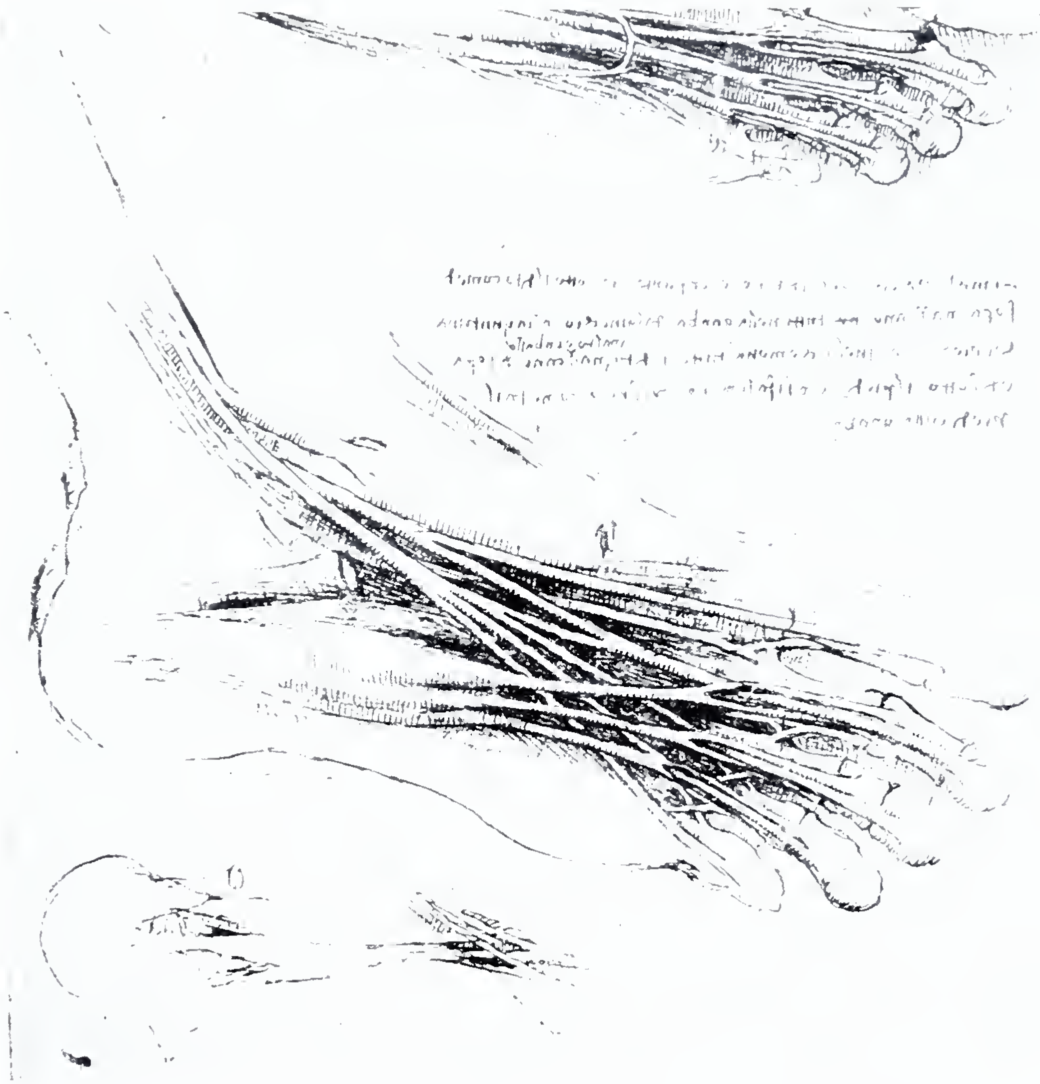

Fig. 42. The muscles and tendons of the sole of the foot. (AnA, 11.)

peroneus longus is seen passing obliquely across the sole of the foot to be inserted in the base of the first metatarsal. The insertion of the tibialis anterior is shown on AnA, 11v, and on AnB, 28, there is an excellent drawing, also showing the tendon of this muscle together with those of the extensor longus hallucis and extensor longus digitorum. On AnA, 17 the tendons of the last-named muscles and that of the peroneus tertius are well shown, and they are represented even more admirably on AnA, 18, the extensor brevis digitorum being also accurately shown.

Leonardo quotes from Mondino, wrongly attributing the statement, however, to Avicenna (AnA, 18), that the muscles of the foot are sixty in number. He does not endeavor to confirm this statement, however, and his dissection of the plantar region is less complete than that of the palmar. He figures the abductor minimi digiti and the flexor brevis digitorum, showing the latter, however, with only three tendons, that to the fifth digit being overlooked (AnA, 11). Of the deeper muscles he shows the flexor brevis hallucis, drawing special attention to its relation to the sesamoid bones, here termed *ossi petrosi* (AnA, 7v), but fails to observe the adductor hallucis. The flexor brevis and abductor minimi digiti are indicated as are also the plantar interossei and what may be two of the lumbricals (AnA, 7v), but the quadratus plantæ seems to have escaped observation.

On AnA, 17, he attributes to Mondino a statement to the effect that the muscles that dorsiflex the digits arise from the outer side of the thigh. As Roth (1907) has pointed out he was probably relying upon an imperfect text or upon his recollection of Mondino's words which are to the effect that the tendons that extend the digits arise from muscles that are in the outer part of the tibia (*i.e.* crus), they can not be located on the dorsal surface of the foot since this region should be without muscles, lest it increase the weight of the foot. His erroneous recollection of Mondino's words seems to have impressed him, since he returns to the idea in two other passages (AnA, 11, and AnB, 20), pointing out that the thigh muscles act on the crus, the foot as a whole is moved by the muscles of the crus and the digits partly by the muscles of the crus and partly by those of the foot. The last portion of this statement he expands (AnA, 11) by stating that the terminal phalanges are moved by muscles that arise in the crus, but the muscles that produce movement of the whole digits have their origin in the foot; he extends this law also to the upper limb, forgetting that the flexor sublimis is a muscle of the forearm.

Mention should be made of Leonardo's analysis of the movements made in ascending a flight of stairs (AnB, 21v), although these are of more interest to the artist than to the anatomist, no mention being made of the muscles concerned. He gives two figures representing a man in the act of mounting a step, one being a representation from in front and the other from the side, and in each the axis of equilibrium is shown and it is demonstrated that in shifting the weight to the upper foot the body must be bent forward and to the side in order that the equilibrium may be properly maintained. It is not a very important matter, but it is pertinent in illustrating Leonardo's penchant for mechanics and his endeavors to apply the principles of that science to the correct representation of the human body.

In the above account of Leonardo's contributions to myology it may be that the omissions and inaccuracies that have been noted may obscure the real merits of his work, which are great. It must be remembered that his manuscripts are for the most part merely notes, intended to serve as a basis for a work that was never completed. Indeed the notes themselves are manifestly incomplete, as is shown by the frequency of queries and memoranda scattered through them, queries that remained unanswered and memoranda for future observations that were never made. And Leonardo recognized their incompleteness, for in one passage he abruptly breaks off a discussion with the words "but since I have not yet completed these observations (*tal discorso*) I shall leave them for the present and this winter of 1510 I hope to finish all this anatomy" (An.A, 17). Furthermore, the work of four centuries ago can not with justice be judged by the standards of today; its worth is to be estimated by comparison with the available knowledge and, when this is done, Leonardo's myology constitutes a remarkable achievement, which becomes all the more remarkable when one considers the difficulties with which he had to contend and the multiplicity of his other interests. But with all this it must be emphasized that it is his illustrations that command our highest admiration, executed as they are with the comprehension, observation and skill of a great artist. They alone mark him as one of the World's great anatomists.

CHAPTER XII

THE HEART

The Arabistic idea as to the structure of the heart prevalent in Leonardo's day was to the effect that it was composed of three ventricles, two larger ones and one which is in the middle, as it were, and serves as—

"a receptacle for nutriment in which is produced a strong condensation similar to the substance of the heart itself and as a storehouse for the spiritus generated in it by the subtle blood. And between the two are passages like openings."

Such are the words of Avicenna as translated from the Latin version of Gerard of Cremona. This median ventricle is a myth, probably having its origin in an attempt by Avicenna to harmonize the descriptions of Aristotle and Galen. The former recognized three ventricles, two of which undoubtedly correspond to what we now term the right and left ventricles, while the third was probably the left atrium, the right atrium being regarded merely as a portion of the vena cava, this vessel, therefore, opening directly into the right ventricle. Galen on the other hand admitted only two ventricles, and the atria were regarded as of minor importance, practically as portions of the vena cava and pulmonary veins respectively, but the septum between the ventricles was supposed to be perforated by minute pores through which some of the blood in the right ventricle could pass into the left.

Avicenna followed Galen in giving the atria a subordinate importance, speaking of them as ear-like, sinewy, rugose attachments of the ventricles, but felt bound to recognize Aristotle's authority in the matter of the ventricles and consequently magnified Galen's septal pores into a third median cavity. Thus it was, apparently, that the misconception of the third ventricle became established in mediaeval anatomy. Mondino follows Avicenna fairly closely, disregarding the atria completely, but stating that the third or median ventricle is not a single cavity but many, thus making it undoubtedly equivalent to Galen's pores. In one of the editions of Mondino, that published at Strassburg in 1513, the editor, Iohannes Adelphus, adds as a commentary to the description of the heart a diagrammatic representation of the organ, in which he endeavors to picture Avicenna's idea (fig. 43). The atria are omitted and the third ventricle is obtrusively shown. Openings *a*, *b*, *c* and *d* in the walls of the major ventricle represent respectively those for the aorta, pulmonary vein, *i.e.*, the left atrium, pulmonary artery and vena cava, *i.e.* the right atrium, while groups of small circles represent the valves guarding the adjacent openings.

In its finer structure Galen considered the heart to be composed of fibers arranged longitudinally, transversely and obliquely, but these fibers were not muscular, though they greatly resemble muscle fibers.

Argumentū rei cum interpre tatione Jo. Adelphi.

A ¶ Artarie adorti p quā mit tit cor spm̄ ad oīa corpis mē bra qñ ꝯstringit. Eī hostiola claudunt pfecta clausiōe ab extra ad intus/ ⁊ aperiuntur econuerso.

B ¶ Artarie venalis portātis vapore a corde ad pulmonē et attrahentis aerem a pulmone ad cor. Cuius hostiola im perfecte claudunt/ hñs tunicā vnicā/ qr natura par sollici ta est de eo quod per ipsum transit.

C ¶ Vene chilis/ per eius orificiū trahit cor sanguinē ab epate/ ⁊ mādat ad oīa mēbra. Claudit hora expulsionis ⁊ apert hora dilatatōis. Eius hostiola aperiunt ab extra ad intus/ ⁊ imperfecte clauduntur.

D ¶ Vene arterialis que portat sanguinē ad pulmonem a corde: arterialē scz. Quaꝝ tunicaꝝ ꝓpter accessuz ei ad membꝝ ꝯtinui motus. Et qr portat sanguinē colericū val de subtilē: eius hostiola aperiunt ab intus ad extra/ ⁊ clau dunt ecōuerso perfecte. Per hoc orificiū cor tm̄ a se expellit hora ꝯstrictōis/ ⁊ nihil retinet hora dilatatōis. Hoꝝ duoꝝ arterie venalis ⁊ vene arterialis/ ꝯtrariū hꝫ Galie. viij. de vtilitate pticulariū. ix. ca. Et de iuuamētis mēbroꝝ. vij. c. vt dt Gentilis li. xxxv. cap. primo.

Fig. 43. Diagram of structure of heart in Ioannes Adelphus' edition of Mondino's *Anathomia* (Strassburg, 1513). After C. Singer, *Fascicula di medicina*, vol. 1, fig. 59, 1925.

He regarded the muscles as being organs of voluntary motion, but the contraction of the heart was involuntary; furthermore, it was rhythmical and continuous, and its tissue differed from muscle in its firmness, in the threefold arrangement of its fibers, in its color and in its taste. It was therefore not muscle, but a tissue *sui generis*. Avicenna adopted these views in their entirety, claiming that those were wrong who regarded the heart as muscular. His object was an abstract of Galen's teaching and consequently he omits the arguments upon which this conclusion rests, but he calls attention to the firm, almost cartilaginous, tissue at the base of the ventricles. Mondino omits all reference to the minuter structure of the heart.

Physiologically the mediaeval conception of the heart was essentially that of Galen, whose ideas may be thus summarized. The heart was endowed with a pulsative faculty which acted through the fibers of which it was composed, the longitudinal fibers by their contraction broadening the organ and so producing the condition of diastole, during which blood was attracted to the ventricles, while the transverse or circular fibers elongated it and produced systole, expelling the contents. The oblique fibers were retentive in function, producing the condition of peristole, during the occurrence of which the heart was utilizing the material that had been attracted. The blood, concocted in the liver, was carried to the right ventricle by the vena cava and also to the various organs of the body, supplying them with nourishment, the pulmonary artery serving to carry nourishing blood to the lungs and also certain fuliginous vapors, engendered in the heart by the innate heat, which had its center in that organ. Some of the blood contained in the right ventricle passed through the pores of the ventricular septum and in the left ventricle mingled with the pneuma, which, manufactured from the air inspired by the lungs, is conveyed to the left ventricle by the pulmonary veins. The blood of the left ventricle with its contained pneuma or spiritus is thence distributed to the body by the aorta, carrying to the various organs the energy necessary for the performance of their functions. There could be no question of a circulation of the blood with such a theory. So far as its function was concerned the venous blood was quite distinct from the arterial, and while the two might intermingle through the pores of the ventricular septum or through anastomoses, which Galen supposed occurred in the organs, the blood in both veins and arteries merely underwent an ebb and flow, a flux and reflux from and to the right and left ventricles.

These were the views that Leonardo had to guide his observations and our task now is to ascertain how far he was governed by them or how far on the basis of his own observations he was able to modify or discard them. The heart was evidently one of the organs whose mechanism especially interested him and his admiration for its efficiency led him to write beneath one of his illustrations of it—a very imperfect illustration at that—the words "Wonderful instrument invented by the Supreme Master" (AnB, 12). Many pages are devoted to illustrations of its structure, indeed the majority of those that have been assembled in QII are concerned either with its structure or action, and the text on several pages is arranged in paragraphs with headings, as if intended for incorporation in the prospective book. Many of his observations were undoubtedly made upon the hearts of animals, probably those of bullocks for the most part, though an observation on a pig's heart is also recorded (QI, 6). His figures show the form of the heart, both isolated and in place, and the internal structure of the ventricles is represented by dissections and both longitudinal and transverse sections.

Special methods, suggested as possible aids in studying the movements of the heart and blood, have already been mentioned in Chapter VII (p. 90, *et seq.*).

The location of the heart is stated to be midway between the brain and the testicles (QIII, 10v). Usually it is represented in an oblique position, inclining downward and to the left; only in a few cases in which it is shown (fig. 44) isolated is it given a vertical position (QII, 1, 2, 3v for example). It is suspended from the middle of its base by the two blood-vessels, the inferior vena cava and aorta (QII, 17), and throws itself toward the left side and is then suspended by the left vessel (QII, 15); its obliquity is explained on the Galenic principle of the arrangement of the organs so that there will be a proper adjustment of weight on either side of the middle line. The liver lies chiefly upon the right side and its weight is counterbalanced by the heart and spleen on the left; part of the heart is, indeed, to the right of the midline, but this is counterbalanced by the greater weight of the stomach being to the left (QII, 15). In another passage (QII, 17v) the obliquity is directly ascribed to the greater weight of the right ventricle, this ventricle containing more blood than the left and on the verso of the same folio it is argued that the greater thickness of the wall of the left ventricle is not a provision for counterbalancing the greater weight of the right, since such counterbalancing is unnecessary in four-footed animals and in man when lying down. But, Leonardo enquires, how is it with the bat who sleeps suspended upside down?

The position of the apex of the heart is supposed to be somewhat higher in the cadaver than it is in the living body, since, at death the heart enlarges and shortens, because its transverse muscles relax and the longitudinal ones contract (QI, 4v). Leonardo does not take into consideration the weight of the liver in the recumbent cadaver pressing upon the diaphragm, now devoid of tone, and so forcing the thoracic organs to a slightly higher level. The conclusion, however, that the heart is a little shorter and therefore a little higher in the cadaver is borne out by certain interesting observations made on pigs (see p. 91).

It is noteworthy that neither in his figures nor his text does Leonardo take definite cognizance of the atria of the heart. He figures in some cases (QII, 3v, 4) the auricles (fig. 44) and speaks of them in various passages as *orecchi* or *additamenti del core,* this latter term recalling

Fig. 44. Two figures of the heart. (QII, 3v.)

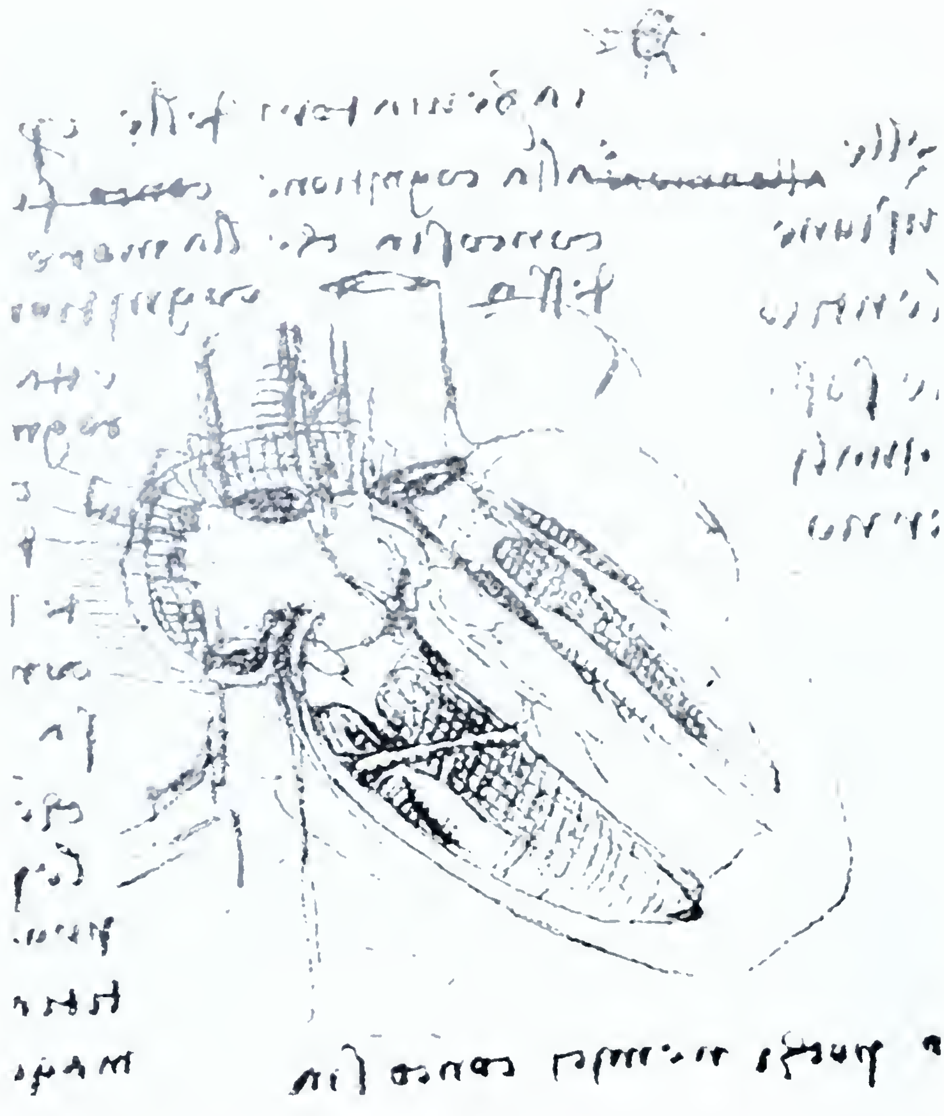

Fig. 45. Dissection of the heart showing papillary muscles and a moderator band. (QII, 14.)

their Avicennian description; but of the more important atria never a word. As a consequence, in endeavoring to interpret his idea of the structure and action of the heart one is confronted with the alternatives, did his *orecchi* include the atria as well as the auricular appendages, or were the atria for him, as for Galen, merely the basal portions of the venæ cavæ and pulmonary veins? Some of his illustrations incline one toward the latter view, especially those on QV, 1; QIV, 7 (fig. 45) and QIII, 10v, in which the venæ cavæ seem to unite to open directly into the right ventricle, while the left pulmonary veins open directly into the left ventricle, those from the right lung uniting with the venæ cavæ. Furthermore in speaking of the passage of blood from the liver, the source of the blood, to the heart, he describes it as passing directly to the right ventricle; indeed, with Leonardo's views as to the movement of the blood, he could hardly describe it otherwise. The figures mentioned above probably belong to the earlier period of his anatomical studies and, as such, should not be taken as representing accurately his final views; it is noteworthy that in these figures not even the auricles are shown.

But in looking through the folios one finds evidence pointing strongly to the first alternative. His theory of the movement of the blood calls for somewhat capacious atrial cavities, since they must be able to accomodate a considerable portion of the blood expelled from the ventricles during their contraction. As soon as he had conceived this idea he began to represent the auricles as circular or spherical cavities, situated upon the base of the ventricles and communicating with them by the atrioventricular openings as in QI, 3, 3v, and QII, 17, while on QII, 14 (fig. 45) he shows the two venæ cavæ opening into the auricle. Unfortunately the text on the page which shows this last figure, the nearest approach to accuracy in the representation of the atrium, contains no reference to the figure and nothing anatomical; it is a eulogy of mathematics and a tirade against human folly. The auricles having thus gained some importance, Leonardo proceeds to exalt them still higher, speaking of them as ventricles, maintaining that the heart has four ventricles, two upper ones which are the auricles of the heart and two lower which are called the right and left ventricles (QII, 17v).[1] In another passage essentially the same statement is made and supported by arguments against supposed objections, the lower ventricles being now described as being in the substance of the heart, while the upper ones are outside it (QI, 3). It seems clear from these passages and figures that Leonardo's auricles or upper ventricles included both the auricles and atria as now recognized, and this identification is confirmed by QII, 11, on which is recorded an observation of a patent fora-

[1] In passing it may be noted that Holl's (1913) suggestion that Leonardo was the first to apply the term ventricles (*ventricholi*) to the lower chambers of the heart can not be accepted.

men ovale, placing the right *orecchio* in communication with the left, and a memorandum is made to see whether it is the same in the *orecchi* of other hearts. The accompanying figure shows that Leonardo had observed the atrial septum and therefore the atria, but under the influence of Avicenna these were regarded as of less importance than the auricles, whose irregular inner surfaces are indicated in all the representations given by Leonardo of his upper ventricles. As will be seen later, these rough and irregular surfaces were essential to his ideas of what took place in the heart.

The upper ventricles or *orecchi*, using Leonardo's term for them to avoid confusion, possess dilatable and contractile walls (QII, 3, 3v) composed of muscle and fleshy membrane (QI, 3). All the ventricles are muscular, but in the extrinsic[2] ones, *i.e.* the *orecchi*, the muscles of the walls form a continuous coating (QII, 3v) in which, it is supposed there are both transverse and oblique muscles (QI, 4), although no fibers are visible. This absence of fibers permits the walls to readily extend lengthwise (QI, 3). The interior of the *orecchi* (QI, 4v) is described as being cellular (QI, 4; QIV, 13v), the cells being evidently what are elsewhere termed the cavernous depressions between the muscles that contract the *orecchi* (QI, 4v), that is to say between the mm. pectinati. These are not described in detail, but they are said to be of the same nature as the mm. papillares of the ventricles (QII, 3v).

Of the two ventricles, *i.e.* Leonardo's lower or intrinsic ventricles, the right is said to be larger (QI, 3) and heavier than the left (QII, 17v), its greater weight being due to the greater amount of blood contained in it (QI, 3v; QII, 17). Its length, however, is only three-quarters that of the entire heart (QII, 3v), a statement which may be interpreted to mean that Leonardo recognized the fact that the apex of the heart is formed entirely by the left ventricle. He notes the greater thickness of the wall of the left ventricle (QII, 11, 17) and represents it in figures of transverse sections through the ventricles (QII, 4v). Judging from a passage on AnB, 33, he regarded this greater thickness as a provision whereby the greater heat of the blood in the left ventricle might be resisted; he disputes the possibility of its being intended as a counterpoise for the greater weight of the right ventricle (see p. 152). It is stated that the right ventricle at its base has only one-quarter the thickness it has at the apex (QII, 3v).

The muscle fibers of the ventricular walls are arranged in the longitudinal, transverse and oblique directions, the longitudinal, in accordance with ancient tradition, serving the attractive faculty of the ventricles by causing their dilation, while the transverse and oblique contract the ventricles and therefore subserve the expulsive faculty. The columnæ carneæ on the inner surfaces of the ventricles are indi-

[2] This term is borrowed from Mondino who describes the auricles as extrinsic and the ventricles as intrinsic parts of the heart.

cated in a figure on AnB, 12, and the papillary muscles, together with the chordæ tendineæ that are attached to them, are frequently figured and mentioned (fig. 47). The papillary muscles are grouped with the mm. pectinati as *musscholi intrinsici* to distinguish them from the musculature of the walls, *musscholi estrinsici* (QII, 3v)[3] and usually but a single papillary muscle is shown in the right ventricle, the smaller ones being disregarded, and two in the left ventricle (QII, 14, 23, 10), but sometimes five or six are represented in the right ventricle (QII, 12) and three or four in the left (QIV, 14). They are described as being very hard, almost like cartilage (QII, 12), and in one note they are described as "the first cause of the motion of the heart" (AnB, 12) and in another it is stated that by their great density they prevent the complete closure of the ventricles during contraction and so afford space in the left ventricle for the blood that passes to it from the right ventricle during systole (QII, 4v). But Leonardo's chief interest in the papillary muscles was in connection with their action on the atrio-ventricular valves through the chordæ tendineæ. These he notes are attached to the under surfaces of the valves (QII, 3, 8v). The effect had by the papillary muscles upon the valves is, however, stated somewhat obscurely and at first reading his statements seem to imply that he supposed the chordæ to push the valves together, an idea absolutely contradictory to his axiom that it is the function of muscles to pull not to push (AnB, 29). Comparison of several passages dealing with the matter serves to explain Leonardo's idea without violation of his axiom. When a papillary muscle contracts it shortens, drawing its ends toward its middle (QII, 23);[4] consequently, when contracted, the action of the papillary muscles would be to draw the valves down into the ventricular cavities and so open the orifice which they guard. But the valves close during the systole of the ventricles and therefore the papillary muscles can not be contracted at that period of the heart's cycle, but must alternate in their contraction with that of the ventricular walls. When the ventricles contract the papillary muscles relax and elongate, allowing the impetus of the blood to bring the valve cusps into contact with one another, and when the ventricles dilate the papillary muscles contract and the atrio-ventricular orifices are opened (QII, 17, 17v, 23). A pretty theory when the available evidence is taken into consideration, but, unfortunately for it, the present-day evidence indicates a simultaneous contraction of the papillary muscles and the muscles of the ventricular walls.

[3] Holl (1913) is in error when he interprets these terms as applying to the musculature of the ventricles and atria respectively. True, Leonardo speaks of these chambers as *ventricholo intrinsico* and *v. estrinsico*, but in applying these terms to the muscles he clearly means by *intrinsici* the papillary and pectinate muscles, as distinguished from those of the heart walls.

[4] It was perhaps this idea that led Leonardo to represent a papillary muscle with chordæ at either extremity as on AnB, 12.

To complete his theory as to the movement of the blood, Galen found it necessary to assume direct communication between the right and left sides of the heart, and consequently taught that the septum of the ventricles was perforated by minute pores through which the blood might pass. Coming down to mediaeval times with all the authority of Galen behind it, this idea was blindly accepted and even Leonardo succumbed to it, letting theory master observation. Again and again he speaks of these pores (QI 3, 4, 4v; QII, 12, 17v; QIV, 11) and in two passages (QII, 4v, 10) bestows upon the septum the term "sieve (*cholatorio*) of the heart." And not only so, but on QII, 3, he represents a portion of the septum, showing its irregular surface and, on the cut edge of it, pores that do not exist! But while in this instance Leonardo allowed tradition to master observation, the latter led him to the discovery of the moderator bands now recognized as important structures in the distribution to the ventricular musculature of the contractile stimulus. On QII, 11, 17v; and QIV, 13 (fig. 45), he shows the band of the right ventricle, probably that of a bullock's heart, extending across the cavity of the ventricle from the septum to the outer wall at about one-quarter the distance from the base of the heart to its apex (QIV, 13). In other figures a greater number of bands are shown schematically (QIV, 7; and QIII, 10v), as many as three in the right and five in the left ventricle (fig. 46). Leonardo speaks of the band as the *catena* (QIV, 13)[5] and suggests that the action of the bands is to prevent over-dilation of the ventricles, whereby they would attract to themselves too much blood and so become overheated (QII, 4v).

Leonardo gives two representations (QII, 10; and QIV, 14) of the base of the heart with the atria and great vessels removed, both of them decidedly diagrammatic (fig. 47). The aortic and pulmonary orifices are shown, both guarded by their semilunar valves, and in the figure on QII, 10, the atrio-ventricular openings are also shown, with the valves that close them. On QIV, 14, however, while the atrio-ventricular orifices are shown, their valves are not clearly represented. It is evident that Leonardo recognized all four orifices of the base, the right atrio-ventricular and that for the pulmonary artery (arteria venalis) opening into or from the right ventricle and the left atrio-ventricular and the aorta (arteria aorta) opening into or from the left ventricle. Some discussion has been aroused as to the correctness of Leonardo's identification of these orifices, or rather as to the interpretation of a statement on QII, 2v, in which it is said that—

> "The right ventricle has two orifices, one for the vena aorta. . . The other orifice is for the arteria venalis and leads from the heart to the lungs."

[5] Holl (1912) has suggested that the bands be called the Leonardo da Vinci muscle trabeculæ in honor of their discoverer.

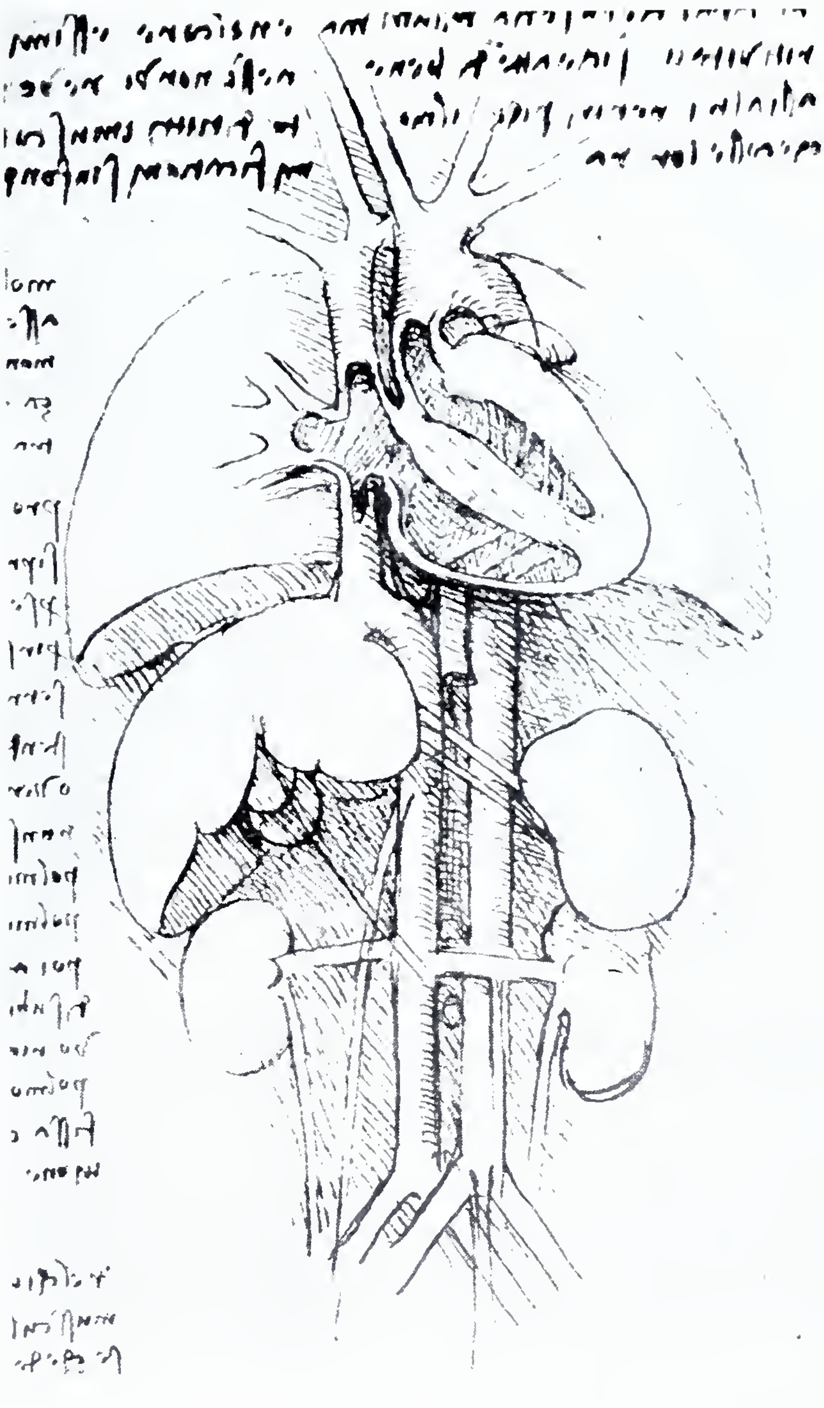

Fig. 46. The thoracic and abdominal viscera, the heart dissected and showing several moderator bands in each ventricle. (QIV, 7.)

Fig. 47. Sketches of base of heart and of papillary muscles and chordæ tendineæ of left ventricle. (QIV, 14.)

The Editors of the Quaderni interpreted "vena aorta" to be a *lapsus calami* for vena arterialis (pulmonary artery), an interpretation which made the passage imply that both the pulmonary artery and the pulmonary vein (arteria venalis) opened into or from the right ventricle. This was pointed out by Boruttau (1913), who maintained that by "vena aorta" Leonardo really meant the aorta and that he was speaking of the left ventricle and not the right. The Editors of the Quaderni suggest that since there is a gap in the passage, as if there had been some interruption in the writing of it, it is possible that Leonardo started to speak of the right ventricle, but on resuming his writing after the interruption forgot this and went on to speak of the left ventricle. This suggestion is ingenious, but Boruttau's explanation seems more probable, since Leonardo in more than one other passage confuses right and left, an error, as Boruttau points out, to which his habit of looking-glass writing may have made him especially prone. As to the difficulty in the way of identifying the arteria venalis with the pulmonary veins, Leonardo's disregard of the atria may be recalled, the left atrium being regarded as part of the pulmonary veins.

The valves that guard the orifices of the heart had long been known and their use determined, and they forcibly attracted Leonardo's attention, many folios containing memoranda in pen and pencil concerning their form and structure and especially their action. He terms them *usscioli* or *pannichuli*, sometimes *porte*, although it is not always possible to determine whether by this last term he meant the valves themselves or the openings they guarded. It is curious that in considering the atrio-ventricular valves he almost entirely neglects the mitrals and, on the other hand, it is the aortic semilunars upon which he concentrates his attention. The mitral valves are shown closing the left atrio-ventricular orifice in two figures (fig. 47) on QII, 10, and probably in another on QII, 11, but no mention is made of them in the text. In the figures the intermediate cusps are almost as large as the main ones, a condition that may be partly explained by the valves being seen from above, closed, and partly on the supposition that the drawings were made from a bullock's heart.

Of the tricuspid valve the account is much fuller. It is shown closed (fig. 48), from above and below (QII, 8v), and the same page shows its three cusps spread out flat with their papillary muscles and chordæ. These papillary muscles are shown alternating with the cusps and sending chordæ tendineæ to both the adjacent cusps; this does not agree with the arrangement in the human heart, where there is usually one large principal muscle and one or two smaller, and again it may be supposed that the preparation was made from an animal heart. With regard to the structure of the valves, Leonardo makes statements (QII, 3, 8v) which are difficult to understand. He says that each papillary muscle is divided into two muscles which are continuously in contact, and then each of these divided into its branches, composed of *chorde nervose* covered by very delicate flesh (*sottilissima charnosità*), and finally becomes converted into a *pannichulo nervoso*, also covered by flesh. It would seem that by his *sottilissima charnosità* Leonardo meant the endocardium. Then he goes on to say—

"But just as the muscles whence they arise cover each other, so too do the *chorde* and *pannichuli*. But their movements in drawing the chorde and extending the pannichuli are not equal, since the superior membranes (*pannichuli*) have more movement than the inferior, because in extending they cover in great part the inferior chordæ, before that they form their pannichulo; and this the inventor has done, for the cause shown in the figure above, which shows that this author does nothing superfluous or defective."

All this is very difficult, nor does the figure referred to help in understanding it, but it apparently leads to the conclusion (QII, 8v) that the valves of the right ventricle are not entirely double, since this would necessitate their having their thickness where this would be unnecessary, and where it was necessary only a double thickness. "In this case Nature would fail in its law."

The semilunar valves are shown in position in the pulmonary aorta on QII, 3v (fig. 44), and in both arteries on QII, 10 (fig. 47); they are shown separately, both open and shut, on QII, 4; from both above and below on QII 9v; and from above and open on QIV, 12. This last figure is interesting because it shows the walls of the aorta bowed out opposite each valve to form what are now termed the sinuses of Valsalva, to which Leonardo assigned great importance in connection with the mechanism of the closure of the aortic opening. In discussing this he frequently speaks of the hemicycles (QII, 13v; QI, 11, 11v, 12v) or semiventricles (QIV, 11v), meaning thereby the hemispheres formed by the individual valves together with their respective sinuses. Holl (1913) identifies the hemicycles with the valves alone, but the identification given above is to be preferred, since in one passage (QIV, 11) Leonardo states that the tissue of the wall of the heart where the three semilunar cusps are attached swells when the left ventricle dilates, and in another passage he locates this swelling tissue in the base of the hemicycles.

"Very powerful is the heart in its dilation, and it would be apt to draw the valves backward, were it not that the base of the hemicycles dilates itself like the flesh of the tongue." (QII, 13v.)

So confident is he of the swelling of this tissue and its ability to prevent regurgitation of blood from the aorta, that he questions whether Nature might not have done without the valves, and relied solely on this swelling (QIV, 11), forgetting for the time his law that Nature never makes anything superfluous.

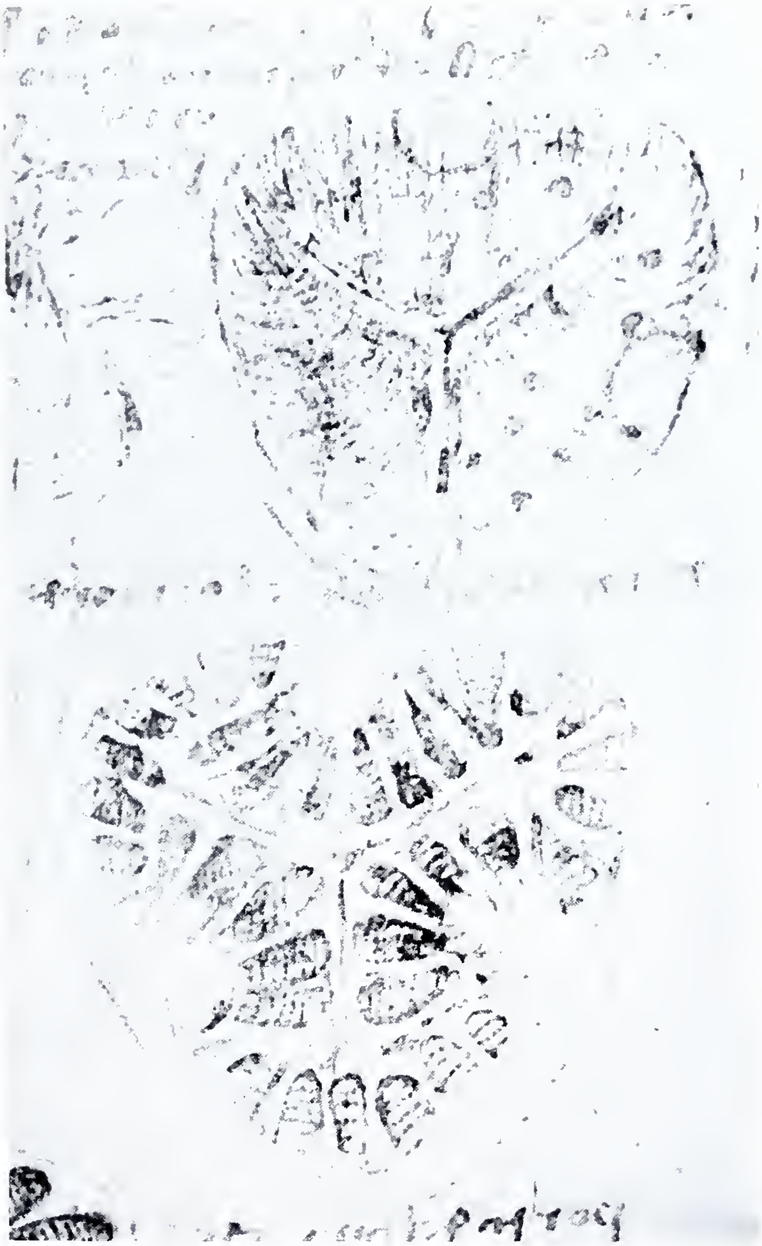

Fig. 48. Tricuspid valve from above and from below, showing attachments of chordæ tendineæ. (QII, 8v.)

On QIV, 14v, in connection with a figure representing the base of the heart with the atria and great vessels removed, it is stated that the base has a somewhat triangular outline, and that the angles between the cusps of the aortic semilunars are opposite the angles of the base, and the cusps themselves are opposite the surfaces of the heart. Leonardo discusses the question why there should be three semilunars instead of four (QIV, 12) and endeavors to show mathematically that in vessels of a given circumference three triangular cusps will have greater strength than four quadrate ones. The embryological explanation, deriving the semilunars from a four-cusped valve in the aortic trunk, the longitudinal division of the trunk to give rise to the basal portions of the aorta and pulmonary artery dividing each of the lateral cusps into two and so giving three cusps to each of the arteries, was not discovered until long after Leonardo's time.

So much for Leonardo's knowledge of the gross structure of the heart; a statement as to his ideas concerning its minuter structure is now called for. On QII, 23 he enumerates the various elements or, as we should call them, tissues that enter into the composition of the heart, illustrating the occurrence of each in a diagram. The tissues mentioned are bone, cartilage, membrane (*paniculo*), nerve (*i.e.* tendon), muscle and nerve; each of these may be considered in turn, and first as to bone. He represents it on QII, 10, as an elongated plate in the vicinity of the left atrio-ventricular orifice. It is well known that normally no bone occurs in the human heart, but an *os cordis* does occur in many of the larger mammals, the ox, for example, in the fibrous tissue (*trigonum fibrosum*) at the base of the heart between the two atrio-ventricular orifices. Leonardo's mention of it is, accordingly, further evidence that he based his account of the heart largely upon the study of bullocks' hearts. It is evident from his diagram that by cartilage he meant the dense fibrous rings that surround the openings at the base of the heart, by *paniculo*, the membrane forming the valves; and by *nervi*, the chordæ tendineæ.

It has been pointed out that Galen regarded the main substance of the heart as something different from muscle, as something *sui generis*, and that this view was accepted by Avicenna. Leonardo discards this idea completely and consistently regards the heart as a muscular organ, its fibers in action obeying the same laws as other muscles.

> "The heart in itself" he says "is not the beginning of life, but it is a vessel made of dense muscle, vivified and nourished by the artery and vein, as are the other muscles." (AnB, 33.)

In another passage it is stated that the heart is the strongest of all muscles (G, IV). This was an important step, a long stride, indeed, toward the correct understanding of the physiology of the heart and it naturally led to an inquiry into the nerve supply of the heart, since if it were a muscle it should, like other muscles, receive its stimulus from a nerve. On AnB, 33v Leonardo states that he had traced the left vagus nerve to the pericardium and was inclined to believe it to be the nerve of the heart, and elsewhere (QIV, 7) he makes a memorandum that this matter was to be pursued further, in words that are worthy of quotation. He says—

"Do not abandon the reversive (vagus) nerves until the heart and see if these nerves give movement to the heart or if the heart moves of itself; and if the movement comes from the reversive nerves that have their origin in the brain, then it will be clear to you that the soul (*anima*) has its seat in the ventricles of the brain and the vital spirits have origin in the left ventricle of the heart. And if the movement of the heart springs from itself, then you will say that the seat of the soul is in the heart and similarly that of the vital spirits. Consequently attend well to these reversive nerves and also to the other nerves, since the movement of all the muscles arises from these nerves, which, with their ramifications, penetrate the muscles."

The probability that Leonardo had observed the endocardium, so far at least as it covered the papillary muscles, the chordæ and the atrio-ventricular valves, has already been noted (p. 158).

Of the pericardium, Leonardo gives no representation and in the text it is merely mentioned, without description. It is termed the capsule of the heart (QI, 3v), the case that invests the heart (AnB, 17, 33v). On QI, 3v it is said to contain air, which it receives from the lung, and on AnB, 17, it is stated that the diaphragm—

"pressing upon the pericardium forces up the small amount of fluid (*omore*) that is at the bottom of it and so continuously, by so bathing it, moistens the heated heart and prevents it from being dried up by its so great movement.

In the endeavor to ascertain Leonardo's ideas as to the movement of the blood through the heart, one meets with many difficulties. A complete statement of the movement is not given; certain portions of it are treated *in extenso* with much repetition, others are barely mentioned and others entirely neglected, so that there is no continuity and one must piece together the complete story as best one may. It is clear, however, that Leonardo's concept was essentially that which had been handed down through the centuries from Galen. He elaborates Galen's theory in some particulars, but a statement of the views of the older author gives a basis for understanding those of the later one.

Galen held that the veins had their origin in the liver. The chyle passed from the stomach and intestines to the concave surface of the liver by way of the portal vein, and in the liver was concocted into blood, certain impurities being removed from it. It then passed from the convex surface, the gibbosity, of the liver by way of what is now termed the hepatic vein, but was regarded by Galen as the beginning of the great vein (*vena magna* or *vena cava*). This quickly divided into two trunks one of which descended to supply the abdominal viscera, forming what we now term the vena cava inferior, while the other ascended through the thorax to the neck and head, giving off a branch to the heart as it passed. This cardiac branch was what is now recognized as the right atrium of the heart and the remainder of the branch is the vena cava superior. Only a small portion of the blood formed in the liver passed to the heart, the greater portion of it being distributed directly to the various organs for their nutrition. Of the blood which reached the right ventricle a portion passed by way of the arterial vein (pulmonary artery) to the lungs for their nutrition, carrying with it certain fuliginous vapors formed in the heart, to be expelled by the lungs. Another portion passed through minute pores in the septum of the heart into the left ventricle, where it met with vital spirits concocted in the lungs from the air and carried to the heart by the venous artery (the pulmonary vein), whose basal portion was the left atrium, whence it is always spoken of in the singular. Under the influence of the innate heat resident in the left ventricle, the blood that had passed through the septal pores and was subtilized by its passage, became imbued by the vital spirits, and, by the contraction of the ventricle, was forced out by way of the aorta to give energy to the various organs.

Such, in brief, was Galen's conception of the movements of the blood, and two points in his theory may be emphasized in view of what is to follow, namely, (1) the idea that the venous and arterial blood had entirely independent functions, the one supplying nourishment and the other energy to the organs, and (2) the existence of innate heat in the left ventricle, heat implanted in it from the beginning, not developed in it, and of such intensity as to require the cooling effect of respiration to keep it in subjection.

In exposing Leonardo's views one may start with the right ventricle in diastole and filled with blood. When it contracts the contained blood may escape in any one of three directions. A portion of it, before the tricuspid valve can close, will be forced into the right auricle (*orecchi*), forcibly dilating it (QII, 4v, 8v); after closure of the valves a portion passes through the minute septal pores into the left ventricle (QI, 3v, 4, 4v; QII, 11v, 13v), and a third portion passes to the lung by way of the vena arterialis (pulmonary artery) (QII, 17v). The blood sent to the auricle can not be very great, for it is only that which does not come in contact with the cusps of the valves (QII, 8v), that is to say, that which lies between the cusps at the beginning of the contraction of the ventricles, for with further contraction the blood is forced against the under surfaces of the cusps and the atrio-ventricular orifice is completely closed; indeed, the more complete the contraction, the more perfectly does the valve close the orifice (QI, 3; QII, 11, 17v). The blood thus sent to the auricle dilates it, but it is in the auricle only "on deposit" (QI, 3, 4, 17v) and is returned to the ventricle when this passes again into diastole. In its dilation the auricle is entirely passive, but it is actively contractile and forces the blood it has received back into the dilating ventricle (QI, 3, 4), and since the dilation of the ventricle is also an active process, effected by the contraction of its longitudinal muscles, a vacuum is created in it (QII, 11), which will tend to attract blood from the nearest available source, namely the right auricle. Thus there are three forces acting in the return of blood to the ventricle, the recoil of the dilated auricle (QII, 3), the muscular contraction of the auricular walls (QI 4) and the vacuum formed in the ventricle (QII, 11), the result being that the blood returns with great impetus, and what with the friction created by its own currents and that produced by contact with the irregular surfaces of the auricle and ventricle it becomes greatly heated and subtilizes (QI, 3, 4, 4v; QII, 3v, 11; AnB, 12).

The production of this heat is, then, the purpose of the flux and reflux of the blood between the auricle and ventricle. The heat of the body was supposed to have its source in the heart, but while Galen and the ancients attributed it to the mysterious innate heat (*calor innatus*) implanted in the left ventricle of the heart, Leonardo endeavored to explain it on purely mechanical principles, depriving it of its mysterious character and transferring its source from the heart to the blood. The premise on which he based his explanation, the flux and reflux, was erroneous, but the theory is of interest as a characteristic attempt to explain natural phenomena upon natural rather than supernatural principles. It was the following out of the method initiated centuries before by Hippocrates, and practically neglected from Galen's day to Leonardo's; it was an ingenious attempt to solve a problem whose solution was made possible only by the discovery of oxygen some two and a half centuries later.

After the escape of the blood to the auricle the tricuspid valve closes effectively and the continued contraction of the ventricle forces a second portion of blood through the pores of the ventricular septum. This portion has been subtilized by the flux and reflux—in QI, 3v, its subtilization is referred to its passage through the pores, as Galen taught—and, after its passage to the left ventricle, what blood remains to the right is more viscid—

"and to some extent is transformed into minute threads like the vermis of the middle ventricle of the brain. And these threads multiply like thick and short tow and eventually entwine themselves among the chordæ of the valves that close the right ventricle, so that in aged animals the opening (*porta*) can not be well closed and a great part of the blood, which ought to penetrate the narrow porosities of the middle wall of the left ventricle for the production of the spirits mentioned above, escapes through the imperfectly closed opening into the superior ventricle and consequently aged persons lack spirits completely and often die while speaking." (QI, 3v.)

Leonardo had evidently observed the formation of fibrin filaments in the ventricle.

A third portion of the blood of the right ventricle passes out by way of the pulmonary artery, probably for the nutrition of the lungs. This is plainly indicated on QII, 17v, but Leonardo's expressed ideas as to the passage of blood to and from the lungs are decidedly obscure and to some extent contradictory. The heating of the blood by the flux and reflux could, he believed, be so intense as to suffocate the heart and deprive it of life (QI, 3), and not only does it convert some of the blood into spirits, but it might even convert it into elementary fire, were it not for the succor afforded by the lungs (QII, 11).[6] The cool air which these attract to themselves cools and refreshes the blood of the heart. But as to the exact way in which this is brought about Leonardo seems to be in doubt. On AnB, 12, showing one of the ventricles opened, the wall of the issuing artery is also cut away, revealing an opening into the artery by which the blood is said to be refreshed by air from the lungs. Since the ventricle is termed the "receptacle of the spirits" it is presumably the left ventricle and the artery is the aorta, so that the opening is probably that of one of the coronary arteries, erroneously identified. The figure is very crude and probably belongs to an early period, and this same remark may be made regarding a passage on QIV, 7, which states that the heart can not dilate without drawing to itself air from the lungs, which it immediately returns with an impetuous motion, independently of the pulmonary rhythm. So again with the indistinct statement that there are two passages between the heart and the lung, one in the concavity of the heart (whatever that may be) which carries air to that organ and another which returns it to the lungs (QIII, 10v).

On QII, 1 and 11 Leonardo takes a position more in harmony with modern ideas, in that he asserts that no air passes from the heart to the lung, but the arteries, which are in continuous contact with the branches of the trachea scattered through the lung, take up the freshness of the air that enters the lung (QII, 11), and he goes on to describe (QII, 1) how the minutest ramifications of the trachea are accompanied by ramifications of the veins, with which they are in continuous contact.

> "It is not here that the air enclosed in the trachea expires through its delicate branches and penetrates through the tips of the smallest branches of the veins."

Thus suggesting that there are no anastomoses between the branches of the bronchi and those of the blood-vessels. Then he adds—

[6] The increased temperature of fever is explained by the greater frequency of the heart beat as shown by the pulse, since the faster the heart beats the greater will be the friction that produces the heat (AnB, 12).

"But concerning this I shall not entirely affirm my statement until I have seen the anatomy which I have in hand."

There is nothing to show what the anatomy revealed. Apparently he believed that blood could flow either from or to the heart in both the pulmonary artery and vein, for he states that the blood regurgitated through the atrio-ventricular opening, evidently the left one, gives due nourishment to the veins of the lung and, after being refreshed in the lung, returns to freshen the blood it had previously left in the ventricle (QII, 4v). This idea of the blood passing in either direction in a vessel comes down from Galen and will be met with again in connection with the portal vein.

Returning to the right ventricle it is evident that, since a portion of its blood passes through the septal pores and another portion through the pulmonary artery, the amount of blood contained in the right auricle will not be sufficient to fill it at the reflux (QI, 3v, 4). But its dilation is an active process and a vacuum will therefor be formed which will attract blood from whatever source it may.

The most available source is the blood contained in the veinules of the gibbosity of the liver and it is thence that the ventricle regains the blood it has lost (QI, 4, 4v; QII, 17v), replenishing itself with new blood freshly concocted in the liver. If, when the ventricle is dilating, the lung is also expanding, the latter will press upon that portion of the vena cava between it and the spinal column and a portion of the blood will be forced into the right ventricle, in which case so much the less is drawn from the gibbosity of the liver (QI, 4).

That there is a flux and reflux of blood between the left auricle and ventricle may be inferred, indeed it is distinctly implied (QII, 4v), but the blood regurgitated through the mitral valves before their closure is described as passing by the pulmonary veins to the lungs, whence it returns to refresh the blood remaining in the ventricle (QII, 4v). In dealing with the left heart, however, Leonardo concentrates his attention on the passage of blood into the aorta and its effects on the semilunar valves. These, like the atrio-ventricular, allow a certain amount of regurgitation into the ventricles before they eventually close (QII, 4v), the blood which is regurgitated being that which occupied the axis of the column of blood in the aorta (QII, 11). This travels faster than the more peripheral portions of the column and passes freely between the valves, while the peripheral portions come into contact with them and force them together. It is not the more axial portion of the column that closes the valves, since it would be more apt to crumple them than force them together, but the peripheral portions, descending into the hemicycles (see p. 158), are thrown into vortices, which force the valves downward and inward and so bring them into contact (QII,

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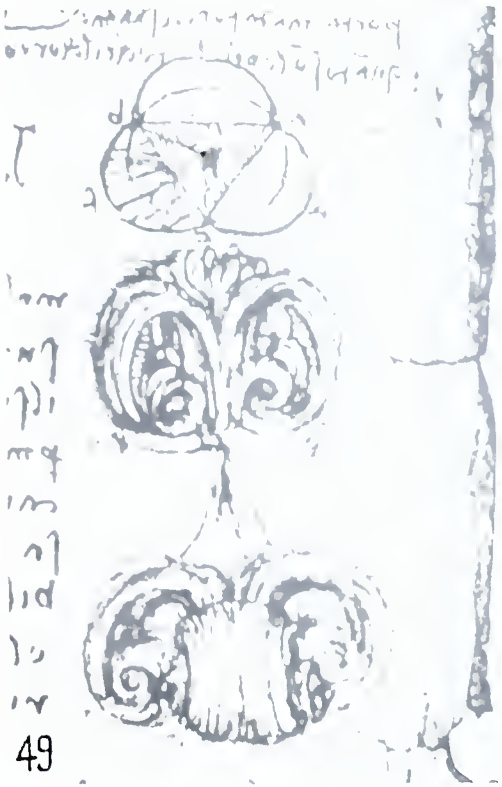

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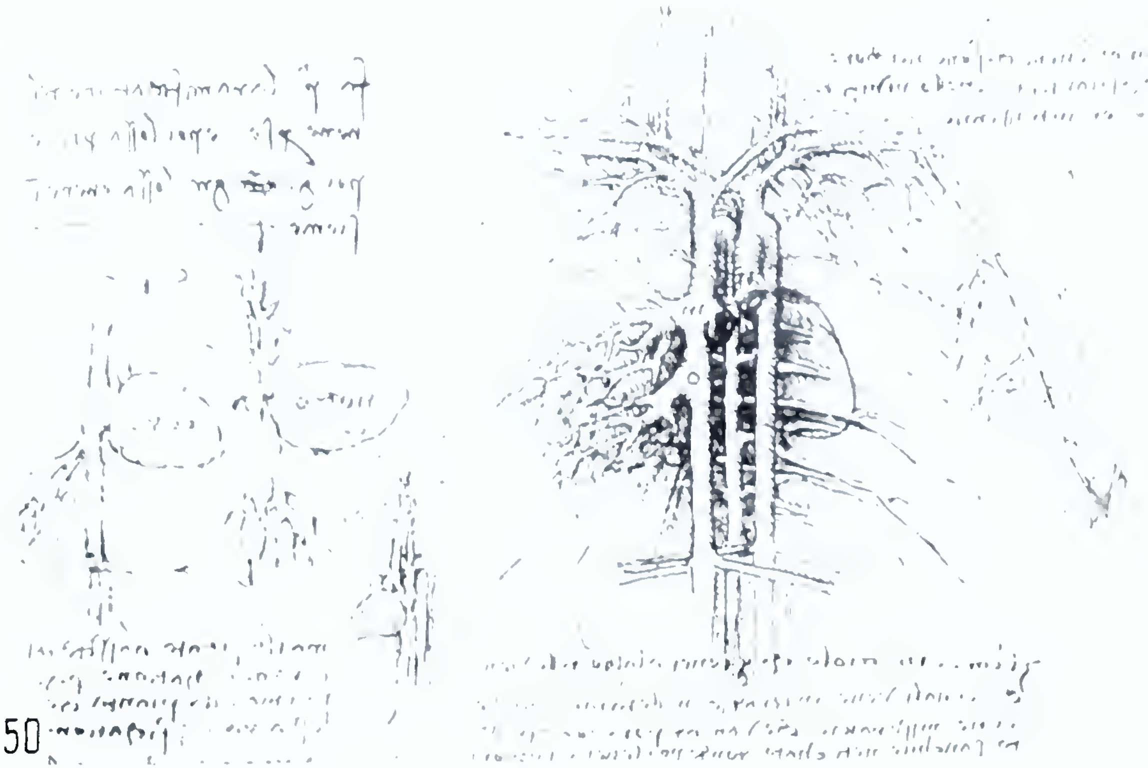

Fig. 49. Studies of vortices in pockets of semilunar valves. (QIV, 11.)

Fig. 50. Figures illustrating the comparison of the heart and blood-vessels with a sprouting nut with its plumule and radicle. In the figure to the right the azygos vein is well shown. (AnB, 11.)

12). The assumption of these vortices appealed strongly to Leonardo's interest in hydrodynamics and several pages of the Quaderni have a greater or less number of sketches (fig. 49) illustrating them (QII, 12, 13v; QIV, 11, 11v, 12); furthermore it was in connection with their study that he purposed to employ the glass model, cast in a plaster of Paris mold (see p. 90).

Since new blood is supposed to be formed more or less continuously in the liver, there must be a corresponding destruction of it. Leonardo recognizes this in his statement that the blood continually dies and is remade (AnB, 10v), but statements as to how and where it is destroyed are not very satisfying. It has been seen that a certain amount of blood is converted into vital spirits and this amount is restored to the heart from the veins of the liver. Leonardo attempts (QII, 17v) an estimate of the amount so restored. He estimates the number of dilatations of the heart as 2,000 per hour, a number decidedly below the average, and remarks "There is a great weight." On the margin of the page there is a sum in multiplication $24 \times 12 = 300$ (evidently the product is a round number) and below this is written "7 ounces per hour." This may be the result of his estimate, but how it is reached is not clear.

It does not seem probable that Leonardo had studied the beat of the heart in the living organ when he made the statement found on QI, 3, as to the succession of the contractions of its different parts. He there holds that the two ventricles alternate in their contraction and dilation, and that the two auricles do the same, so that when the right ventricle dilates the left auricle contracts, and when the left ventricle dilates the right auricle contracts. This is evidently pure speculation uncontrolled by observation, and yet a little consideration will give a clue to the reasoning that led him to such an erroneous idea. Its foundation was the Galenic assumption that blood passes through pores in the ventricular septum from the right to the left ventricle, an assumption that played an important part in delaying the discovery of the circulation of the blood and had established itself so firmly that even Vesalius at first accepted it and only later began to doubt. Leonardo, as has been seen, accepted it. The passage at best was a difficult one, the pores being so small as to be invisible, and if the two ventricles were to contract simultaneously it would have been impossible; the left ventricle must be relaxed to receive the blood which the right was endeavoring to force into it. Hence the supposed alternation in the contraction of the ventricles. But for the flux and reflux each auricle must alternate in contraction with the ventricle of its side, and so the statement. It was perfectly logical, granting the correctness of the supposed facts upon which it was based, but unfortunately it was unchecked by observation or experiment.

However, on another page, QII, 4v, Leonardo does correct this statement, giving a more accurate one, which, however is not very clearly expressed. He says, speaking of the ventricles:

"Their dilatation and contraction are made at the same time by the flux of the blood; and the reflux of the blood is made at the same time, succeeding the first, by the reflux from the upper ventricles (*i.e.*, the atria) placed above the base of the heart."

Apparently he means by this that the two atria contract synchronously and so do the two ventricles, their contraction, however, alternating with that of the auricles.

Leonardo recognized that the pulse was a result of contraction of the heart; the contraction of the ventricles, the beat of the apex against the chest wall, the beating of the pulse and the entrance of blood into the aorta are simultaneous (QIV, 11), The apex beat is said to occur when the heart "contracts with impetuous motion and drives the blood out of itself into the passage of the vein that is intended for it" (QII, 11), and, further, it is stated that the time that elapses between two beats of the pulse is half a musical tempo, during which the heart closes twice and opens once. In each musical or harmonic tempo the heart makes, accordingly, three movements and since there are 1080 tempi in an hour, the heart moves in each hour 3540 times. Leonardo seems to have erred here in his calculations, since if from pulse beat to pulse beat there is an interval of half a tempo, in an entire tempo there would be three pulse beats, that is to say three contractions and three dilations, six motions in all. Consequently the number of movements of the heart per hour should be 6480, which would mean 3240 pulse beats per hour, a number considerably below what may be taken as the average normal number. In extenuation it must be remembered that Leonardo had no accurate means of counting the pulse; there were no time-pieces in his day and more than sixty years were to elapse after his death before Galileo invented his *pulsilogia*, the first instrument designed for the accurate measurement of a physiological phenomenon. There is a possibility that by "movements" Leonardo may have meant contractions, but this is negatived by the concluding words of the sentence, and no matter how one attempts to reconcile the discordant statement, it is clear that an error has been made, for the result could be 3540 only if the number of musical tempi per hour was 1180.

Attention is called to the fact that the beat of the heart as determined by the pulse is discontinuous, a distinct interval occurring between each two beats. This interval allows time for the liver and the meseraic veins to form and restore to the "gibbous part" of the heart that amount of blood that the left[7] ventricle had taken from it (QI, 4v), and it further brings it about that the nourishment of all parts of the body must also be discontinuous (QI, 7).

That the beat of the heart was automatic seems to have been accepted at one time. Thus it is said of the heart "This beats of itself and never stops, except eternally," and on the same page it is pointed out that none of the inferior organs of the body can be stopped by the will, unless it be the lungs. The heart acts automatically and so does the stomach and the other intestines joined to it; and it is similar with the liver, the gall-bladder, the spleen, the testicles, the kidneys and the bladder (AnB, 13). But in another passage, probably written later, after he had observed the possible relation of the vagus nerve to the heart, Leonardo is not so certain as to the automaticity of the heart and makes a memorandum to inquire whether the stimulus to contract does not come to the heart through a nerve as in the case with other muscles (QIV, 7). This passage, which is full of interest, has already been quoted (p. 160).

[7] Leonardo has "right" here, but it is evidently a slip.

CHAPTER XIII

THE BLOOD-VESSELS

Leonardo's treatment of the blood-vessels is less satisfactory than that of some other portions of his Anatomy, partly on account of its incompleteness, partly because the fact that it was largely based on animal dissections is so much more obvious than it was even in the case of the heart, and partly because the acceptance of certain mythical traditions stand out more egregiously than elsewhere. It seems probable that the representations given of the great vessels date back to the earlier periods of his studies and, from the lack of later illustrations, there are no means for determining how far he may have eventually progressed toward an accurate knowledge of human vascular anatomy.

It is significant that Leonardo uses the term *vena* with some indefiniteness. Sometimes it clearly means "vein," at other times it just as evidently means "blood-vessel." It was not that he did not distinguish between arteries and veins; the difference in their contents was a fundamental part of his theory of the heart's action and he also accepted Galen's teaching that the walls of the arteries consisted of two coats and those of the veins of but one (QII, 2v). The indefiniteness came rather from the lack in his day of an appreciation of the necessity for an exact nomenclature, an appreciation that was slow to develop in Anatomy. But while he followed Galen in this particular he departed from his teaching and that of his follower, Avicenna, in another point of some importance. Galen claimed that while the arteries arose from the heart, the veins had their origin in the liver, an idea in harmony with his theory that the nutritive blood was formed in that organ. Leonardo, however, while accepting Galen's views as to the origin of the blood, states positively that "all the veins and arteries arise from the heart" (AnB, 11) and again that "the root of all the veins is in the gibbous part of the heart" (AnB, 34v), and finds reason for this belief in the fact that the veins and arteries are largest where they join the heart, "and the more they separate from the heart the more they diminish in size and divide into smaller branches" (AnB, 11). He then proceeds to discuss the idea that the veins arise from the branches in the liver just as a plant arises from its rootlet, pointing out that plants do not have their origin from the roots, but these and the other branches, *i.e.* the radicle and plumule, have their origin from that part of the plant which is situated between the air and the earth. He illustrates this by two figures (fig. 50), one of which represents a nut from which a plumule and radicle are sprouting, while in the other the heart takes the place of the nut and the ascending and descending parts of the vein correspond to the plumule and radicle.

"The heart is the nut which gives rise to the tree of the veins." (AnB, 11.)

The casting aside of Galen's theory was an important step, not only because it was a revolt against accepted authority, but also because it meant progress toward a more correct understanding of the heart's action. As a matter of fact, Aristotle, long before Galen's time, had maintained that both arteries and veins arose from the heart, and it is interesting to note that another idea which suggests Aristotelian influence occurs in Leonardo's memoranda. Aristotle describes the walls of the aorta as being tendinous, in contrast with those of the veins, which were membranous, and claimed that its ultimate branches were neura (tendons) and consequently were solid and impervious. Leonardo expressed the same idea with the words—

"The artery, by being doubled with *nervosità* in many places, performs the office of simple *nervi* (tendons)." (QIII, 10v.)

There is much similarity between this statement and Aristotle's, but hardly enough to warrant the conclusion that Leonardo was familiar with Aristotle's anatomical treatises, in the face of the fact that he makes no mention of them (see p. 29) and that his reliance is so definitely on the Galenic tradition.

His comparison of the veins to a sprouting seed has already been mentioned. Much more attractive to him was the comparison of the blood to the ocean and rivers and of the microcosm to the macrocosm, and one finds it made more than once in the various manuscripts.

"As man has within him a pool of blood wherein the lungs as he breathes expand and contract, so the body of the earth has its ocean, which also rises and falls every six hours with the breathing of the world; as from the said pool of blood proceed the veins that spread their branches throughout the human body, so also the ocean fills the body of the earth with an infinite number of veins of water." (A, 55v.)

One finds the same comparison in Leic, 34 (see p. 97) and again in CA, 171 (see p. 179), while in AnA, 4 it is pointed out that in reality—

"The origin of the sea is the reverse of that of the blood, for the sea receives into itself all the rivers, which are produced only by the aqueous vapor raised into the air; but the sea of blood is the cause of all the veins."

This last passage is of special interest in that Hopstock (1919) to whom we are so deeply indebted for the Quaderni, quotes it as partial evidence for his belief that Leonardo came very near to the conception of the circulation of the blood. One might say the same of Erasistratus, but the question as to how far, if at all, Leonardo had envisaged a circulation of the blood in the modern sense will be better considered later (p. 177).

Some general statements concerning the blood-vessels may be briefly mentioned. On AnB, 1, it is stated that the function of the veins is to convey heat to the body; veins in this case probably means blood-vessels, for they are contrasted with nerves whose function is to give sensation. On AnB, 10 it is noted that veins and nerves follow the same pathways and that they pass with the arteries from muscle to muscle and ramify in the muscles with equal branchings, but on QIV, 8 he notes as exceptions to this rule that in the arms and legs the veins are superficial and do not accompany the arteries, making a memorandum to discover where they leave the arteries. Two varieties of branching occur in the veins, the simple variety in which the branching goes on indefinitely and the compound in which two branches anastomose to form a single vein. As an example of a compound branching he refers to two branches from the superficial epigastric veins uniting to form the single superficial v. dorsalis penis, a rather unusual course for the single vein.

Though not a physician, Leonardo was interested in pathological conditions, especially such as seemed to promise light upon the causes of the cessation of life. Mention has already been made (p. 53) of a dissection that he made in Florence of the body of an aged man who claimed to be a centenarian; he hoped from the dissection to discover the cause of his easy death and believed that he had found it in the condition of certain vessels. He observed that the splenic artery was tortuous, contracted, wrinkled and empty of blood, whereas in youth it was straight and full of blood (AnB, 22) and attributed this condition to a thickening of the walls of the vessels, so that the blood can not pass through their smaller branches, and so the liver, the heart and the great veins are deprived of blood and all the body of its nourishment (fig. 51). The effect on the liver is especially noted; it loses its color and becomes highly friable, so that by rubbing or washing its substance breaks up into fine particles like sawdust, leaving the branches of the veins intact (AnB, 10v). The cause of death, then, was lack of nourishment caused by a thickening of the walls of the vessels (AnB, 10v) and this thickening is explained by the principle that that augments most which is nearest to the source of nutrition and, since the vessels are envelopes of the blood and this is the source of nutrition for all the body, their walls in time will thicken (AnB, 11v).

Leonardo evidently had under observation the condition now termed arterio-sclerosis; he does not, however, mention calcification of the contorted vessels, but in the same subject he observed in the veins that pass beneath the clavicle calcifications (*pietre*) that were as large as chestnuts, were of the color and form of truffles and were contained

Fig. 51. Superficial veins of arm and a sketch comparing the arteries of a centenarian with those of a child. (AnB, 10.)

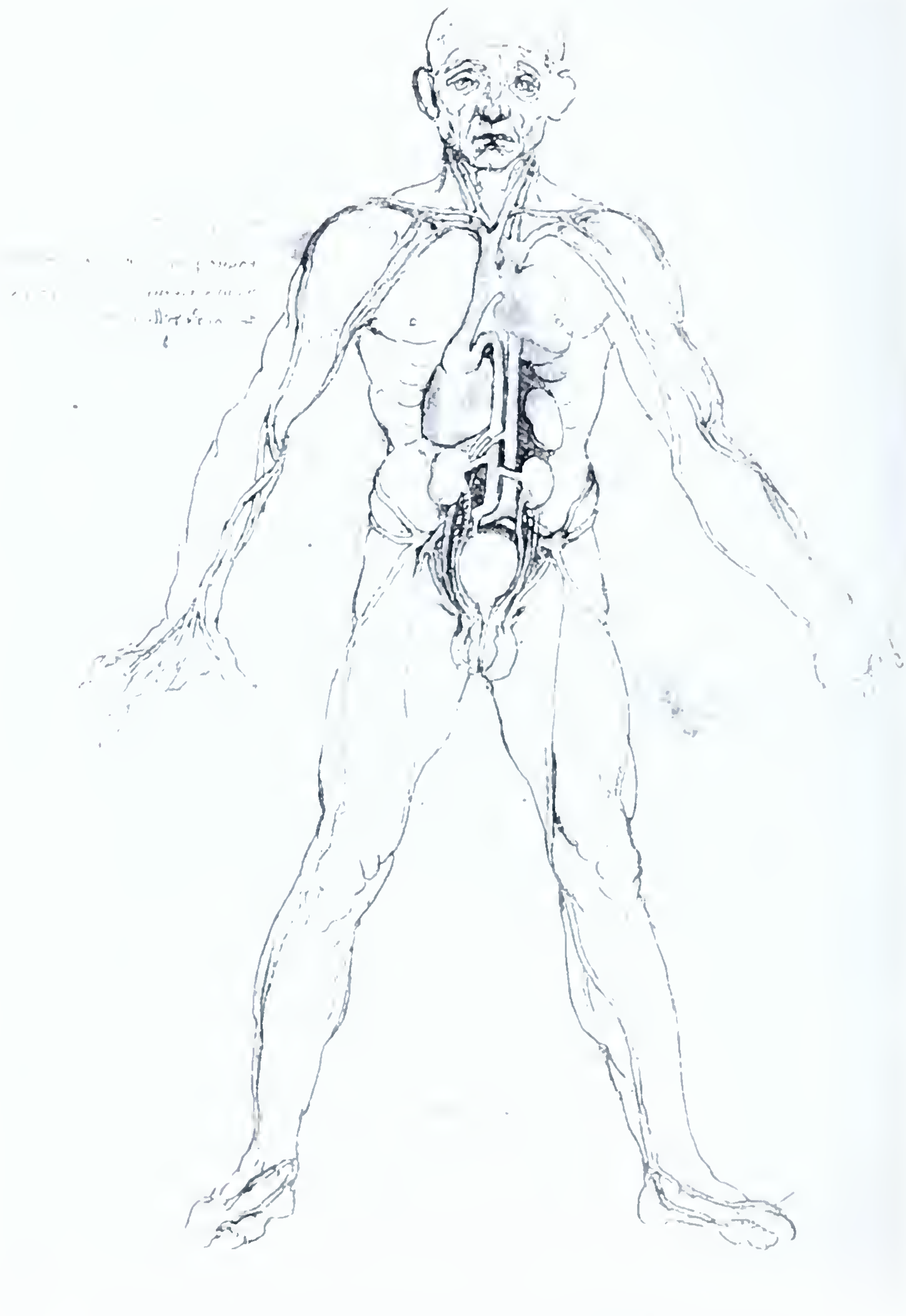

Fig. 52. Early study of the heart and blood-vessels. (QV, 1.)

in pouches attached to the veins, like goiters (AnB, 10v). He also records that he saw an accidental wound of the vena communis to which a tight bandage was immediately applied and in a few days there developed a large swelling, the size of a goose-egg and full of blood, and it remained for many years (AnB, 10). He mentions this as evidence of the great distensibility of the veins; it was probably, however, a hæmatoma, rather than a venous aneurism.

Leonardo has left ten drawings representing the great vessels and all, with one exception, give evidence that they were based on animal rather than human dissections and, furthermore, it is probable that several of them, indeed the majority, date from the earlier period of his studies, since in those in which the heart also is shown (QI, 12; QIII, 3, 10v; QIV, 7; and QV, 1) its atria are altogether omitted (figs. 52, 53), except on QIV, 7, where the left one is sketchily shown. This would seem to indicate that these figures were drawn before Leonardo had formulated his flux and reflux theory and had realized the importance of the atria.

That the great majority of these figures are based on animal dissection is shown most clearly by the arrangement of the arteries arising from the aortic arch. The aorta arising from the left ventricle is shown passing directly upward for a short distance and then it divides into two branches, one of which curves to the left and then downward and is evidently the arch of the aorta, while the other continues the upward course but quickly divides into the two common carotids and the two subclavians. This is the arrangement shown on AnB, 11 (fig. 50), in one of the figures on QIII, 10v, and on QIV, 9v, while on QI, 12, and QIV, 7, it is essentially the same except that the right subclavian is not shown. It is the ungulate arrangement, not the human. What Leonardo saw in the dissection of an ungulate he represented correctly; he erred, however, in assuming that the human arrangement was the same and in representing the ungulate arrangement in a human body (QI, 12; QV, 1). In extenuation of the error it may be observed that he had the support of Avicenna, for that author described the origin of the branches of the aortic arch just as Leonardo represents them on the folios mentioned and makes no suggestion that Galen's description, on which he based his, was made from animal dissections. When Leonardo had opportunity to see these vessels in a human body, as he did in the dissection of *il vecchio* (p. 53), he represents (fig. 54) their origins as they are in human beings, and a figure on QIII, 10v (fig. 53), in which the left subclavian arises directly from the aortic arch, may possibly have also been drawn from a human preparation, though in some respects it possesses suggestions of the ungulate type.

In his representations of the great veins, Leonardo agains relies on what he found in animal dissections, interpreting his findings in the light of Avicenna's description. Thus Avicenna describes the vena cava as arising from the gibbosity of the liver and dividing into an ascending and a descending branch (*cf.* fig. 53). The former when it reaches the level of the heart divides again, one of the branches opening into the right ventricle, the opening being guarded by the valves. This branch is evidently the right atrium and the valves the tricuspid; for Galen, whom Avicenna followed, relying on animal dissections, regarded the inferior and superior venæ cavæ as continuous and the right atrium as a branch of this main stem. Having thus brought the vena cava into relation with the right ventricle, Avicenna confuses with it the pulmonary artery (*vena arterialis*) and so does Leonardo, representing a branch of the vena cava passing directly to the right lung. Furthermore, if the right atrium were regarded as merely a branch of the vena cava, it is natural that Avicenna would describe the coronary sinus of the heart also as a branch of that vessel, and in this too he is followed by Leonardo (QII, 4), who furthermore assigns the origin of the right coronary artery to the pulmonary artery (*vena arterialis*), although he represents both it and the left coronary as arising from the aorta in QII, 3v. The statement on QII, 4 is probably a *lapsus calami*. A third branch of the vena cava in the heart region is described by Avicenna as passing downward to the upper thoracic vertebræ. This is what is now know as the azygos vein and is shown by Leonardo on AnB, 11 and 12v (fig. 50), draining or supplying the upper intercostal spaces. Beyond the junction of the azygos, the main stem of the vena cava continues upward to finally divide into two more or less equal branches, corresponding to what are now known as the innominate veins, each of which divides into an internal jugular, accompanying the common carotid artery, and a subclavian vein.

But all this must be assigned to Leonardo's earlier days when he was more under the influence of Avicenna. Later he certainly recognized the existence of the right atrium, speaking of it as an upper ventricle; when figure 44 was drawn he recognized that the superior and inferior venæ cavæ were not continuous, but both opened into the right atrium; in figure 45 he shows the pulmonary artery arising from the right ventricle, quite distinct from the vena cava; and later he maintained that both arteries and veins arise from the heart. His own observations revealed to him the errors of his predecessors which he at first accepted.

Many of Leonardo's observations on the blood-vessels were based on his dissection of *il vecchio* (see p. 53), and in connection with one of the figures made from this dissection (AnB, 32v) he records a time-honored belief, based on experiments performed by Galen, to the effect that if both carotid arteries and jugular veins are tied, the victim suddenly falls to the ground unconscious as if dead, nor will he ever recover if the ligatures are allowed to remain for even the hundredth part of an hour. It is as a result of this belief that Leonardo speaks

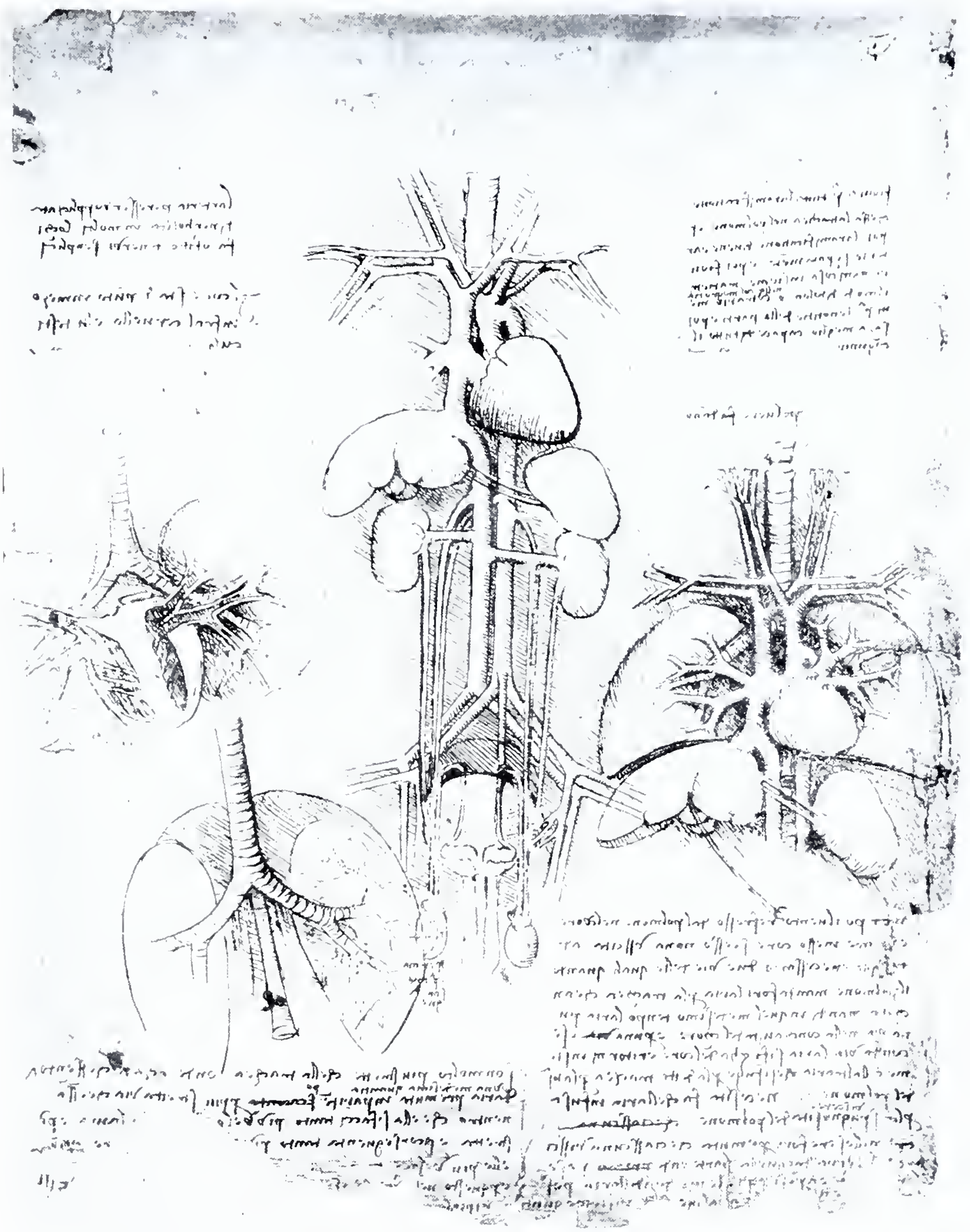

Fig. 53. Dissections of heart, lungs, abdominal viscera and blood-vessels. (QIII, 10v.)

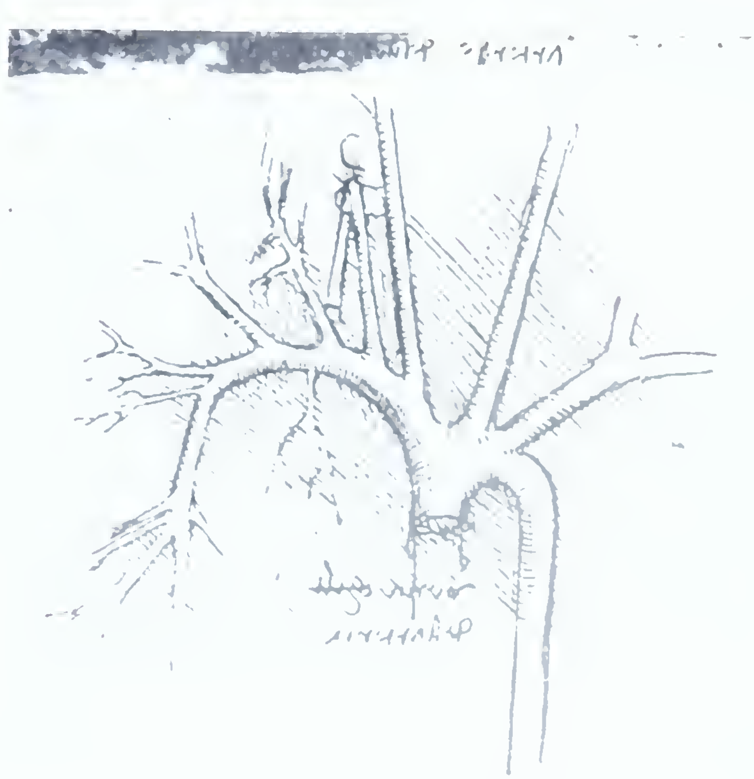

Fig. 54. The great vessels of a centenarian. (AnB, 33.)

of the jugulars as the *venæ apoplectiche*, a term probably borrowed from Mondino, who states that they are also called *venæ somni*, since sleep is caused by the natural blocking of their branches. Avicenna terms the carotids *art. soporariæ* (*subeticæ*).

Leonardo has left no systematic account of the blood-vessels, he considers them piecemeal, but when one has collected all the pieces one finds that the majority of the principal vessels have been described or figured. The veins, on the whole, are more fully represented than the arteries as was customary, since they were more obvious, being gorged with blood while the arteries were empty. There are, however, many gaps and many imperfections in the story, especially when he is dealing with the arteries of the limbs.

The coronary vessels supplying the walls of the heart are well shown on QII, 4 (see also fig. 44) and, as an indication of Leonardo's sharpness in observation, it may be mentioned that he speaks of the great cardiac vein (*vena nera*) that winds around the heart in the atrio-ventricular groove as running in the opposite direction to the accompanying artery (*ssi fa inchontro all arteria*), meaning thereby that as one traces the vein toward the back of the heart it grows larger, becoming the coronary sinus, while the artery grows smaller. He recognizes three distinct veins, two of which are accompanied by arteries and mark the boundaries of the right ventricle; the third, however, the posterior vein of the left ventricle, seems to have no companion artery and he makes a note to ascertain by further observation whether this was really the case (QIV, 13v).

It is strange that he does not describe nor figure the external carotid artery, unless it be intended on QIV, 9v, but he does represent several of its branches without tracing them back to their origin. Thus he shows the superficial temporal and internal maxillary arteries on AnB, 42, while the infraorbital branch of the latter is again shown on AnB, 12, and the intracranial portion of its middle meningeal branch on AnB, 41. Of these meningeal branches he notes that they are half buried in grooves on the inner surface of the skull and are covered over by the membrane of the brain, the dura mater. The lingual artery is shown more fully, but it is made to arise from the internal carotid; there is an excellent figure of its terminal ranine branch on QIII, 10. Of the veins of the head the anterior facial is shown on AnB, 12, and again uniting with the posterior facial to form the external jugular (QV, 17; 20v), while the veins of the forehead and lateral portions of the scalp are shown on AnB, 1 and 1v.

The branches of the subclavian artery can not be identified with certainty, but the vertebrals seem to be indicated on AnB, 32v. Pectoral branches connected with the axillary vessels are also shown on the same folio, but the arteries of the arm are almost neglected, being shown only toward the wrist where they appear from under the muscles that cover them (AnA, 12v, 13v). On the other hand the superficial veins of the arm are repeatedly figured (AnA, 4, 6 and 12v; AnB, 10 and 32v; QIV, 9v) (figs. 51, 55) and the network formed by anastomoses of the mammary and pectoral veins is well shown on AnA, 6 (fig. 55). Leonardo studied the veins of the arm on the living as well as by dissection, for he makes a memorandum to "draw the arm of Francesco, the miniaturist, which shows many veins" (AnB, 10), and possibly the drawing on the same page as the memorandum (fig. 51) represents the arm of Messer Francesco.

Of the branches of the descending aorta the cœliac artery, with the beginnings of its hepatic and splenic branches, and the superior mesenteric are shown on AnB, 13v, the last being described as nourishing the root of the *zirbo* (omentum), its distribution having been confused with that of the right gastro-epiploic. The renal veins are shown in many figures (fig. 46) and the arteries on AnB, 11v and 13v. The internal spermatic vessels are also figured, sometimes one or both arteries, sometimes one or both veins, and both arteries and veins on QIII, 10v (fig. 53); it is interesting to note that the left vein is correctly shown, opening into the right renal vein instead of into the vena cava (figs. 46, 53), an arrangement, however, that might have been learned from Avicenna, who adopted it from Galen's description written several centuries earlier. Below, the aorta and vena cava end by dividing into the common iliacs, and just before the artery divides it gives off a branch that runs directly downward (QIII, 4v, 5 and 10v; QIV, 7) and seems to be the caudal artery, corresponding to the human middle sacral (fig. 53).

In his earlier drawings, Leonardo figures of the portal system of veins only the splenic and this, together with what is probably the splenic artery, is shown passing directly from the liver to the spleen (QI, 12; QIII, 5, 10v; QIV, 7) (figs. 4, 46, 53, 56), Leonardo having, apparently, been deeply influenced by the theory of black bile and its passage to the spleen. On AnB, 11v, and again on AnB, 34v, the artery is represented as arising from the aorta and quickly dividing into what are evidently the hepatic and splenic branches, and what may be intended for the left gastric artery is also shown on AnB, 34v (fig. 56). In both these figures, however, the vein still passes directly from one organ to the other, receiving in the AnB, 11v figure the left internal spermatic vein (evidently a slip since that vein is correctly shown on QIII, 10v (fig. 53) joining the left renal) and in those on AnB, 22 and 34v (fig. 56) the right gastro-epiploic vein, the artery having a corresponding branch. In the text of AnB, 11v the vein is described as arising by five branches from the liver, a branch corresponding to each of its *penulæ* (lobes), an idea adopted from Mondino, and at about the middle of its length it gives off a branch that passes to the base of the omentum (*zirbo*); farther along a branch passes upward to the left

Fig. 55. Superficial pectoral and epigastric veins. (AnA, 6.)

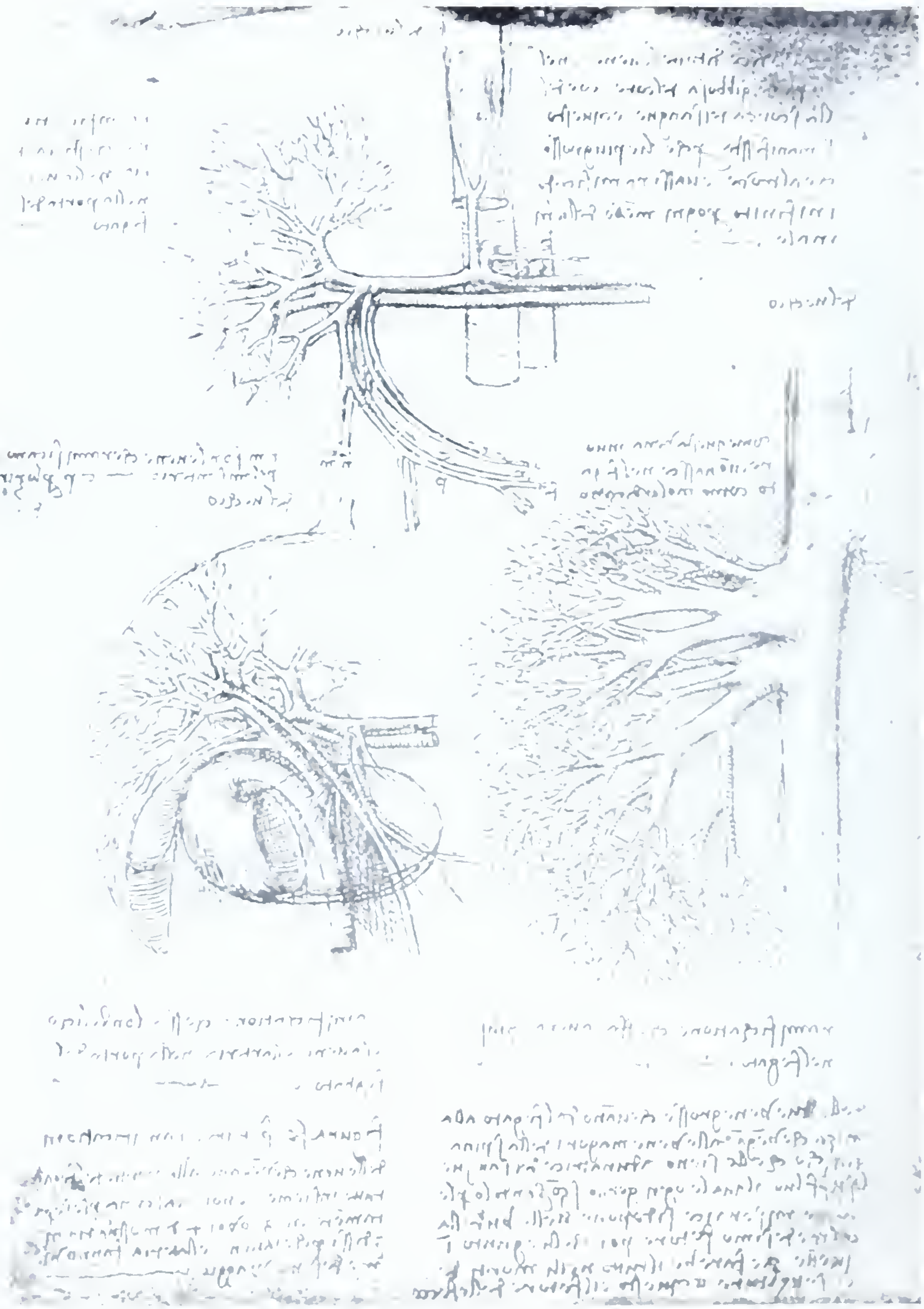

Fig. 56. Figures of the hepatic artery and portal vein. (AnB, 34v.)

lower portion of the stomach, probably one of the gastric branches of the splenic vein, and finally the vein terminates by dividing into two branches at the spleen. This arrangement of the vein and its branches is also shown on AnB, 3. It may be noted that the figures on AnB, 3, 11v, 22 and 34v are based on the dissection of *il vecchio*. It is strange that the participation of the mesenteric veins in the formation of the vena porta is nowhere clearly figured, notwithstanding that they were essential to the accepted theory as to the function of the liver in concocting into blood the food-substances brought to it by these veins from the upper part of the intestine, as well as by those from the stomach. The latter were the more important and it is possible that having noted the right gastro-epiploic vein from the region of the stomach, Leonardo did not consider it necessary to look farther, a supposition that might account for his conjecture that the branches of the superior mesenteric artery were distributed to the omentum. This supposition is not advanced in extenuation of Leonardo's carelessness in this part of his dissection, but merely as a possible explanation of that carelessness. He does, however, represent a fragment of the vein on AnB, 3, and mentions it in the text as—

"The ramification of the mesentery, which joins all the intestine, returning to this the blood that dies and taking from it the new nourishment, just as the roots of any herb or plant mingle with the earth that covers them and suck from that the humor that nourishes them."

Furthermore, he says on the same page—

"In the mesentery are planted roots of all the veins that unite at the porta of the liver and purify the blood in this liver. And it then enters the *vena del chilo* (vena cava) and this vein goes to the heart and makes the blood more noble, and this enters the artery (as) spirituous blood."

He apparently failed to observe the mesenteric arteries for he has a note (AnB, 3) to "see if the mesentery has arteries or not."

The division of the common iliac vessels into the external and internal iliacs is shown on QIII, 4v and 10v (fig. 53), but the account of the branches of the internal iliacs is very incomplete and probably based, so far as it goes, on animal dissections. In a drawing on AnB, 6v (fig. 57) the left common iliac vein is shown coming from the right side of the vertebral column and it continues as the external iliac over the brim of the pelvis, giving off a branch which passes down into the pelvis. In addition, two other large branches are shown, one ascending, evidently the ilio-lumbar, and one descending, which resembles the lateral sacral; it gives off two branches that make their way through the obturator foramen. A more detailed, but at the same time an incomplete and somewhat confused statement as to the pelvic veins is given on QIII, 7v:

"The first branching of the great vein below the renals is where the spinal column unites with the sacrum (*alchatim*); the second are the branches which divide to nourish the coccyx (*? spina della calucda*); the third is in the *mestri* of women and the uterus; the fourth in the bladder; the fourth, a finger and a half further on, goes to the testicles; the fourth arises a finger and a third distant from this and passes out of the abdomen (*sifac*) and divides into two, and one is the saphenous and the other . . . "

The various branches indicated are the common iliacs, the lateral sacrals, the uterine, a vesical, the ovarian, and the external iliac, which divides into the saphenous and femoral. On AnB, 36v mention is made of the hæmorrhoidal veins.

"Divide the subject through the middle of the spine; but first tie the *chilo* (vena cava) and the artery, so that they do not empty, and thus you will be able to see the hæmorrhoidal veins on either side, *i.e.* in each division of the subject."

One doubts whether the preparation was ever made, although there is a sketch representing it which shows a vein arising from what seems to be an obturator vein and ramifying in the region of the pelvis that would be occupied by the upper part of the rectum.

Quite early in his anatomical studies, Leonardo must have had opportunity for dissecting a fetal mammal, perhaps the calf that is represented, enclosed within the chorion, on AnB, 38 (fig. 84). In it he might have observed the hypogastric arteries passing up the abdominal wall to the umbilicus from the internal iliacs and the umbilical vein passing from the umbilicus to the porta of the liver. So indeed he figures them on AnB, 29v (fig. 87), but, curiously, he assumes that they also occur as functional blood-vessels in the adult human body and he represents them in such drawings as that on QI, 12, and those drawn from *il vecchio* on AnB, 4, 22 and 34v (figs. 58, 64). The umbilical vein in the adult is represented by a solid cord, the so-called round ligament of the liver, but Leonardo shows it (fig. 58) as a patent vein, branching in the substance of the liver (AnB, 4, 34v), just as does the portal vein. The hypogastric arteries are also represented by solid cords in the adult, but Leonardo shows them as open arteries and furthermore shows them accompanied by veins, the artery and vein of each side uniting to form a single trunk before reaching the umbilicus (AnB, 4, 34v). These veins are, of course, figments of the imagination, presented, perhaps, on the supposition that every artery has a companion vein (see p. 170).

The representation of the vessels of the lower limb is as incomplete as that of the vessels of the upper. The femoral vessels, in their upper part, are shown on AnB, 8 and on QIV, 8, and their course through the adductor canal is shown on AnB, 18, the sartorius muscle being cut away to expose them. But, as in the upper limb, it is the superficial veins that attract chief attention and the arteries are neglected. The

Fig. 57. The iliac vein and its branches. (AnB, 6v.)

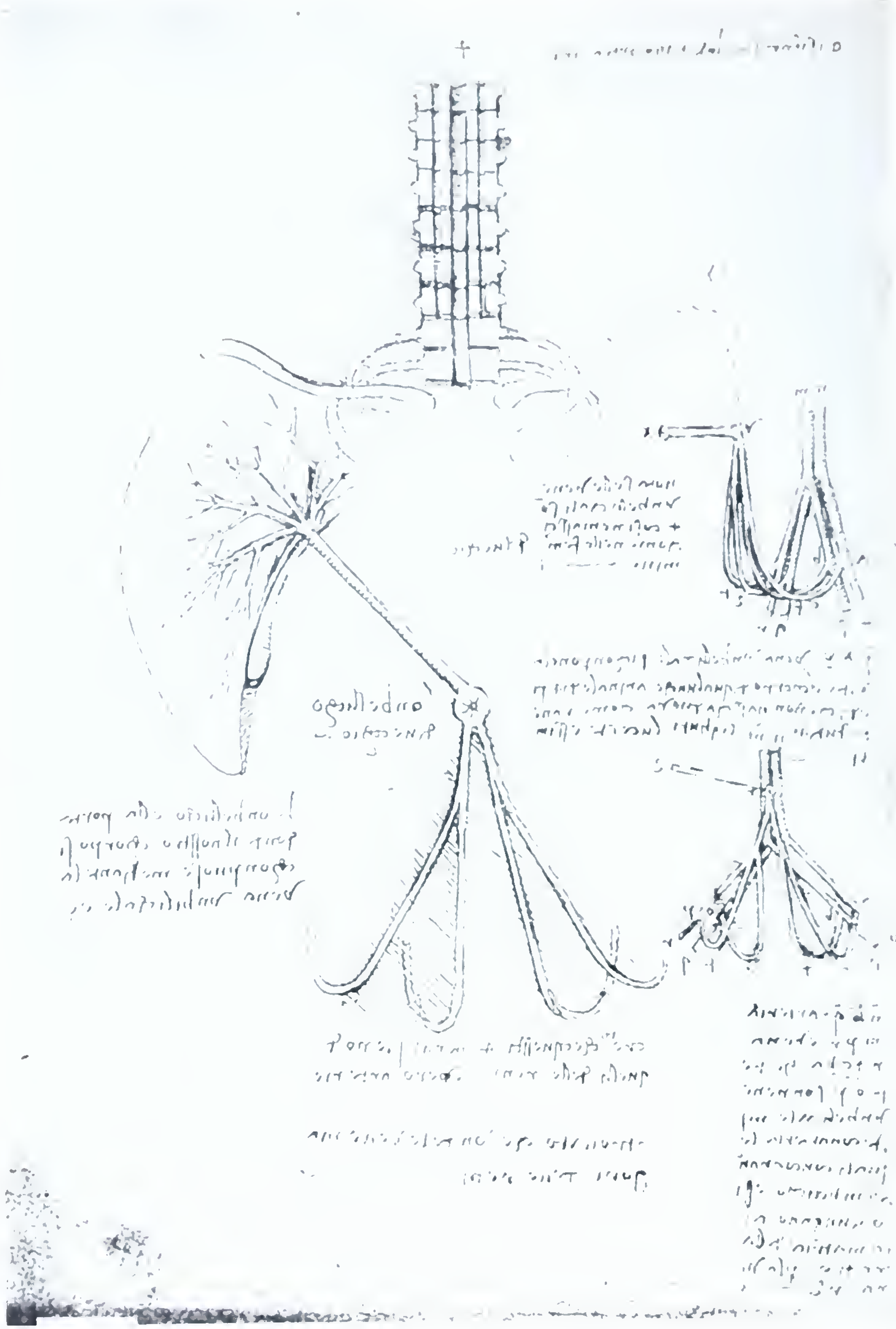

Fig. 58. Hypogastric vessels and umbilical vein. Above is a frontal section through cervical vertebræ showing the costotransverse foramina. (AnB, 4.)

saphenous vein is shown throughout almost its entire course on QV, 3v, and in its upper part on AnB, 8, where it is accompanied by an artery, and on QIV, 8, where the superficial epigastric is shown opening into it. These latter veins are also well shown on AnA, 6 (fig. 55).

Of the vessels of the lower leg little can be said. The small saphenous vein is shown on AnB, 7, and possibly on AnB, 7v. A somewhat curious representation of the vessels behind and below the knee-joint occurs on AnB, 7. A nerve, the posterior tibial, occupies the mid-line with an artery on one side of it and a vein on the other; each of these vessels gives off a branch, which passes medially behind the nerve, and, the two branches crossing each other, there is below an artery and a companion vein on each side of the nerve. This is probably a representation of the formation of the peroneal vessels from the posterior tibials. There are no figures or descriptions of the plantar vessels, but what seems to be the dorsalis pedis artery is sketchily shown on AnB, 7v.

Leonardo's first uncertainty regarding the pulmonary vessels has already been noted, but he seems to have made one important discovery in connection with them, namely, that there are passing to the lung special bronchial vessels, quite distinct from what are usually termed the pulmonary vessels. His statement regarding these arteries is as follows:

"You may say that the trachea and the lung have to be nourished, but if you had to do with a single large venarteria, this could not accompany the trachea without great interference with the movement which the trachea makes in its dilation and contraction, as well in length as in thickness; wherefore for this She (Nature) gave a vein and an artery to the trachea, which would be sufficient for its life and nourishment, and the other large branches She separates somewhat from the trachea to nourish with more convenience the substance of the lung." (QII, 1.)

His figure shows two bronchial arteries arising apparently from the aortic arch and ramifying upon the walls of the bronchus through all its branches. He seems to have recognized the bronchial arteries.

The suggestion that Leonardo may have had an idea of the circulation of the blood has been made more than once, and first of all by Richter (1883), who first made a thorough study of the manuscripts. Richter based his suggestion on Leonardo's statement that the blood that returns to the ventricle is not that which closes the valves, and also on one of the comparisons of the microcosm with the macrocosm. The latter is not pertinent, nor, indeed, is the former, since it is merely a restatement of the belief that on the contraction of the ventricle the portion of its blood that lay between the cusps of the valves passed back into the atrium, while the remaining portion forced the cusps together and closed the opening. Roth (1907) regards the suggestion as improbable, and while Holl (1910) is at first inclined to accept it, he later (1911) doubts, while expressing a belief that if Leonardo had continued his studies he might have discovered the true state of affairs. Boruttau (1913) takes the same position remarking—is it in irony?—that if Leonardo had practised surgery or vivisection or had had the advantage of the use of the microscope to show him the capillary circulation, he would no doubt have perceived the true state of affairs. If Erasistratus had had a microscope he too might have discovered the circulation! More recently Hopstock (1919), while admitting that the matter is still open to discussion, expressed the opinion that it is not impossible that Leonardo may have seen *circulationum sanguinis* with his inner eye. He bases this opinion on (1) a passage on AnB, 3—

> "By the ramifications of the *vena del chilo* (vena cava) in the mesentery the aliment from the corruption of food in the intestine is attracted and finally returns by the extreme ramifications of the artery to the intestine, where, being dead blood, it is corrupted and takes on the fetor of the feces . . ."

And (2) a passage on AnA, 4, *à propos* of the microcosm idea, which has already been quoted (p. 97).

The passage on AnA, 4, does suggest a circulation of the waters of the macrocosm, but it contrasts rather than compares the conditions of the blood in the microscom. Similarly the passage on AnB, 3, does suggest a circulation, but it deals with a special case, it is incorrect in statement, it is obscure in that it does not explain how the blood could pass to the artery and, furthermore, it does not describe a continuous circulation, but a method of disposal of useless, dead blood. Hopstock makes out a stronger case than Richter, but even so the passages quoted are unconvincing in the light of Leonardo's definitely expressed beliefs as to the movement of the blood in the heart and as to the significance of venous and arterial blood. It was the doctrine of the *pneuma* that delayed the discovery of the circulation of the blood for centuries after the valves of the heart and their action were known. If the Galenic teaching that the blood of the veins was for nutrition and that of the arteries was for imparting energy were accepted, there was no incentive to seek for any connection between the two sets of vessels—indeed any such connection would be disadvantageous. And so it was left for Harvey in the seventeenth century to overthrow the time-honored doctrine by an accumulation and logical presentation of pertinent facts, which allowed no other conclusion than that there was a circulation and therefor a connection between the arteries and veins, a connection that was actually demonstrated later by Malpighi.

One of Harvey's strong arguments in favor of the circulation was based on the amount of blood pumped by the heart. It has been seen (p. 165) that Leonardo also attempted to estimate this amount, but did not carry his results far enough. They left him, however, with the problem of what became of all the blood that passed through the heart. The passage from AnB, 3, quoted above (p. 178), is an attempt at a solution and on AnB, 34v there is a second similar attempt.

"Of the two larger veins that come from the liver to the spleen and come from the larger veins of the spine (aorta ?), I judge that they are collectors of the superfluous blood, every day removing it by the meseraic veins and depositing it in the intestines, with the same fetor when it has arrived in these as the whole would have in the dead from the tomb, and this fetor is that of the feces."

Apparently the meseraic veins from the upper part of the intestine were supposed to carry food material to the liver to be manufactured into blood, but those of the lower part of the intestine carried superfluous, dead blood to the intestine.

Vital spirits are also being continuously produced and there must be some way for disposing of the excess. Leonardo meets this difficulty by supposing that—

"Mingled with heat and inspissated moisture (*umito spesso*) it evaporates through the tips of the small veins (*vena chapillari*) at the surface of the skin in the form of sweat." (QII, 11.)

He refers to a case he claims to have seen, that of a man whose heart burst while he was fleeing from his enemies and he emitted sweat mingled with blood from all the pores of the skin (QIV, 13). It seems strange that with his knowledge of the heart-beat Leonardo did not see in it the *vis a tergo* that forces the blood to the uppermost parts of the body. On CA, 171 he states that—

"The cause that moves the humors in all kinds of animated bodies against their natural weight is the same as that which moves the water enclosed within them through the terrestrial veins and distributes (*distingue*) it through subtle pores, and as the blood from below surges upward and is shed through the ruptured veins of the forehead and as the water rises from the lower parts of the vine to its divided branches, so too from the lowest depths of the sea the water ascends to the summits of the mountains, and there finding the natural veins it falls through these and returns to the sea below. Thus within and without it goes changing, sometimes rising upward with accidental motion, sometimes descending with natural freedom. So joined together in a continuous revolution it goes circulating (*girando*)."

This might be taken as another piece of evidence that Leonardo had some sort of perception of the circulation of the blood, but there is no suggestion of a passage of the blood from veins to arteries or vice versâ, merely a flow from and to the heart. It is how the blood reaches the head, how the sap ascends in the plant and how water comes to be found far above the sea-level, it is these problems that disturb him. Bottazzi (1910) referring to the passage just quoted suggests that the inexorable analogy of the two living beings, the greater and the lesser, so conquered the spirit of Leonardo as sometimes to diminish his penetrative powers. It seems to have done so in this case, for he returns to his problem elsewhere and maintains that the water ascends from the sea to the mountain tops by the same cause that carries the blood to the head (A, 55v), and in still another passage he defines the cause, stating that blows on the head should not cause bleeding since the veins should be able to contain all the blood that is there and blood should not ascend; the cause of the bleeding is that the heat mingled with the blood desires to return to its element and draws the blood with it (A, 56v).

Fig. 59. An early sketch of the digestive tract and longitudinal and transverse sections of the penis. (QIII, 3v.)

CHAPTER XIV

THE ORGANS OF DIGESTION

Of the pre-Vincian illustrations of the digestive tract the pregnancy figure of Ketham's *Fasciculus Medicinæ* (fig. 4) may be taken as a type, since, although it was not published until 1491 it was evidently based on earlier figures (see p. 36). It is difficult to believe that its representation of the digestive tract could have been regarded otherwise than as a conventionalism, since at the time of its publication dissections and autopsies were being made more or less frequently, and no one who witnessed one of these could have supposed that the Ketham figure made any pretensions to accuracy. The same remark applies to the torso figures of Peyligk and Hundt (figs. 6 and 7) and even the visceral figure of Phryesen's *Spiegel der Artzny* (fig. 9) can hardly have been taken as exact. Leonardo's figures illustrating this portion of the anatomy are fewer in number than those of some other portions and probably all were made at an early period, but nevertheless even the poorest are superior to those mentioned and the majority do give an approximately correct idea of the form and arrangement of the various parts.

The earliest of Leonardo's figures of the digestive tract are those on QIII, 3v, the folio of the coition figure, the male of that figure showing the tract partly, while in another figure (fig. 59) it is shown more fully, though still very crudely, the sketch being evidently a diagram from memory rather than from an actual preparation. Furthermore, it shows some anomalous structures that can not be readily identified. From a globular enlargement of the intestine, possibly a greatly distended cæcum, a tubular structure passes to the anterior body wall, suggesting a Meckel's diverticulum, and from the large intestine a second stout diverticulum projects through the wall and is labeled *matron*. Can this be intended for a hernia? A second and better profile view of the entire digestive tract is shown on QV, 20, this time together with the other thoracic and abdominal viscera; in this too there is a connection of the intestine with the umbilicus (*belico*). Neither of these figures, however, is Leonardo at his best, his more accurate drawings being those of portions of the tract and these may be considered in order.

And first of all regarding the teeth. He notes that those teeth that are farthest away from the line of the temporomandibular articulation are at a mechanical disadvantage as compared with those that are nearer, and finds in this an explanation of the form of the teeth. Those that act most powerfully, the *mascellari*, have broad flattened crowns suitable for grinding the food, but not for tearing or cutting it; those that act less powerfully, the incisors, are suitable for cutting the food, but not for grinding it; while the canines (*maestre*) are intermediate between these two sets, their function being presumably that of tearing the food, that being the purpose ascribed to them in Avicenna. The recognition of the different groups of teeth long antedates Leonardo, his contribution being the correlation of form with function. The term *maxillares* applied to the grinding teeth is found in Mondino, but is applied by him only to the bicuspids, the rest of the grinders being termed *molares;* Avicenna does not distinguish between the bicuspids and molars proper, but terms them all molars. The source of the term *maestre* for the canines is unknown.

An excellent figure of the tongue seen from the side is on QIV, 10, the tortuous course of the ranine artery along its lower surface being well shown. Details of the upper surface are, however, lacking, although attention is called to its great roughness in many animals, and to emphasize this condition Leonardo cites an observation of his own in Florence, where twenty-five or thirty lions were always kept, to the effect that one of these lions with a few licks of its tongue completely removed the fleece from the carcass of a lamb before beginning to devour it (QIII, 9v). Leonardo's views as to the muscles of the tongue and its movements have already been considered (p. 136). As to its functions he notes that it is the sensory organ for an infinite number of savors, simple and compound (AnB, 28v); it acts in the pronunciation and articulation of syllables, the components of all words; and it effects the necessary rotation of the masticated food and cleanses from this the inner part of the mouth and the teeth. He makes a memorandum to enquire how the frenum (*briglia*) is placed in the tongue (AnA, 3).

On QIV, 9v is a sketch showing from the side the upper part of the trachea, the epiglottis and the tongue, and a circular area situated at about the junction of these three structures is intended to indicate the position of the tonsil (*amandibula*). In the text the tonsils are described as two cushions interposed between the mandible and the base of the tongue, forming a space between these two, which may receive the lateral convexity of the tongue when it is curved and allow it to cleanse away the food that may collect at the sides of the base of the tongue.

He speaks also of the uvula (*uvola*), in one passage (AnB, 41) assigning to it a participation in the sense of smell, in another (AnA, 3) merely making a memorandum to remove the side of the mandible so as to show the uvula *in situ* and to determine its distance from the opening of the larynx; and in a third, on the same page, he expounds

[Fig. 60. Above, a supposed arrangement of intestine; below, stomach, liver and spleen with splenic vein; to right the caecum and appendix. (AnB, 14v.)

Avicenna's (Galen's) theory, describing it as the gutter which receives the humor descending from above and directs this humor to the œsophagus, so that there is no reason for it to enter the trachea and so descend to the spiritual places, *i.e.* the lungs. The uvula is clearly shown on AnA, 3, and also on AnA, 6v.

Leonardo does not distinguish between the oral cavity and the pharynx, nor does he mention, although he undoubtedly knew of it, the communication of the nasal cavity with the latter. He shows the œsophagus (*meri*) in whole or in part in several figures as a practically straight simple tube extending between the mouth cavity and the stomach, one of the best figures (AnB, 37v), though probably not drawn from a human preparation, showing it in its relation to the trachea, the carotid artery (*ipopleticha*) and spinal column. He probably observed the peristaltic contraction of the œsophagus, for he writes (QII, 9):

"Since all the muscles have a dilating and extending motion, note, in making the anatomy, what are the nerves which, between the œsophagus and the cervical vertebræ, enter the muscles in that place (*i.e.* the œsophagus), which by their dilation constrict and close successively the œsophagus when food is propelled through its narrow canal to the stomach; and so in this case be diligent to note every least circumstance."

The representations of the stomach, with the exception of that in the coitus figure and that in the diagram on the same page (QIII, 3v), bear a close resemblance to the human stomach and are therefore a great advance upon the travesties seen in the Ketham figure and in those of Hundt and Peyligk. And yet the form given it is not exactly that of the human stomach (fig. 60). The œsophagus gradually widens as it approaches the stomach, so that there is no abrupt transition from one to the other as in man, and the fundus of the stomach is not so sharply defined, even though the œsophagus opening is somewhat farther to the right than is usual. But more striking is the course of the pyloric end and first portion of the duodenum. In the majority of the figures instead of passing upward, backward and to the right, the direction is upward, backward and to the left, so that the duodenum descends behind the stomach and makes its appearance from behind it opposite the middle of the greater curvature.

In man, it is true, the œsophagus does enlarge in its subdiaphragmatic portion to form what has been termed the cardiac antrum, but its union with the stomach is abrupt and not gradual as Leonardo represents it. So too a curvature of the pylorus and duodenum such as Leonardo figures does occur as a rare anomaly in man (Taylor, 1908), but so rare that it would be a remarkable coincidence if Leonardo had chanced upon an example of it. One must suppose that Leonardo was drawing what he had seen, and accordingly one must suppose that he was not representing a human stomach, but that of some animal, the pig most probably, since it presents the peculiarities that Leonardo figures and, as is stated in Copho's *Anatomia porci* of Salernitan days, "there are no animals so like us in their internal parts as pigs." Leonardo had, no doubt, seen the human stomach, for he represents the pyloric bend correctly in several figures (*e.g.* AnB., 14) (fig. 61), in one indeed (AnB, 12) showing both types of curvature, as if uncertain as to which was the proper one. He found the form of the human stomach so similar to that of the pig, that he represented the latter with which he was most familiar, as human.

Few details as to the structure of the stomach are given. The pylorus (*portinaro*) is evidently regarded as a sphincter since it is said to close so as to prevent the return of expelled material to the stomach (QI, 6v). He accepts the Galenic teaching, handed down by Avicenna, that there are circular and longtiudinal muscle fibers in its walls, but denies that these have the function of retaining and attracting the food. All the intestines and all structures capable of enlarging and contracting have longitudinal and circular muscles, but, like the web and the woof in fabrics, these are only to give strength so that the organ may not readily be broken or torn (QI, 5v). The mechanism of the expulsion of the stomach contents, like all questions of mechanisms, interested Leonardo greatly, but this may more conveniently be considered with that governing expulsion from the intestines.

The arrangement of the intestines (*budella*) is shown in several figures, but in none quite accurately, the characteristic loop of the duodenum, for example, being overlooked. The small intestine is shown quite digrammatically in QV, 24, and more in detail in AnB, 14v and 14, as arranged in two descending and one ascending limb whose relative position varies. Indeed Leonardo seems to have supposed that there was considerable variation in the arrangement, for he makes a memorandum that he should "write of the varieties of the intestines in the human species" (AnB, 37). In the figure on AnB, 14v (fig. 60), the pylorus bends to the left and is continued into a descending limb on the left, the ascending limb is in the middle and the second descending limb on the right, these limbs being named respectively duodenum, jejunum (*degiuno*) and ileum, an application of the terms somewhat different from the usual. In AnB, 14 (fig. 61), the pylorus bends to the right and in this case the first descending limb (duodenum) is the middle one, the ascending (jejunum) is to the right and the second descending (ileum) to the left, passing at its lower end transversely across to join the colon. As to the purpose of the coiling of the intestine it is said (AnB, 14v) that—

"Animals without feet have a straight intestine, for they are always lying down. But man, being erect, the stomach would quickly empty itself were it not for the coiling of the intestine and, if the intestine were straight, every

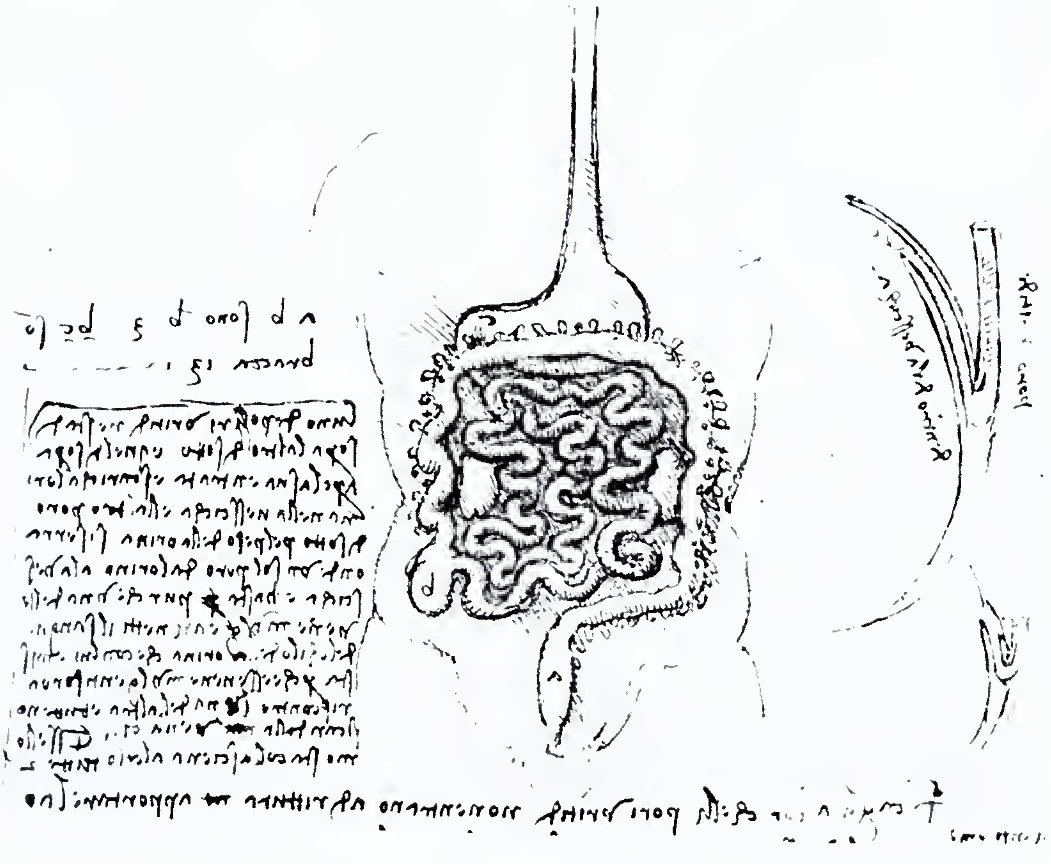

Fig. 61. A second arrangement of the intestines. To right, suggestion as to mode of entrance of ureter into bladder. (AnB, 14.)

part of the food would not be touched by the intestine, and thus much would remain undigested and could not be absorbed by the intestines and carried to the meseraic veins."

The large intestine is shown forming three sides of a quadrangle occupied by the coils of the small intestine. The cæcum (*monoculo*) is shown in several figures, but only in that on AnB, 14v (fig. 60) is it provided with a vermiform appendix (*orecchio*), which is represented as a short, stout process attached close to the entrance of the ileum. The colons are distinctly sacculated and in the figure on AnB, 14 (fig. 61) are well supplied with epiploic appendages. There is no distinct sigmoid colon, but the rectum (*intestino retto*) contrasts with the rest of the large intestine by the absence of sacculations and appendages. Leonardo seems to imply (QIV, 11) that there are special muscles guarding the anal orifice, these muscles being relaxed under a stimulus provided by the superfluities of the food; indeed he formulates a general law that all sphincters guarding orifices of the body are relaxed by the stimuli furnished by the substances that pass through them. Some sketches on QIII, 1 perhaps represent the structure of the anal canal and the internal sphincter ani. They show five petaloid structures situated at the summits of as many columns, the petals being formed of loops of muscle fibers which are continuous around the entire circumference of the rectum. When the loops contract it is supposed that they will pull the columns after them, shortening and thickening them so that the anus is closed with considerable force. Leonardo speculates why there should be an odd number of columns and why, if the number is necessarily odd, it should be five rather than three or seven. Presumably the columns may be folds in the contracted anal canal and the petals the upper edge of the internal sphincter where it passes over into the circular musculature of a distended rectum.

Leonardo found the length of the large intestine to be three braccia, that of the small intestine to be thirteen braccia (AnB, 14). Placing the value of the braccio at 58.36 cm. these numbers become respectively 1.75m. and 7.5m., both of which are somewhat above the average, though within the limits of variation. In *il vecchio* he found the colon much diminished in diameter and regarded that condition as characteristic of old age (AnB, 10v, 11v), stating that the colon in the aged is no thicker than the middle finger, while in young people it is as thick as the arm (AnB, 22v).

Leonardo devoted considerable attention to the mechanism by which the contents of the stomach and intestine are expelled. He made the interesting observation that the stomach expels its contents rhythmically or, as he expresses it, "by jerks or with impetus, with intervals of quiet" (QI, 6v), but does not ascribe it to rhythmical peristalsis, the characteristic wave-like contractions of the intestinal musculature being unknown to him. Indeed he specifically denies that the stomach "moves of itself in the expulsion of chyle" (QI, 5v), the rhythmical expulsion being due to the alternate contractions of the abdominal wall (*mirach*) and the diaphragm in respiration. When the diaphragm relaxes it is forced upward by the expansion of the gas in the intestines, aided by pressure due to the contraction of the abdominal walls. The stomach is pressed up against the diaphragm and is forced to emit a portion of its contents, and when the diaphragm contracts it presses on the stomach from above and again forces an expulsion of some of the stomach contents. The pressure from above is more powerful than that from below, but nevertheless that produced by the abdominal musculature may be sufficient to cause vomiting. Four functions are assigned to the abdominal wall, (1) it presses upon and elongates the coils of the intestine; (2) by this pressure it forces the intestines against the stomach and causes it to emit chyle through the pylorus; (3) it forces the stomach against the diaphragm, causing the latter to assume a convex form; (4) thereby pressing out of the lungs the air that had previously been inspired (QII, 16).

With the expulsion from the intestines the case is different. At first Leonardo was inclined to ascribe it to the simultaneous, instead of the alternate, contractions of the diaphragm and the abdominal muscles (QI, 5v), but later, noting the posture assumed by dogs in defecation, he begins to doubt whether the muscles of the abdominal wall have anything to do with it, since in the assumed posture they would be relaxed (QII, 16) and the more the body was curved the greater would be their relaxation. The longitudinal muscles (*recti*) would obviously be relaxed (QII, 16v) and he argues that the latitudinal ones (*obliqui*) can not act, since if one shoulder is depressed and the other elevated, the muscles on the depressed side would be relaxed and without force (QII, 16). Furthermore he claims that the diaphragm can have no action, since the expulsion is performed during expiration (QIV, 3), a statement that it is not quite correct, but, accepted, it leaves Leonardo with only the transverse muscles to compress the intestines, and these he regards as belonging to the peritoneum (*sifac*) rather than to the *mirach*. His conclusion then is that—

> "It is the *sifac* which acts, because it becomes so much the more powerful the more the body is curved, since in curving the body becomes thicker and also the intestines, these shortening with the curvature. Therefore four powers act in expelling superfluities from the intestine; the forward curvature of the body, which, like a band, compresses the intestine between its weight above and the pelvis (*alcatin*), a bone that forms a support for the intestine; and besides this the *sifac*, which encircles the intestines with large bands, becomes stretched by their increase in thickness and acquires power; and there is to be added the force of the muscles of the *sifac*, which draw upon it and press and squeeze it on the intestines." (QII, 16.)

Active movement of the intestinal walls does not come into the story, since the longitudinal and circular fibers were for Leonardo merely for strength and not contractive (see p. 184). What then prevents the pressure on the intestines from forcing their contents back into the stomach? This is answered by the supposition that when the pressure is being exerted the stomach is being compressed against the diaphragm and would be more apt to void its own contents than to receive those of the intestines (QI, 7). Furthermore, since the contents of the duodenum and jejunum are more fluid than those of the rest of the intestines, they would be the first to yield to the pressure and, the pylorus being closed, would pass on to other portions of the intestines. Hence it is that the jejunum is always found full of gas (QI, 7v).

Gas, or as Leonardo termed it air or wind, accumulates also in the colon and the cæcum is regarded as being a reservoir for any superfluous amount that may be formed, while the appendix (*orecchio*), being capable of dilation and contraction, serves to protect the cæcum from rupture by a too great accumulation of "superfluous wind" (AnB, 14v). This gas is developed by evaporation from the intestinal contents as they pass downward and gradually become more solid and, commingled with the fetor due to corruption (see p. 178), it collects especially in the jejunum (QI, 7v) and colon (QI, 12) and gives rise to pain when it returns from the rectum to the colon (AnB, 17). To it is ascribed the expulsion of the solid contents of the rectum and it—

"makes a noise provided that it is more than sufficient for refilling the vacuum due to the evacuation of the aforesaid superfluities." (QI, 12.)

Of the glandular adnexes of the digestive tract, Leonardo has little to say; of the salivary glands and pancreas nothing. The liver, however, is shown in a number of figures, but it is not always the human liver that is represented and in two figures on QIII, 8v, it is apparently the liver of a fetus or infant, concerning which it is stated that the liver is greatly diminished or wanting on the left side when fully developed, since on that side it has to make space for the stomach and spleen and also for the heart. The torso figures of Peyligk and Hundt (figs. 6 and 7) and mediaeval manuscripts in general represent the liver as divided into five lobes or *penulæ* (*pænula* = a cloak or mantle) which, as it were, grasp or invest the stomach, and the descriptions given by Avicenna and Mondino are in harmony with that idea, although the latter notes that the lobes are not always distinct in the human liver. Leonardo followed Mondino's lead. He accepted the five-lobed condition as fundamental for the liver, describing the portal vein as arising by five roots in the liver, one from each of the lobes (*penule*) (AnB, 11v), but in his more finished drawings, he either shows no indications of the lobes (QIII, 8v; probably from the pig) or suggests them only by slight indentations of the ventral border (AnB, 37v, also from an animal) (fig. 62). In several figures in which the liver is shown, it is represented in a highly diagrammatic manner and as if confined to the right side of the body. These figures probably belong to the earlier period of Leonardo's studies, but even in them there is little or no lobation shown (*e.g.* QIII, 10v). It is noted that in *il vecchio* the liver was paler in color than usual and its substance very friable and dry like sawdust, washing away readily from the vessels (AnB, 10v, 22).

The fundus of the gall-blader is shown *in situ* in several figures, but only in those on QIII, 8v is the connection of the bladder with the intestine, by means of the common bile-duct, represented. The gall-bladder is described as the servant of the liver, sweeping up and cleansing all the impurities and superfluities from the food distributed by the liver (AnB, 2v), and it is possible that this manner of expressing its function is a reminiscence of the teaching of Avicenna. He recognized four principal organs in the body, the heart, brain, liver and testes, and for each of these there was a preparing servant (*serviens preparator*) and a carrying servant (*serviens lator*). Thus for the heart the preparers are the lungs and the carriers the arteries, and for the liver the stomach is the preparer and the veins the carriers. Leonardo's statement is not quite in agreement with this, but the idea of another servant, a *serviens purgans*, may have been suggested by it.

In the Galenic physiology, which was, essentially, that of Leonardo, the function of the liver was to concoct the chyle into blood and to pass this blood on to the heart and other organs, whence it was termed "the distributer and dispenser of vital nourishment" (AnB, 2v). The heat necessary for the coction can not, however, be developed by the liver, since it has no motion of its own and can not impart a rapid motion to the contained blood, but the heat is brought to it by the artery that enters at the porta. And it is necessary that this heat be continually renewed, since the liver can not retain heat, as does the heart, being less dense in substance (QI, 4). During the coction in the liver, fluid is withdrawn from the chyle and sent by way of the vena cava to the kidneys, and certain impurities are also separated, part of these as yellow bile collecting in the gall-bladder and thence passing to the intestine and eventually to the stomach. In this last part of its course the yellow bile passes in a direction contrary to the chyle that is expelled from the stomach, a curious contradiction of the arguments advanced to show that there could be no return of material from the intestine to the stomach, but explained by the supposition that the contrary currents need not conflict any more than do contrary currents in a river (QIII, 8v).

Of the spleen, which may be considered here on account of its supposed function in the purification of the chyle, Leonardo gives several illustrations (figs. 4, 60, 62), representing it as a somewhat elongated

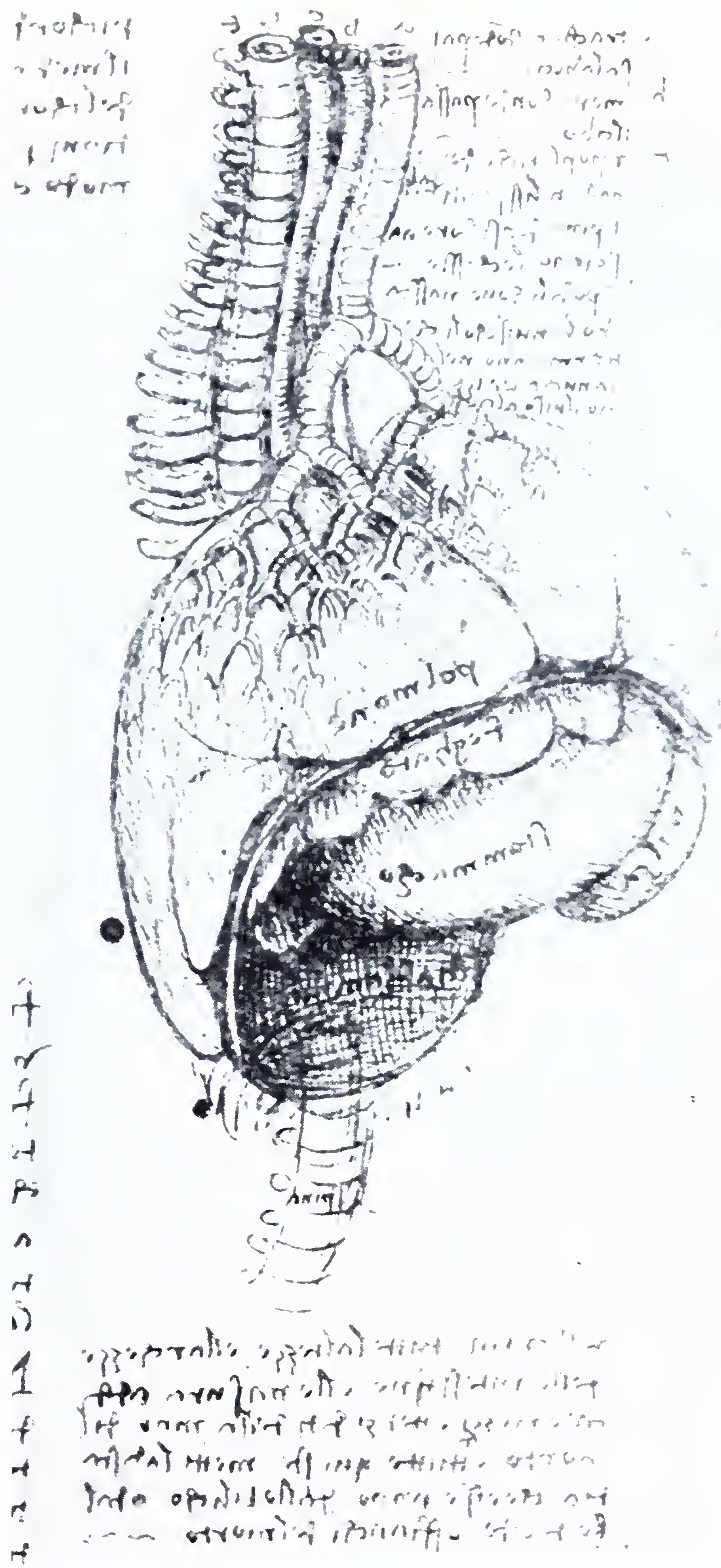

Fig. 62. Lungs, diaphragm, liver, stomach and spleen of an animal.
(AnB, 37v.)

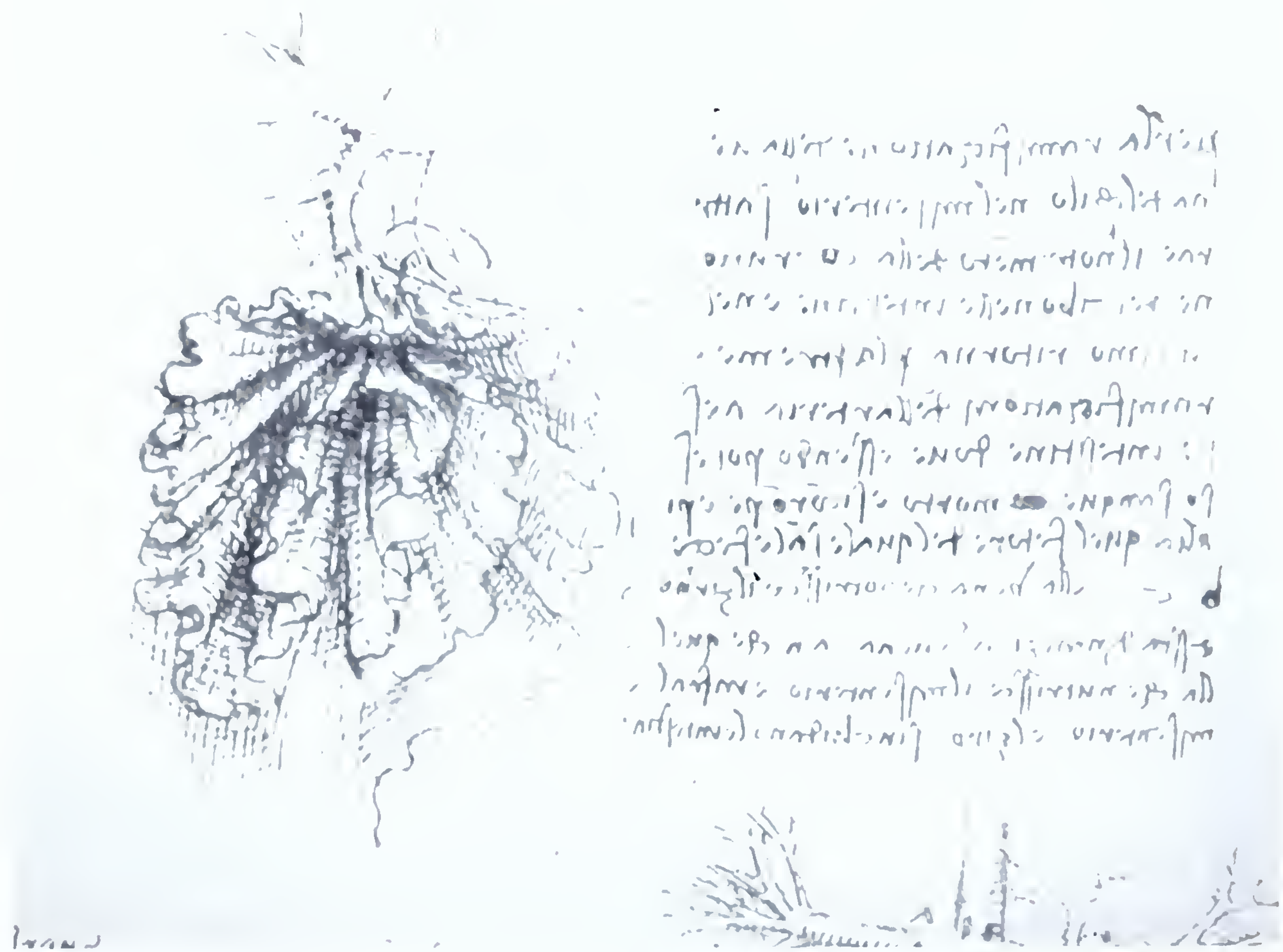

Fig. 63. The mesentery. (AnB, 3.)

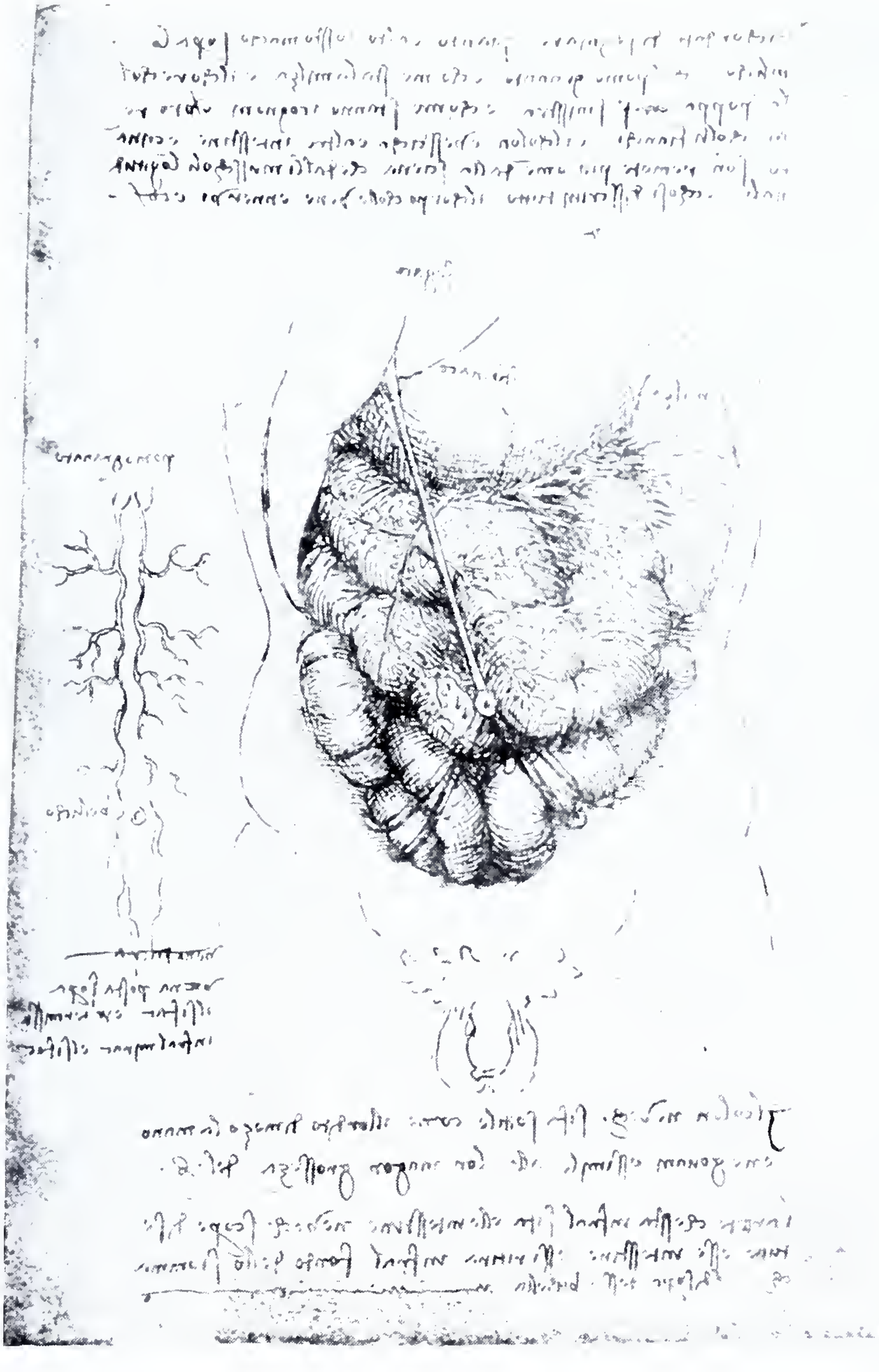

Fig. 64. The great omentum with the hypogastric vessels and the umbilical vein. To the left the deep epigastric veins. (AnB, 22v.)

oval structure, more or less concave on its medial surface, where it is in close relation to the stomach. Its substance is said to be less dense than that of the liver and therefore less capable of retaining heat (QI, 4), but, nevertheless, its function according to the Galenic physiology was to attract the more earthy impurities of the chyle and, with the aid of the heat conveyed by the splenic artery, to convert them into *melanchole* or black bile. It was this theory that induced Leonardo to represent veins passing directly from the liver to the spleen.

As to the final disposition of the black bile there is some discrepancy between the statements of Galen and Avicenna, the former supposing that like the yellow bile it was conveyed to the stomach, while Avicenna held that it passed from the spleen to the great vein (vena cava). Mondino followed Galen in this respect and Leonardo followed Mondino, representing a vein passing directly from the stomach to the spleen (fig. 60), and stating that—

> "It is impossible to remove the spleen in men, as is believed by those who are ignorant of its essence, since, as is shown here, it can not be removed without death, which results on account of the veins with which it nourishes the stomach." (AnB, 11v.)

It will be convenient to consider here also Leonardo's descriptions of the peritoneum of which he recognizes three portions, the parietal peritoneum (*sifac*), the mesentery (*misenterio*) and the great omentum (*zirbo*). The sifac lines the interior of the abdominal wall (*mirach*), enclosing the intestines (QII, 7), and is so closely related to the transverse muscle of the abdomen, that Leonardo regarded this as a muscle of the sifac rather than of the mirach, and accordingly attributed to the sifac an important part in the expulsion of the abdominal contents (see p. 186). He notes that it covers the surface of the bladder or, as he expresses it, separates the intestines from the bladder, and he suggests as a topic for investigation how it is that the intestine can at times descend into the scrotum (QIII, 4v).

From the dorsal wall of the abdomen the peritoneum is reflected forward to form a nervous (*i.e.* fibrous), fatty membrane, attached above to the under surface of the diaphragm, having in it the roots of the twelve chief veins that pass to the liver, and being attached at its free edge to the intestines throughout their entire length (AnB, 3). On QV, 24 Leonardo makes the following memorandum:

> "Draw the intestines in position and sketch them yard by yard, tying first the ends of the detached part and of the remainder; and when you have detached them draw the lips of the mesentery from which you detach such part of the intestine; and when you have drawn the position of this mesentery, draw the ramifications of its veins; and so you will proceed successively up to the end; and you will commence at the rectum and will enter the colon on the

left side; but first remove with a chisel the pubic bone and the hip bone in order to note well the position of the intestines."

The result of this dissection is, in part, to be found in two figures on AnB 3, showing the mesentery after the removal of the intestines. The frilled character of the mesentery is well shown (fig. 63), but the figures can not be said to be anatomically correct, since the line of attachment of the mesentery follows the same course that the intestines do in the figure on AnB, 14v, and there is a well-developed mesentery for both the ascending and descending colon. The great omentum (*zirbo*) is spoken of as a network structure between the intestines and the *sifac,* and is well shown on AnB, 22v (fig. 64), covering the greater part of the intestine.

Fig. 65. Dissection of neck, in which an animal's larynx is represented as human. (QV, 16.)

CHAPTER XV

THE ORGANS OF RESPIRATION

Leonardo's treatment of the respiratory apparatus is less satisfactory to the human anatomist than much of his other work, for the reason that his observations are apparently made on animal forms exclusively. At least among all the illustrations of the organs of respiration there is not one that can certainly be regarded as representing a human structure, while many are obviously based on animal dissections. They are not human but animal lungs that he figures (fig. 62), it is not a human but an animal larynx that is shown, and yet the larynx is drawn into an outline sketch of a human neck and head (QV, 16) (fig. 65). Nevertheless, the figures are a marked advance on those of his predecessors; they are not merely conventional, but represent what Leonardo actually saw and he gave a more detailed portrayal of the structure of mammalian organs than had been available. To that extent they make an addition to the knowledge of the human organs just as did Galen's observations on monkeys and pigs.

Leonardo's views as to the mechanism of respiration have already been considered in connection with the thoracic musculature (p. 138). They were essentially those of Galen and, briefly restated, were to the effect that by the elevation of the ribs by muscular action and by the flattening of the diaphragm, a vacuum was created in the thorax and air rushed into the lungs to fill it (QI, 5). Expiration was also partly a muscular act, the internal intercostal muscles drawing down the ribs, while the abdominal muscles by pressing upon the intestines caused these and the stomach to press against the diaphragm, so forcing it upward (QI, 5v). There was thus an alternation in the contraction of the diaphragm and that of the abdominal muscles, the one acting in inspiration and the others in expiration. The expired air passed through the trachea and larynx and to the exterior either by the mouth or the nose, and Leonardo notes that one can not breathe by the nose and the mouth at the same time, as is shown by the fact that one can not blow a whistle or flute through the nose and through the mouth at the same time (AnA, 3).

The larynx, sometimes termed *epigloto* after the Arabistic manner, was merely the constricted uppermost portion of the trachea, constricted so as to condense or compress the air issuing from the lungs and thus make it available for the production of voice and cause it to "press and dilate the various passages and ventricles of the brain" (QI, 5).

The function of the vocal cords in the production of sound was unknown, but they are represented in some figures on AnA, 3 (fig. 66), and the depressions between them, later known as the ventricles of Morgagni, are termed ventricles and it is stated that they may become filled with fluid (*omore*) and then produce a roughness of the voice.

Of the parts of the larynx the epiglottis is well shown and its function as a protection against the entrance of food particles into the trachea is noted, a figure (fig. 66) showing a bolus of food passing over the epiglottis (*linguella*) and forcing it back over the entrance to the larynx. On the same folio (fig. 66) is a diagram of a frontal section through the larynx showing two folds projecting forward from where the arytenoid cartilages might be (the ary-epiglottic folds) and between these and the thyreoid cartilage on either side a pocket, evidently a piriform recess, whose purpose is said to be to receive particles of food which might otherwise accidentally pass through the glottis, an event that would have fatal results. The food particles are retained by the recesses until, by coughing, the air from the lungs issues from the glottis with such force as to produce vortices in the recesses, whereby the food particles are carried back to the mouth. The thyreoid cartilage (*scutola*) is shown, but it is that of an animal, and below it is the cricoid cartilage separated from it by a distinct interval bridged by membrane. The arytenoid cartilages are not shown, but in a view of the larynx from above the tubercles on the ary-epiglottic fold formed by the cornicula laryngis and the cuneiform cartilages are distinctly figured (AnA, 3). There is a memorandum (QI, 10) to describe what and how many are the muscles that move the larynx (*epigloto*) in the production of voice, but no such description is recorded. A figure on AnB, 33v (fig. 75), drawn from *il vecchio,* shows the recurrent laryngeal nerve ascending alongside the trachea and sending branches to that structure and to the larynx.

The trachea is described in the notes as composed of a succession of cartilaginous rings, incomplete posteriorly where the trachea is in contact with the œsophagus (QI, 9), this incompleteness having two uses, (1) to aid in the production of voice and (2) to give room for the passage of food down the œsophagus, which is between the trachea and the cervical vertebræ (AnB, 33v). It would seem too that it was recognized that the successive rings were not in contact, the intervals between them being occupied by muscle tissue, but in none of the figures are these intervals shown, except in two small diagrams (QII, 1) (fig. 67), where they are represented as dilated during inspiration and collapsed in expiration. In fact there is no accurate representation of the structure of the trachea except in the figure of a moderately sized bronchiole in which the cartilaginous rings have broken up into irregularly scattered plates (QII, 1) (fig. 67). It is to be noted that

Fig. 66. Various figures of larynx and trachea; surface modeling of leg. (AnA, 3.)

Fig. 67. The heart and bronchi after maceration away of the lung parenchyma. To the right representations of the bronchi. (QII, 1.)

Leonardo does not use the terms bronchus or bronchiole, the air passages being termed trachea or tracheal branches to their ultimate ramifications.

Deeply interested in all mechanical problems and seeking to explain observed phenomena in the terms of structure, Leonardo gave some attention to the mechanics of phonation. He was, of course, handicapped by his ignorance of the vocal cords and the part they play, but accepted the current view that sound production occurred in the upper part of the trachea, *i.e.* in the larynx, but true to his principle, *experientia docet,* he proposed to test this view by removing the trachea and lungs and suddenly compressing the latter (AnA, 3). This experiment was suggested by the knowledge that it succeeds in the case of a swan or goose, "which frequently may be made to sing even when they are dead," but evidently Leonardo was unaware that the organ of sound (*syrinx*) in birds is quite a different affair from that of mammals and one finds no record of the results of the experiment.

Accepting the larynx as the essential organ of voice, Leonardo goes on to point out that other organs are involved in phonation. He states that the trachea (larynx) takes no part in the formation of the consonantal elements of phonation, but merely produces the voice and especially the vowel sounds *a*, *o*, *u*, and ascribes the difference of these sounds to the air impinging on the curved surface of the soft palate and to the position of the lips. If the lips are protruded the sound *a* passes into *o* and if they are still further protruded *o* becomes *u*, this last sound also requiring that the epiglottis (larynx) be drawn upwards toward the palate (QIV, 10). Expressed in modern terminology he is pointing out the importance of the shape of the resonating chambers in the production of the vowel sounds. As to the mechanism by which the pitch of the voice is altered, as in singing, he is of course far astray. He compares the trachea to an organ-pipe and notes that the pitch of such a pipe does not depend upon the size of its mouth, but upon whether the pipe is long or short or broad or narrow (QIV, 10). Consequently he concludes that the pitch of the human voice is dependent upon the length and diameter of the trachea.

"Note well the use of the trachea and how it disposes itself to make high, middle and low voice, and what muscles produce these. Consider if the muscles between the œsophagus (*meri*) and the spinal column of the neck can, by their contraction, press the œsophagus against the flexible part of the trachea, where there is a deficiency in the rings. And also note if the movement that produces the size of the trachea in its contraction may not be made by the lateral muscles of the neck. The cause of the dilation need not be sought, since this is due to the rings acting like a spring and the dilation is increased by shortening the trachea, as do those who sing contrabasso; the shorter the trachea the lower the voice." (QI, 9.)

In another note, however, he seems to doubt that the shortening of the trachea is sufficient and suggests that it also dilates to some extent in its upper part—

"which does not receive any degree of sound and the voice comes to rise in the rest of the shortened trachea (*channa*)."

This seems to contradict the idea that the voice is produced in the larynx, but it was merely a suggestion which he proposes to test on various animals,

"Giving air to their lungs and squeezing them, contracting and dilating the *fistola* which is the generator of their voice." (QIV, 10v.)

Another point that interested him was how voice could be produced without sound, as when one whispers in another's ear (AnA, 3), but he does not attempt an explanation. Further he inquires as to the cause of the feebleness of the voice in aged persons and concludes that in old age there is a contraction of the trachea just as there is of the intestines (see p. 185).

Following the usage of his predecessors, Leonardo speaks of the lungs in the singular (*il pulmone*), regarding them as a simple organ with two lobes, perhaps because they were regarded as being composed essentially of repeated branchings of the trachea, and this is a single organ. That the two lobes were separated by what was regarded as a median partition, the mediastinum, did not affect the case; the trachea and lungs were a single organ, just as was the brain with its two cerebral hemispheres. In addition to the branches of the trachea there were accompanying arteries, veins and nerves, the whole being bound together by a certain amount of proper substance or parenchyma, dilatable and extensible and placed between the branches of the trachea like a soft feather bed (AnB, 37v). In the figure of the tracheal branches after the parenchyma had been macerated away (QII, 1) (fig. 68), the terminal branches shown still had cartilage in their walls, so that the multitudinous systems of respiratory bronchi, alveoli, air-sacs and air-cells, the actual respiratory tissue of the lung, were all included in the parenchyma.

Leonardo erroneously assumed that the total area of the cross-section of the ultimate branches was equal to the cross-section area of the trachea itself (QI, 5v), believing, presumably, that such an equality in size was necessary in order that there might be free passage for the air to and from the ultimate branches. He was considering only the tidal and complemental air, but was aware that air, residual air, still remained in the lung after the completion of an expiration (AnB, 17). From his studies on animals and especially on the pig he was inclined to believe that when air was drawn into the lungs they expanded laterally only, not lengthwise (AnB, 17), perhaps finding support for

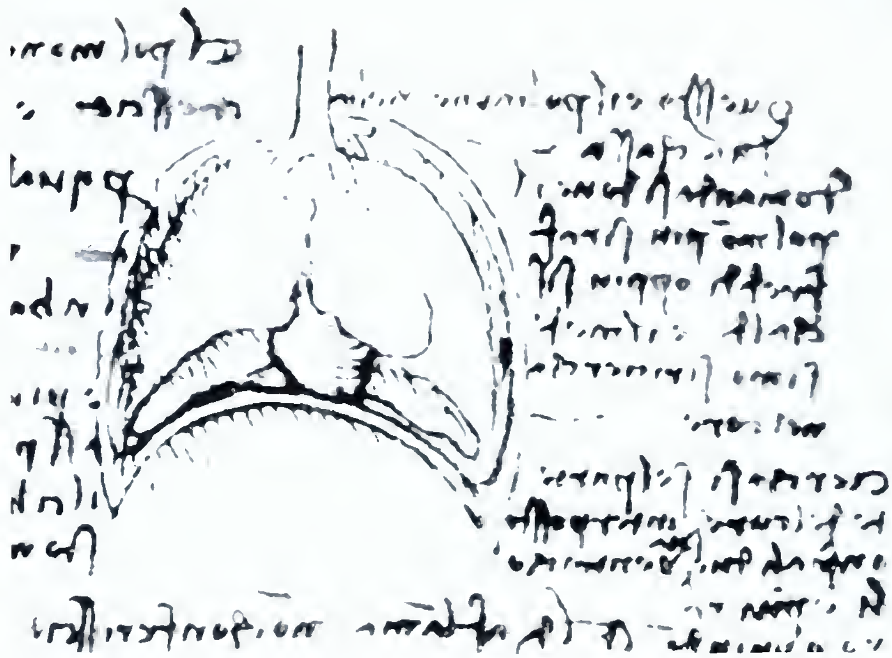

Fig. 68. Sketch of lungs and heart, showing pleural cavities. (QIV, 3.)

this opinion in the idea that the muscular intervals between the rings of the bronchi bulged out in inspiration and contracted in expiration. In what is probably a later note, however, it is stated that the lungs increase and decrease in all directions, but chiefly lengthwise, since their expansion in this direction is useful in expelling food from the stomach (QIV, 3). It has already been noted (p. 177) that Leonardo had probably observed the bronchial arteries. The pulmonary vessels he describes as accompanying the branches of the trachea, the vein always lying above the artery, *i.e.* further away from the tracheal branch, an arrangement that was to be expected, since the arterial blood, being hotter, is in greater need of being refreshed by the air drawn into the lung (QII, 1). He represents (QII, 1) slender cords accompanying the branches of the trachea and identifies them as nerves, but the identification is more than doubtful.

Galen held the opinion that a certain amount of the inspired air filtered through the lungs into the pleural cavities. Neither Avicenna nor Mondino mention this idea, but nevertheless Leonardo in two of his figures of the lungs (AnB, 17, and QIV, 3) (fig. 68) represents a distinct space between the lungs and the thoracic wall, and in the notes on AnB, 17 he definitely states that there is air between the lungs and the chest wall, and when the lungs expand this air is forced downward between the lungs and the diaphragm, causing the latter to press upon the stomach and so aid in the expulsion of its contents. It also presses upon the pericardium and causes the small amount of fluid contained in the pericardial cavity to ascend and bathe the heart, moistening that heated organ and preventing it from drying up. Later Leonardo seems to have become sceptical as to the existence of this pleural air space, for on QII, 7 there is a memorandum inquiring whether or not there is such a space.

The traditional functions ascribed to the lungs were the cooling and refreshing of the heated blood sent to them by the heart and the supplying of the crude substance out of which the vital spirits were elaborated in the heart. Leonardo accepted the first of these functions, the cooling and refreshing of the blood, but improved on the Galenic view that some portions of the inspired air were actually brought to the heart. So far as he was able to trace them, the branches of the trachea in the lungs had thick walls and showed no pores by which they might communicate with the blood-vessels, and he was consequently inclined to believe that the relation of the pulmonary arteries to the tracheal branches was merely one of contact and that the refreshing of the blood took place through their walls. Of course he could not be certain of what might take place in the so-called parenchyma of the lungs, but, so far as he could determine, there was contact only and no communication, although he hesitates to pronounce positively on the matter until he should have completed a dissection then in hand (QII, 1).

Leonardo's attitude as to the formation of vital spirits in the lung is not so clear. In certain passages he seems to imply quite definitely that the heart was the sole agency in the process as, when speaking of the heat produced by the friction of the blood on the heart walls, he says:

"And this heat subtilizes the blood, vaporizes it and converts it into air (*i.e.* spiritus)." (QII, 11.)

Or when speaking of what would result from the cessation of the flux and reflux of the blood he states that it would not be heated and "consequently the vital spirits could not be generated and therefore life would be destroyed" (QII, 4v). It may be, however, that the blood had already been refreshed in the lungs and had acquired some spiritual essence which the heat of the heart elaborated, and Leonardo may have been thinking only of the last part of the process. For in another passage where he refers to the psychic or animal spirits, "which command the nerves," he ascribes their formation to the lungs without mentioning any participation of the heart (QI, 13v). But here again his attention was concentrated on the activities of the lungs and, indeed, the animal spirits are mentioned only incidentally. Notwithstanding the discrepant statements it is not unlikely that Leonardo accepted the Galenic theory as to the formation of the vital spirits, except that he doubted a direct transference of air from the lungs to the heart. A spiritual essence might, however, pass through the walls of the bronchioles into the arteries.

The passage on QI, 13v really is a setting forth of the necessity for a firm support for the lung tissue that the "compression, restriction and condensation" of the contained air may result from the action of the intercostal muscles and diaphragm. The ribs, with which the lung is in contact, provide this support, by which also "the lung secures itself against bursting from the violence of the air that is condensed in it." Yet even with this support a rupture of a bronchiole may take place, and he describes the repair of such a rupture by the formation around it of a crust like a nut-shell, cartilaginous and callus-like, "and in the interior are dust and aqueous humor" (QI, 13v). Evidently Leonardo had observed a pulmonary tubercle.

Leonardo does not directly discuss the cause of the rhythm of respiration, but he notes (AnB, 13) that the lungs may cease to act at will or by forgetfulness. During their inaction, however, the heart has returned to it the heated air which it sent to the lungs, and accordingly these can not long remain inactive lest the heart should be suffocated.

In several figures on AnA, 3 (fig. 66), which, as has been stated, were based on animal dissections, a bilobed structure, evidently the thyreoid gland, is shown attached to the upper part of the trachea, and regarding it Leonardo says:

"These glands were made to fill in where muscles are lacking and they keep the trachea apart from the clavicle (*osso della forcula*)."

This is the Galenic idea regarding glands, which were held to be merely a kind of flesh (*caro*) useful as a packing material (so here) or serving to retain moisture in subjacent structures. Bottazzi (1910) ascribes to Leonardo the discovery of the thyreoid. In one sense it may have been a discovery for Leonardo, for no mention of it is made either by Avicenna or Mondino; but it was known to Galen. It was a discovery for Leonardo in the same sense that the mesenteric lymph nodes were a discovery for Aselli.

CHAPTER XVI

THE EXCRETORY AND REPRODUCTIVE ORGANS

To the classical and mediaevel anatomists the kidneys were solid masses of parenchyma to which a plentiful supply of blood was brought by the emulgent (renal) veins, and from this blood the parenchyma by its attractive faculty (Galen) extracted the superfluous aquosity. The kidneys, therefor, disposed of the third of the triad of superfluities, yellow bile, black bile and aquosity, engendered in the liver during the concoction of blood from chyle.

Leonardo's views as to the anatomy and physiology of the kidneys are essentially these. He did recognize, however, the need for a further study of the structure of the organs and especially of the arrangement of the vessels in the parenchyma, and suggested that the study might be facilitated by boiling the kidney (QIII, 3). But there is no indication that he carried out the investigation. On AnB, 13v he proposes to cut the kidney in half to show how the paths of the urine contract and how it is distilled, having apparently observed the renal pyramids later described by Malpighi. His figures of the kidney far surpass in accuracy contemporary illustrations, even though a suspicion may be entertained that they were based on animal preparations, a suspicion that is strengthened by the fact that when both kidneys are represented the left is a little lower than the right (fig. 53), a condition found in many animals but unusual in man. It is noted (QII, 7) that the kidneys, together with the ureters, the great vein (vena cava) and the emulgent veins, are retroperitoneal.

The only note bearing on the physiology of excretion is to the effect that the quantity of urine is an index to the quantity of blood passing to the kidneys, some of the blood first passing through the heart, though the greater part descends by the vena cava without traversing the heart (QI, 10).

The ureters are shown in several figures as slender gently curved tubes of uniform caliber, opening into the bladder at about half its height (fig. 69). The manner in which they traversed the wall of the bladder is discussed at some length in two passages (AnB, 14 and 37). The opinion of earlier authors that they traversed the bladder wall obliquely is mentioned, and the arrangement is regarded as a provision of Nature to prevent a backward flow toward the kidneys, since the pressure of the urine on the bladder wall would occlude the ureteric pores when it had reached a level a little above them. Leonardo finds

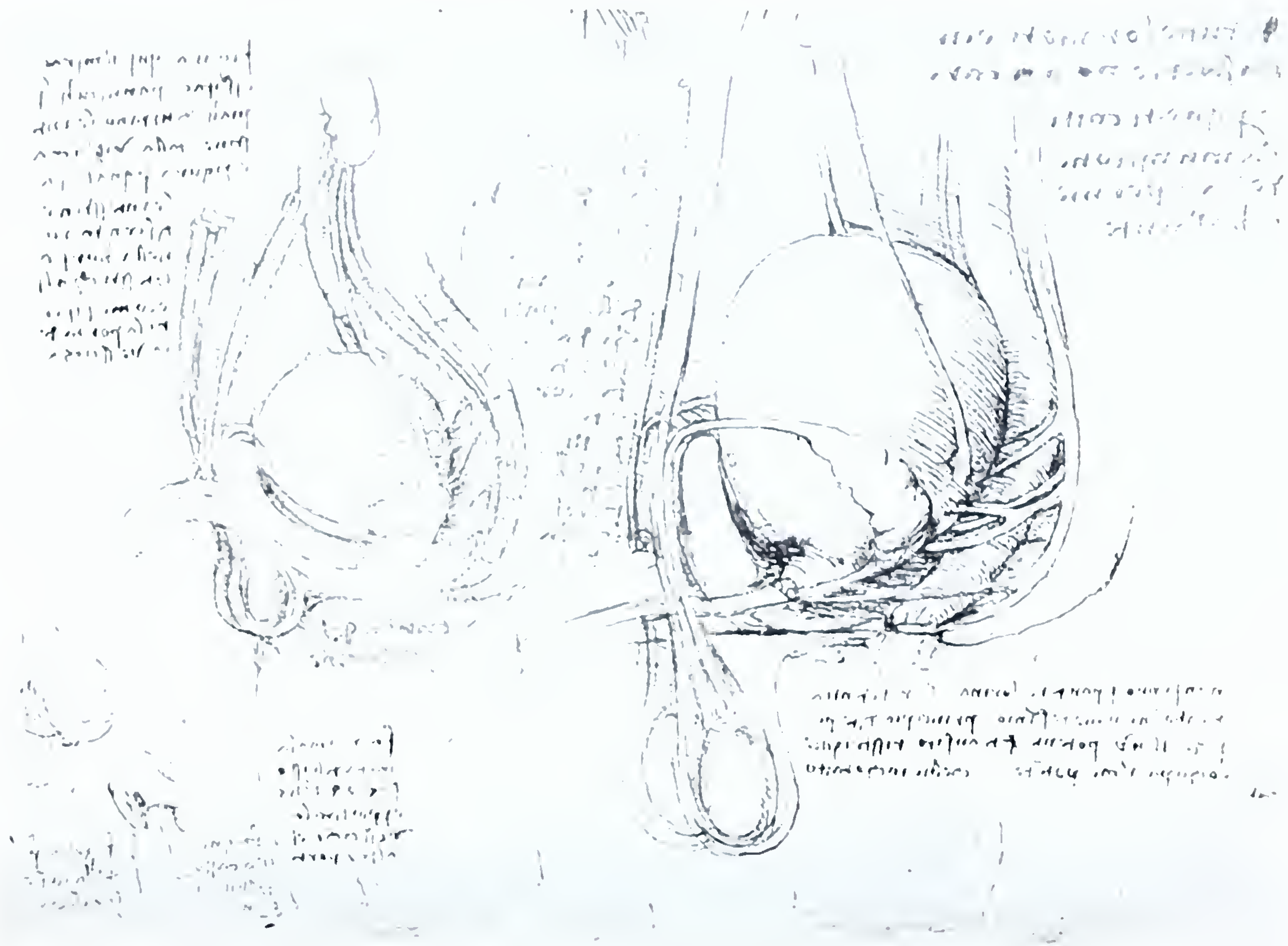

Fig. 69. The male organs of reproduction. (QIII, 4.)

this reasoning defective for, since the ureters open into the bladder at about half its height and since occlusion of their openings would prevent the entrance as well as the exit of urine, the bladder could never become more than half full. Half its capacity would be useless, a superfluity, and Nature never permits superfluities! Further it is argued that in the erect position the urine can not rise in the ureters above its level in the bladder, but if one is standing on one's head it might pass back to the kidneys. This latter posture, however, as Leonardo quaintly suggests, is not often assumed. Lying on the side the ureteric pore of that side will be closed by the pressure of the urine, but the other will continue to convey fluid to the bladder; while if one lies prone both pores can admit urine until the bladder is filled. He meets the suggestion that the more the bladder is distended the greater will be the compression of the intramural portions of the ureters, resulting in stoppage of the entrance of urine into the bladder, by assuming that the newly produced, subtle and high (*sottile e alta*) urine is more powerful than the low and large (*bassa e larga*) that is in the bladder.

On folios AnB, 14 and 37 are illustrations of another mode of passage of the ureter through the bladder wall. On penetrating the outer coat of the bladder the ureter bends sharply on itself and runs upward for some distance, gradually passing through the successive coats. This is pure imagination and does not harmonize with the statement on AnB, 37, that the ureter enters the bladder "by small perforations made transversely between the coats." One is inclined to believe that Leonardo had never opened the bladder to observe its interior.

The bladder is always represented in a fully distended condition, almost globular in form (fig. 69), and in some instances veins and arteries are shown ramifying over its surface (AnB, 37). That its walls are formed of several layers is implied, but no description of these is given. On QIII, 11v there is a memorandum "where the neck of the bladder shuts and why?" but the inquiry remained unanswered, although there is another memorandum to describe "the nerves, or one may say the muscles, that shut the gate of the bladder" (QIV, 11).

Leonardo's ideas regarding the reproductive organs present a curious commingling of accurate observation with acceptance of tradition. Never before had the organs been represented so accurately as to form, but the influence of tradition as to function led to inaccuracies in detail and, what is more remarkable, to the portrayal of structures that had no real existence. It seems probable, however, that those drawings in which tradition is most in evidence belong to the earlier periods of his studies.

In the double folio QI, 12 (fig. 70), Leonardo represents his idea of the female internal organs of generation, based apparently partly on observation, for his representation is far more accurate than those of any of his predecessors, and partly on preconceived notions gained from earlier authors. The uterus, somewhat exaggerated as to size, is shown as a broad pyriform structure, to each of whose sides there are attached, at about the middle of its length, two cylindrical processes, one of which is directed upward and outward and the other outward and slightly downward, almost parallel with the external iliac vessels. The upper process probably represents the tuba uterina and the lower the round ligament of the uterus, but of neither is a description given. Leonardo may be assumed to have been ignorant of the purpose of the tubæ uterinæ; Mondino does not mention them and Avicenna's description of them is exceedingly obscure and the function he ascribed to them altogether inaccurate. It is to Leonardo's credit that he should observe and portray them even imperfectly and still more to his credit that he should be the first to figure the round ligaments.

Lower down, opposite the middle of the length of the cervix, are two broadly fusiform structures to which blood-vessels descend from above. These are evidently the ovaries, or, as Leonardo, following earlier examples, calls them, the testicles (*testicholi*). They are, of course altogether too low in position and each is connected with the cervix by a short cylindrical structure which, if it were higher, might be taken to be the ovarian ligament, but it is much more probably intended for a duct, by which the ovary may communicate with the cavity of the uterus. For Leonardo held the common belief that there was a female sperm as well as male sperm, and that it was formed from the blood brought to the ovary by the ovarian vessels, receiving its generative virtue in the ovaries and thence passing to the uterus where it was stored, its generative virtue being called into activity, however, only when it was mingled with the male sperm (QIV, 1v). That it was stored in the uterus demanded a communication between the ovary and that organ and this communication Leonardo supplied.

On QIII, 7 the uterus is again figured and this time it is almost triangular in outline, and from the upper angle on each side the three structures shown on QI, 12 (fig. 70) arise. The upper structures may be taken to be the tubæ uterinæ, the middle ones the round ligaments, here sadly displaced since they are directed upward toward the kidneys, while the lower structures represent the ovaries as fusiform enlargements with the ovarian vessels descending to them from above and with a short duct connecting them with the uterus and strongly suggesting the ovarian ligament. Neither in this figure nor in that on QI, 12 is there any indication of the anteflexion of the uterus, but in four figures on QIII, 1v the long axis of its body is approximately at right angles with that of the vagina.

The classical authors, basing their ideas on the dissection of animals, describe the uterus either as bifid or as containing two cavities, and in the Middle Ages, under the influence of the Salernitan School and its

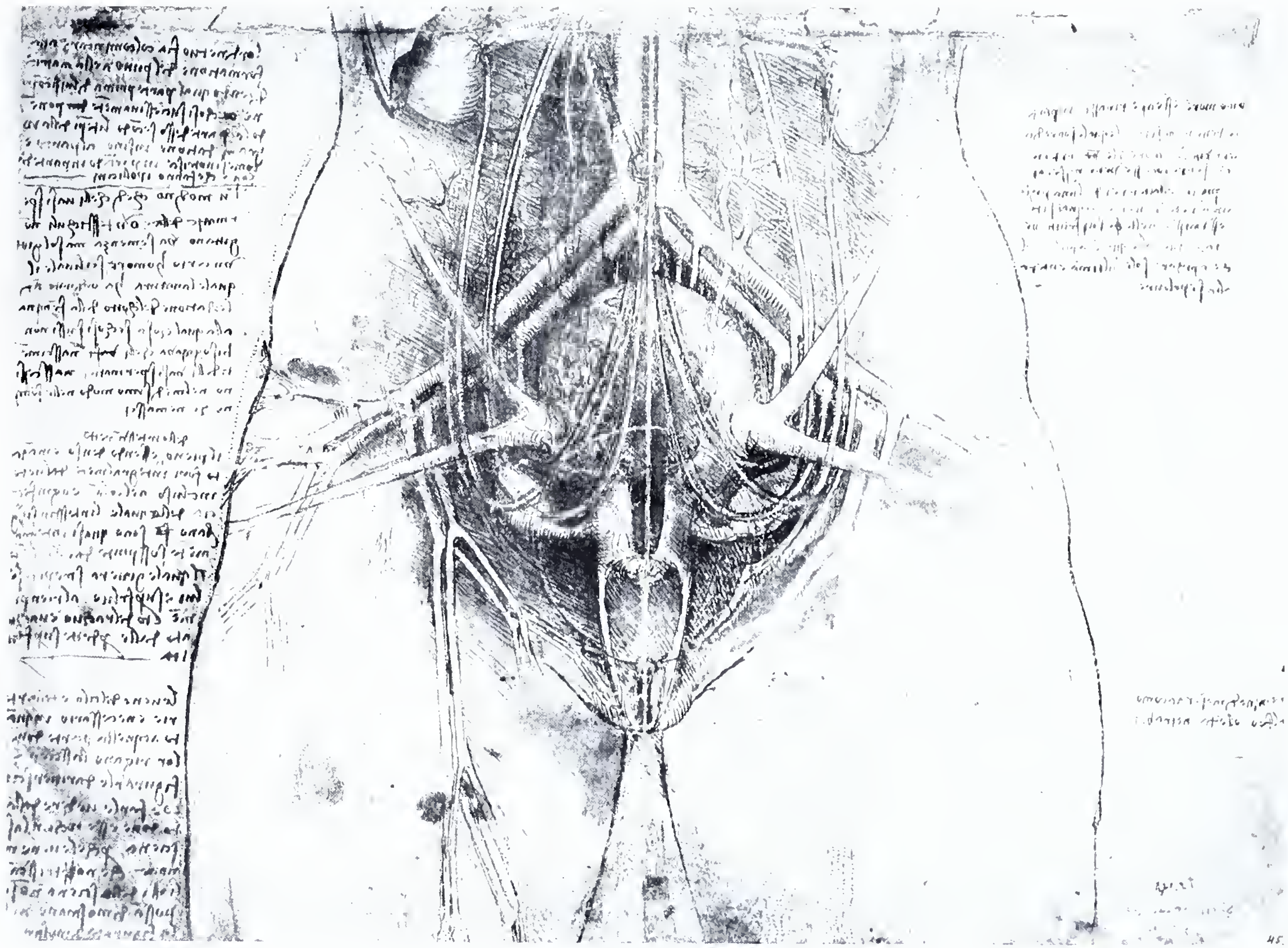

Fig. 70. The female organs of reproduction. (QI, 12.)

dissection of the pig, it was a common belief that it was a seven-chambered structure; so it was described by Mondino, so it was figured in the *Anatomie* of Guy de Vigevano (1345) and in the *Antropologium* of Magnus Hundt (1501). The extreme teleological views of their times led to the doctrine that in any animal the uterus would contain as many chambers as there were mammary glands, and Avicenna found support for his statement that the human uterus was bilocular in the fact that the mammary glands are two in number. The bilocular theory died hard; it was maintained by Berengar da Carpi as late as 1535, he associating with it the ancient theory of sex-determination, to the effect that the infant developing in the right chamber would be a male, and that from the left chamber a female. On QIII, 7 are two figures showing the cavity of the uterus and in both that cavity is single. For Leonardo the human uterus was a *uterus simplex,* a fact that became generally accepted after the publication in 1543 of Vesalius' *De Fabricâ.*

In the case of the male organs, the mingling of clear observation and reliance on tradition is even more distinctly shown. The testes are shown in a number of figures as oval bodies (fig. 69), each contained within a scrotal sac and surmounted by a coiled apparatus, this representing the epididymis and being formed partly by the terminal portions of the spermatic vessels and partly by the beginnings of the ductus deferens. The course of the ductus is correctly shown, passing upward over the pubic bone and then curving backward to the back of the bladder, where it seems to dilate into a somewhat corrugated sac, the seminal vesicle (*spermatic ventricle,* QIV, 11), and beyond this it is continued forward to open into the proximal portion of the urethra. It is curious that the prostate gland is neither mentioned nor figured; it was probably regarded as merely flesh (*caro*), hardly worthy of notice.

The idea that the spermatic vessels formed an important part of the epididymis was based on the belief that the male sperm, like that of the female, was formed directly from the blood, receiving its third and final concoction (QIII, 10v) and its germinal virtue from the testes, whence it passed to the seminal vesicles which served as reservoirs for it (QIII, 1v). Other theories as to the function of the testes are disputed, such as that of Mondino which assigned to the seminal vesicles and testes merely the production of a saliva-like humor intended for the delectation of the female during coition (QI, 12); and another that the testes might occlude or, by retraction, open the mouths of the seminal vesicles and so prevent or permit the emission of sperm (QII, 17).

But Leonardo was not always so sure as to the function of the testes, for on QIII, 3v, there is a memorandum to enquire as to what the testes (*coglioni*) have to do with coition and with the sperm, and another to enquire why the testes are the cause of ardor. On AnB, 13 this last query is definitely answered, the organs being held to be the seat of emotion, the proof being found in the fact that bulls, rams, boars and cocks, all very fierce creatures, become cowardly when castrated, so that a flock of castrates may be chased away by a single ram and a number of capons by a single cock.

But these queries are not the only indications of uncertainty; he also figures structures that are altogether imaginary and which he had found mentioned by older authors. QIII, 3v is the folio on which is the coition figure and in this two canals are represented traversing the intromittent organ, a lower one which communicates with the bladder and therefore serves for the passage of urine, and an upper one that gives passage to the sperm. These canals are more precisely shown in two other figures of the same folio, one representing a longitudinal and the other a transverse section of the male organ (fig. 59). The idea of a special canal for the sperm may have been obtained from Mondino; Avicenna describes three penial canals, a *meatus urinarius*, a *meatus spermatis* and a *meatus alquadi*.

Another peculiarity of the coition figure may be noted. The spinal cord is represented as extending to the very tip of the spinal canal and in the sacral region a stout nerve arises from it by three roots. It passes over the side of the bladder and is continued onward to the tip of the penis, forming the spermatic canal of that organ, the nerves being regarded as hollow tubes. This imaginary nerve seems to trace back to an ancient Greek theory that the medulla spinalis was concerned in the formation of the sperm; in a figure on QV, 21 the spinal cord is labeled "virtu genitiva." In the Hippocratic treatise *De semine* the origin of the sperm is said to be from all four humors and also from all the solid parts, the fluid so formed passing to the spinal cord and thence to the testes. Whence Leonardo got this idea is uncertain; it was not from Avicenna, who is inclined to assign the ultimate origin of the sperm to the brain, whence it passed downward through veins that run behind the ears. Leonardo, however, later relinquished the idea of the nervous system as the origin of the sperm, regarding it as a final concoction of the blood in the testes, a view which is strictly Galenic.

It was a common belief in the Middle Ages that the uterus possessed a certain amount of individuality independent of that of the body, and could at its own volition leave its proper place, thereby producing a series of symptoms known as the *passio hysterica*. Similarly on account of its involuntary behavior, an amount of individuality was attributed to the male organ and both Plato and Aristotle speak of it as being to some extent an independent animal. Leonardo was sufficiently mediaeval to accept this idea; "This animal" he says of it "often has a soul and intellect apart from the man" (AnB, 13). But while he was mediaeval in this idea he was decidedly modern in his view as to the cause of the occasional turgidity of the organ. The ancients and, following them, both Avicenna and Mondino, ascribe the turgescence to the organ becoming inflated by a "ventosity," but Leonardo disputed this idea, claiming that it was due to the organ becoming replete with blood. For he had observed that many persons, and especially those who are hanged (QIII, 7), die with the organ in erection, and in an Anatomy of such an one that he witnessed the organ was full of blood, so that the tissue was very red in color (AnB, 2v).

CHAPTER XVII

THE NERVOUS SYSTEM

On QV, 6v there is a diagrammatic figure (fig. 71) drawn with red crayon and subsequently outlined with ink. It represents a sagittal section through the skull, with labels indicating the various structures cut, and is the translation into a drawing of a description by Avicenna. On the surface there are the hairs (*capigli*) of the scalp; beneath these a layer termed the *codiga*, corresponding to the epidermis and superficial fascia; then follow the galea aponeurotica, termed, however, *carne musculosa*; then the pericranium, the layer of areolar tissue being disregarded; then the bony cranium; then in succession the dura mater, pia mater and brain (*celabro*).

Nothing of the structure of the brain is shown except the ventricles, and these are represented as three cavities separated by constrictions and placed in a row, one behind the other, a prolongation of the anterior one extending to the eye and probably representing the optic nerve. In another figure on QV, 20 three ventricles are again shown but they are connected by short stalks or passages. A short stalk projects forward from the anterior one and quickly divides into the two optic nerves, while to the middle one are attached what are apparently in-intended for the olfactory and auditory nerves. These and other similar figures with the ventricles in one, two, three order show the influence of mediaeval tradition, but on other folios there are figures which, while still very imperfect, approach nearer to the actual arrangement and suggest that they date from a time when Leonardo was relying on his own observations of an organ, which, without special preservation, presents many obstacles to dissection.

On QV, 8 there is a representation of the brain from the side which still shows three ventricles (fig. 72), but they have now quite different relations. The middle one has a short canal passing downward, presumably the infundibulum, and posteriorly it is connected by a short canal, which may be identified as the iter, with the posterior ventricle. From the anterior part of its roof a short canal arises which leads into a large crescentic cavity arching backward over the other two cavities. This is undoubtedly a lateral ventricle, but the figure shows no indication that it is a paired structure; Leonardo apparently had not yet reached that stage in the development of his studies of the ventricles. From the base of the brain, not from the ventricles, a number of nerves stream out, the optics with the eyeballs anteriorly,

Fig. 71. Section through skull and brain showing brain membranes. (QV, 6v.)

Fig. 72. Ventricles of brain and cranial nerves. (QV, 8.)

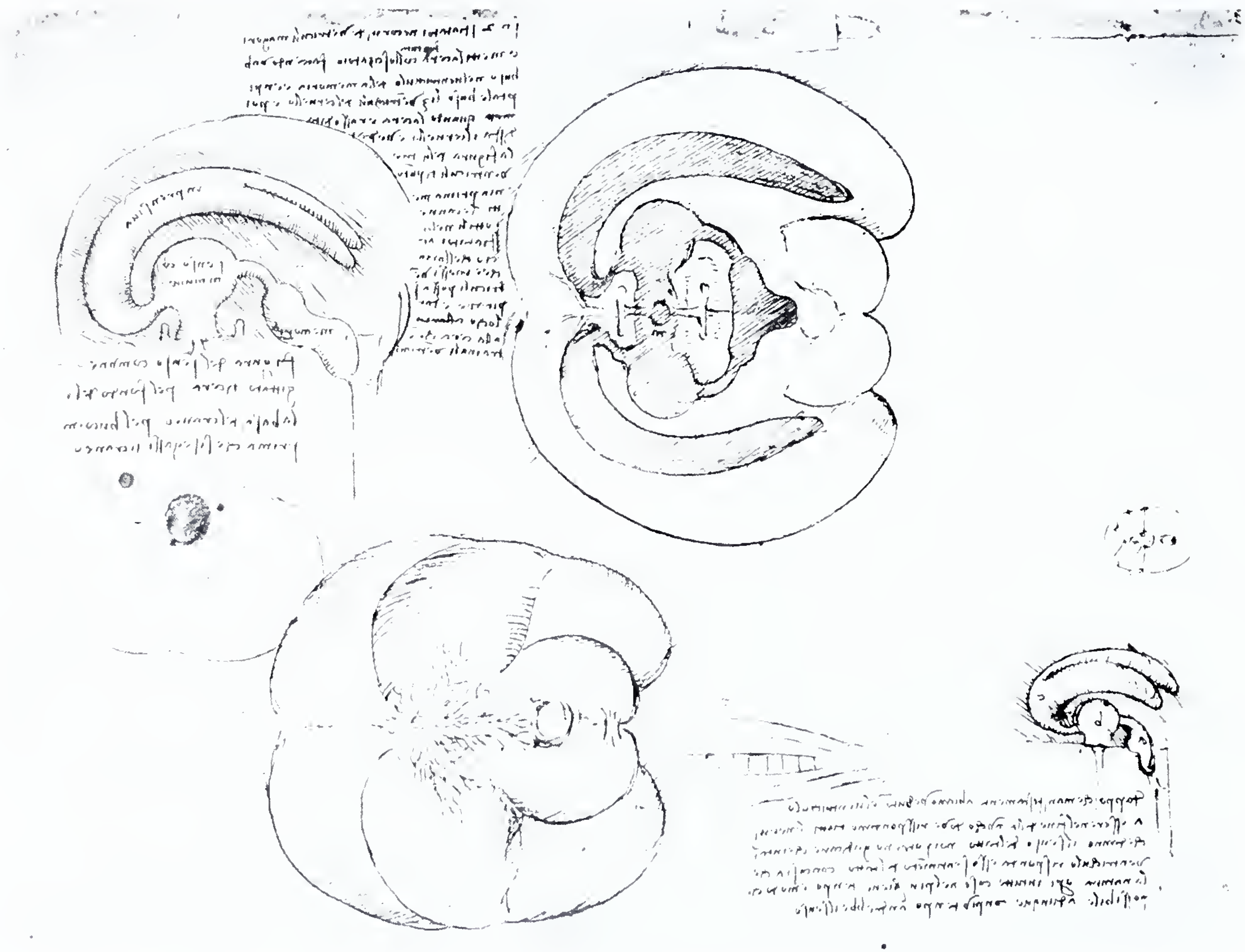

Fig. 73. Ventricles of brain and view of its base. (QV, 7.)

then a number of nerves from the region of the middle ventricle and still others from below the posterior one.

On QI, 13v and on QV, 25 are figures that show a beginning appreciation of the paired character of the lateral ventricles, they being represented as paired in their posterior fourth, while for the rest of their extent they are a single cavity. On QV, 7 (fig. 73) the story is completed. One figure on that folio resembles closely that of QV, 25; in another the paired condition extends almost to the anterior extremity of the ventricles; while in a third they are shown completely paired even as to the passageways connecting them with the middle or third, ventricle. This last figure, together with a companion one on the same folio, apparently represents the brain of an ox, seen from its basal surface, the rich plexus of blood-vessels (rete mirabile) surrounding the infundibulum, present in ungulate animals but absent in man, being clearly indicated. Possibly it is the figure of a brain that had been injected with wax (see p. 87), a supposition that might afford some explanation for the altogether erroneous form of the third ventricle.

These figures seem to form a series which illustrates clearly the development of Leonardo's ideas of the ventricles, from a reliance on tradition to a reliance on personal observation. Whence Leonardo got the idea of three ventricles one behind the other is uncertain. It was not from either Avicenna or Mondino, since both these authors, following Galen, state distinctly that the anterior ventricle is paired. It may have been from a figure in the *Philosophia naturalis* attributed to Albertus Magnus and published at Brescia in 1490, or from one of the similar figures common in mediaeval manuscripts (*cf.* fig. 8, p. 45).[1] The unpaired anterior ventricle is shown as late as 1504 in the *Margarita Philosophica* of Gregor Reisch, but in Peyligk's *Compendium* (1499) it is represented as paired (fig. 6), its two cavities lying side by side, but in the same plane as the middle and posterior ventricles instead of above them, while Magnus Hundt in his *Antropologium* (1501) represents it (fig. 7) more crudely as consisting of two portions lying one behind the other.

Of parts of the brain other than the ventricles Leonardo gives little information. A small pencil sketch on QV, 7 shows the human brain viewed from above, the great longitudinal fissure being clearly shown and the sulci of the surface represented by scattered wavy lines, which give the general effect but not the actual arrangement. In the basal views of the brain of an ox (QV, 7) the temporal lobes of the cerebral hemispheres and the cerebellum are distinctly shown (fig. 73) and

[1] An excellent account of the early ideas as to the structure of the brain may be found in Jules Soury's *Le Système nerveux centrale, structure et fonctions*, Paris, 1899, and the manuscript descriptions and illustrations of it have been discussed by Walther Sudhoff in his paper *Die Lehre von den Hirnventrikeln in textlicher und graphischer Tradition des Alterthums und Mittelalters, Archiv für der Geschichte der Medizin*, Bd. 7, 1913.

the infundibulum, cut across and surrounded by the *rete mirabile,* is indicated in one figure, while a T-shaped structure projecting from the third ventricle may represent the hypophysis. These, together with the ventricles, form the sum total of Leonardo's contribution to the structure of the brain.

True, there is a memorandum (QI, 13v) that the porosities of the brain substance are to be examined and one suspects that what were in mind were minute passages through which the vapors, supposed to be engendered in the brain, might escape. Also, mention is made on QI, 3v of a *vermis* in the middle ventricle and on QIV, 11 it is described as a muscle which lengthens or shortens to open or close the passage from the third to the fourth ventricle. This is, of course, a fiction, probably adopted from Avicenna's misunderstanding of Galen's description of the vermis of the cerebellum.

But the mediaevalists and the early writers of the Renaissance were more interested in brain function than in brain structure. Galen had located the intellectual faculties in the brain substance in close proximity to the ventricles, which contained the psychic pneuma, but his successors, notably Poseidonius and Numesius, transferred their seat to the ventricles themselves. Galen held that the anterior part of the brain was of a softer consistency than the posterior, and associated this difference with a supposed relation of the softer sensory nerves with the anterior part and the harder motor nerves with the posterior part, and so the anterior ventricle came to be regarded as the center of sensation, the *sensorium commune,* as well as of the imaginative faculty (*virtus fantastica*), which combined the sensations. Similarly the posterior ventricle was identified as the center from which the voluntary motor impulses originated, and at the same time as the seat of memory. The Galenic triad of faculties served for a time, but Avicenna, with somewhat of the penchant for metaphysical subleties that characterized Arabic thought, added to them *existimatio,* which would seem to mean judgment, though usually taken as equivalent to imagination, and associated this with *cogitatio* and referred them to the middle ventricle. Similarly he associated the *sensus communis* with *phantasia,* referring them to the anterior ventricle, while memory and motion were assigned to the posterior one. A crude representation (fig. 74) of this localization of functions is to be found in Reisch's *Margarita;* it shows a primary triple division of the cerebral cavity and the concentration of all the special sensations in the anterior division or cellula, producing the *sensus communis;* behind this and connected with it are *fantasia* and *imaginatio*; *estimatio* and *cogitatio* are represented in the second or middle cellula and *memoria* in the third or posterior, the motor center being omitted. The figure from the *Philosophica Naturalis* of Albertus Magnus shows a variant of this arrangement, *imaginatio* replacing *fantasia* in the anterior chambers and again appearing in the middle chamber, where it is associated with *extimatio* (*sic*), while memory and motion occupy the posterior chamber. Mondino furnishes another variant in that he locates *fantasia*

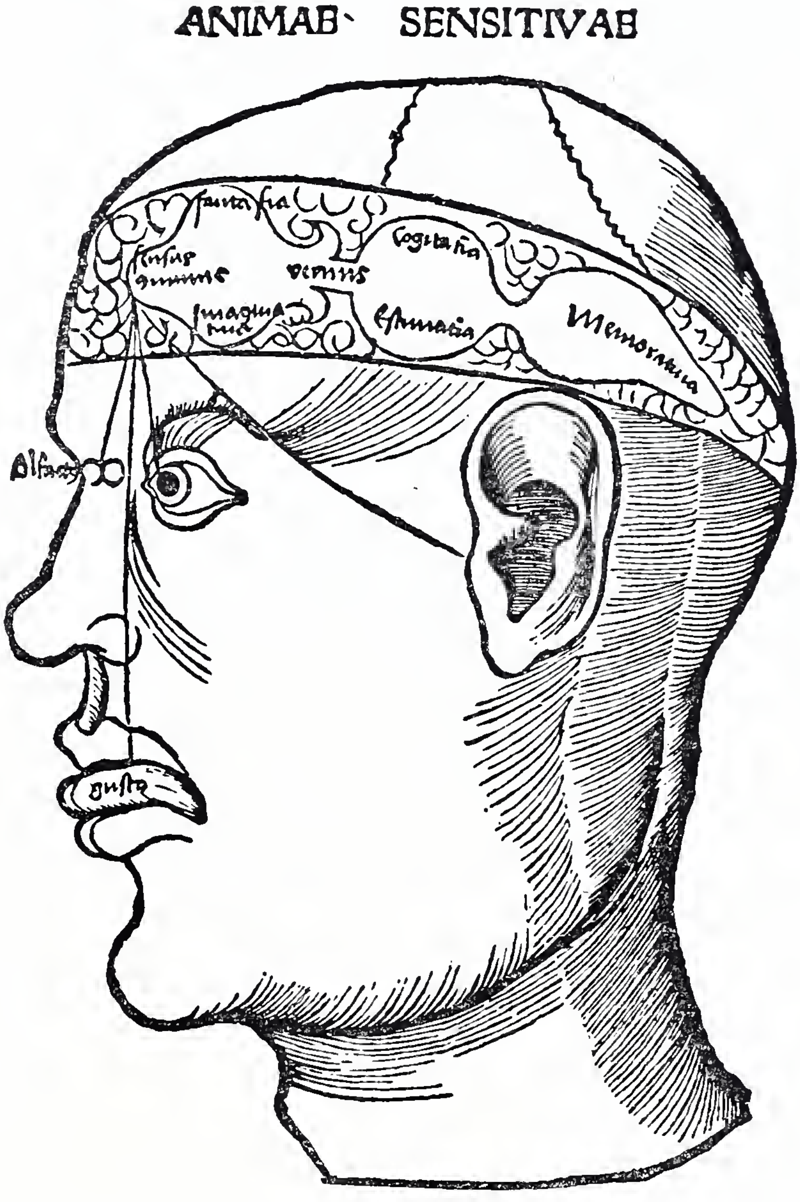

Fig. 74. Cerebral localization. From G. Reisch's *Margarita philosophiæ* (Strassburg, 1504). After C. Singer: *Fasciculo di medicina*, part 1, fig. 69, 1925.

in the anterior angle of the anterior ventricle, *imagination* at its posterior angle and the *sensus communis* between these two in its middle part. The middle ventricle takes care of *cogitatio* and the posterior of memory.

Other modifications might be mentioned[2] but these would merely emphasize what is already evident, namely, that the mediaeval writers based their ideas as to the activities of the brain mainly on Avicenna, who accepted Galen's views as a foundation and built on them a superstructure less definite in the relations of its parts and therefore subject to differences of interpretation. Leonardo has his own interpretation. In one of his early figures of the ventricles (QV, 20v) showing their ground plan, the anterior ventricle has the legend *imprensiva* instead of *phantasia*, as if he desired to emphasize its receptive and combinatory functions; *comocio*, the legend for the middle ventricles is probably a misspelling of conoscio or conoscimento and the posterior one has *memoria* assiged to it. The fact that in QV, 6v he represents both the optic and auditory nerves as arising from the anterior ventricle, indicates his belief in the location in it of the sensus communis, but in other similar sketches (QV, 15 and 20v), while the optic nerves still take origin from the anterior ventricle, two other pairs, the olfactory and auditory, arise from the middle ventricle. Leonardo had evidently discovered that the great majority of the cranial nerves could not well be attached to the region of the anterior ventricle, the observation which led to this conclusion being probably that recorded in AnB, 35, where the anterior part of the base of the skull, seen from within after the removal of the brain, shows the position of the intracranial portion of the more anterior cranial nerves. Further, on QV, 8 is a sketch (fig. 72) that represents an accumulation of nerves below the floor of the middle and not the anterior ventricle. Here was a point in which Leonardo's observations did not agree with tradition and he promptly disregarded tradition and transferred the origin of the sensory cranial nerves, except the optic, to the region of the middle ventricle, and as a result of this in QV, 15 he also transfers to that ventricle the *sensus communis*, and retains it in that location in his later figures (QV, 7). Indeed it would seem that he was even prepared to carry it still further back, for in a passage of text on the sheet just mentioned he expresses his belief that the sense of touch had its center in the posterior ventricle.

Having thus discarded the teachings of Avicenna and Mondino, Leonardo proceeds to give expression to his own theories as to the localization of function in the brain. In QV, 15 the posterior ventricle still bears the single legend *memoria*, but the other two have each a double legend. To the middle ventricle, in addition to *senso commune*, there is assigned also *voluntà*, and the anterior one besides the legend *inprensiva* bears also that of *intelletto*. The association of the will with the *sensus communis* finds an explanation in QII, 18v, where the nerves are said to "move the members at the good-pleasure of the will (*vol-*

[2] These modifications have been tabulated by Walther Sudhoff in the paper referred to in the foot-note on p. 205.

untà) of the soul" and the soul, in an earlier passage (AnB, 2), is located "in the judicial part (of the brain), and that seems to be the place where all the senses come together, which is termed the *senso commune*." The use of the word "judicial" suggests Avicenna's faculty *existimatio*, and, if so, Leonardo had additional reason for transferring the *senso commune* to the middle ventricle.

The psychological significance of the faculties thus located in the ventricles is indicated in the following passage.

"Accordingly the joints of the bones obey the tendon (*neuro*), the tendon the muscle, the muscle the nerve (*corda*) and the nerve the *senso commune*. And the *senso commune* is the seat of the soul, memory is its admonition and the *imprensiva* is its referendary." (AnB, 2.)

On AnB, 41 some measurements are given which serve to locate the relative position of the *sensus communis*. It is said to have directly below it at a distance of two fingers (*i.e.* finger breadths) the uvula, where the food is tasted, and it is above the tube of the lungs (*i.e.* trachea) and a foot's length above the "foramen" of the heart. Above it, at the distance of half a head, is the juncture of the bone of the skull (sagittal suture) and on a level with it at a distance of one-third of a head is the "lagrimatoio" of the eyes and further to the sides the two temporal pulses. On QV, 2 is the further statement that the ventricles of the brain and those of the sperm (seminal vesicles) are equally distant from those of the heart.

Leonardo gives no description of the spinal cord (*nuca*), although he figures portions of it on several folios and on one (AnB, 23) shows a portion enclosed within its membranes. These are the same as those of the brain, pia mater and dura mater, but he states that in the spinal canal the dura is between the cord and the bony wall, apparently recognizing the difference of the arrangement of the spinal dura from that of the brain. He held, as the results of experiments on the frog mentioned on p. 91, that the cord was the center of life of the animal, and although his conclusions are not quite accurate, the observations are of interest, since they were the first experimental observations on the central nervous system since the time of Galen.

Nowhere are the nerves shown to arise by more than a single root, the discovery of the two roots, motor and sensory, not having been made by Volcher Coiter until 1573, more than fifty years after Leonardo's death. There is no doubt that Leonardo, since he accepted the theory of the *pneuma*, believed the nerves to be hollow cylinders in whose lumina the *pneuma* might flow in either direction. Thus he says—

"These nerves (*corde*) having entered the muscles and lacertæ command them to move; they obey and this obedience sets them in action so that they swell, and the swelling shortens their length and pulls back the tendons (*nervi*) that are interwoven with the particles of the member. Being infused in the extremities of the digits they carry to the sensorium the cause of their contact." (AnB, 2.)

That is to say, they carry a knowledge of the object with which they are in contact. Further the term sensation (*sentimento*) is used for both efferent and afferent stimuli, for he states, for example, that the nerves that give stimulus (*sentimento*) to the intercostal muscles have their origin from the spinal cord (*nuca*) (AnB, 30); and again—

"The function of the nerve is to give a stimulus (*sentimento*). They are the knights (*cavallari*) of the soul and have their origin from its seat, and command the muscles that move the members at the good pleasure of the soul." (QII, 18v.)

And yet in a passage on AnA, 13v it is implied that there are two kinds of nerves, those of sensation and those of motion, since it is stated that in injuries to the hand sensation in the fingers may be lost in some cases, but not motion, while in others it may be motion that is lost, but not sensation. Whether this statement was based on a personal observation is uncertain; it might have been a following out of Galen's classification of nerves, repeated by Avicenna, in which "hard" (motor) and "soft" (sensory) nerves were recognized, the latter being associated with the anterior softer portions of the brain and the former with the harder posterior portion and spinal cord. Leonardo seems to have accepted the idea of differences of consistency in different parts of the brain, for he made a memorandum to enquire whether the region whence the vagus nerve took origin was hard or soft, with the object of determining whether that nerve was motor or sensory (AnB, 33v).

The idea that the nerves were bundles of fibers had not developed in the sixteenth century. For Leonardo each nerve was a tubular prolongation of the substance of the central nervous system, invested by coverings from the pia and dura mater, the prolongation of nerve substance being continued through all the ramifications of the nerve—

"and each fiber of the muscles is enclosed within an almost imperceptible membrane into which the ultimate ramifications of the said nerve are converted, these nerves obeying (commands) to shorten the muscle by retracting and to dilate it at each command of the stimulus (*sentimento*) that passes by the lumen of the nerve." (AnB, 23.)

In some passages, however, Leonardo expresses himself carelessly, giving the impression that he thought the nerve to be a cylindrical projection of the pia mater. Thus in the continuation of the passage just quoted he states that the pia mater on emerging from the spinal canal becomes converted into a nerve, and on AnB, 35 it is asserted that "the nerves arise from the last membrane (*i.e.* the pia) which

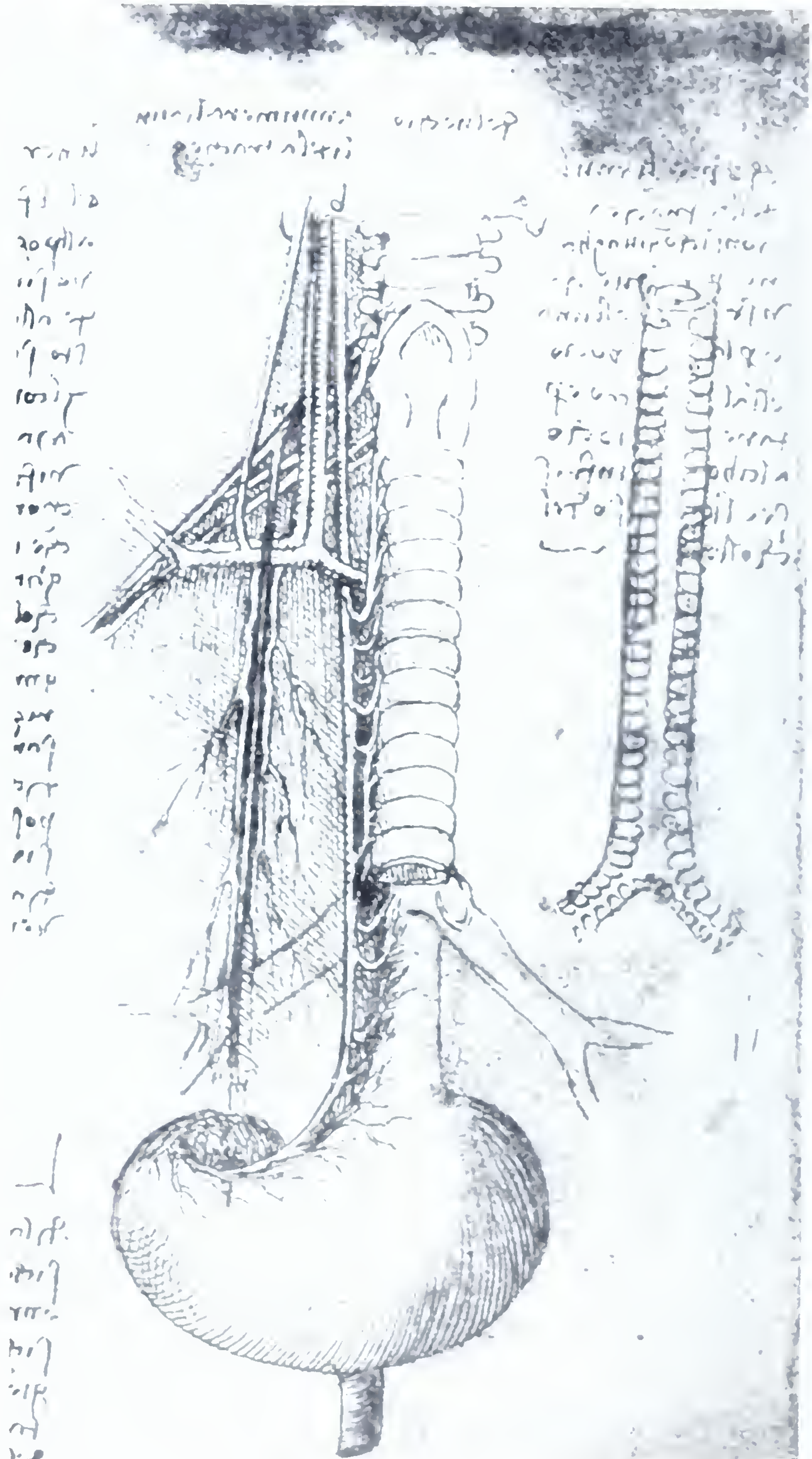

Fig. 75. Figure showing course and distribution of reversive (vagus) nerve. To right a longitudinal section of trachea. (AnB, 33v.)

invests the brain and spinal cord." But such statements must be interpreted as merely meaning that the pia is continued out over the nerve as an investment, the nerve itself being a prolongation of the nervous system. On AnB, 17v there are two sketchy representations of the entire nervous system and accompanying them is the inscription "Tree of all the nerves, which shows how they all have origin from the spinal cord (*nuca*) and the spinal cord from the brain."

The cranial nerves are shown in several figures (QI, 13v; QV, 8) as a mass of cords depending from the floor of the middle ventricle (fig. 72), but few of them can be identified. The olfactory tracts are best shown in a view of the base of the skull (AnB, 35) and in this they are somewhat dilated at their extremities to form the olfactory bulbs. They are called *caroncule,* a term used by Mondino, but hardly applicable to the human tracts; probably it traces back to the olfactory lobes of some lower animal. In some figures the tracts are attached well forward on the brain, but in others they pass back to the region of the middle ventricle. The optic nerves are also connected with the anterior ventricle in some figures, but in others they are more correctly related to the middle one and in such cases their union to form the commissure is distinctly shown, although the commissure is quite separate from the floor of the ventricle.

Galen and, following him, Avicenna, enumerate the oculomotor nerves as the second pair in their list of the cranial nerves, but the other two pairs to the muscles of the orbit, the trochlearis and abducens, were overlooked. In a figure of AnB, 35 Leonardo shows, in addition to the optic nerve, two or three others passing forward toward the eye ball, on the surface of which one of them branches. They can not be certainly identified with the three motor nerves of the orbit, but it would seem that Leonardo had observed at least one of the nerves that Galen overlooked. However, Leonardo was evidently somewhat uncertain about these nerves for he has a memorandum on QIV, 11 suggesting that he should—

> "Search for the motor nerves of the eyes and consider if the principal ones are four more or less, because in the infinite movements (of the eyes) four nerves do all, since as you leave the jurisdiction of one, aid comes from the second."

Of the remaining cranial nerves the only one to receive particular attention is the vagus, which Leonardo terms *nervo reversivo,* applying to the entire nerve a term applicable only to one of its branches. On AnB, 33v (fig. 75) the right vagus is shown descending from the base of the skull in company with the carotid artery and internal jugular vein. It passes under what may be regarded as the subclavian vein and gives off the recurrent branch which runs upward *over* the vein to supply the trachea and larynx. Below this the main nerve continues downward, the text accompanying the figure stating that—

> "*bf* is the *nervo reversivo* descending to the *portinario* of the stomach. And the left nerve, the companion of this, descends to the envelope of the heart and I believe that it may be the nerve that enters the heart."

The course of the recurrent nerve is rather feebly explained as protecting it from injury when the neck is bent forward (QI, 13v), and it would seem that Leonardo was uncertain as to the relations of the left nerve, for he adds a memorandum to "enquire in what part the left *nervo reversivo* turns and what is its function," adding a further query as to the manner in which "the *nervi reversivi* give sensation (*sentimento*) to the rings of the trachea."

Leonardo's interest in the spinal nerves was concentrated mainly on those that pass to the limbs. Of the intercostal nerves he barely makes mention (AnB, 30), stating that they arise from the spinal cord, the lowest one having its origin at the level of the kidney; and of the nerves from the cervical plexus he figures only the phrenic (AnB, 33v and 34), which he traces from the fifth cervical nerve, instead of the fourth, to the pericardium, failing to note its continuation to the diaphragm, although its connection with that muscle had been shown experimentally by Galen and is mentioned by Avicenna.

There are a number of attempts at representation of the brachial plexus but in none of them are its complexities correctly elucidated. In the majority of figures (AnA, 4v, 23, 23v; QV, 21v) but four nerves enter into its formation (fig. 76), the participation of the first thoracic being overlooked, but in that on AnB, 3v (fig. 77) five nerves are shown and, furthermore, the three main divisions of the plexus are correctly represented. The rearrangement of the fibers to form the three cords is not, however, clearly shown, although the posterior cord may be identified. Leonardo, of course, could have no idea of the significance of the plexus as a means of distributing the preaxial and postaxial fibers—the fibers were unknown to him—and he seems to have supposed it to be an arrangement for the continuance of function in case one or more of the nerves should be injured, since he has a memorandum to enquire which of its five branches would suffice to give sensation to the arm, if the others were destroyed by a sword wound (AnB, 3v).

The three main nerves of the arm, median, ulnar and radial, are shown in several figures so far as their general course is concerned, but their origin from the plexus is lacking in accuracy. Other nerves are also indicated, such as the axillary passing to the *omero* (deltoid), the musculo-cutaneous to the *pesce del brachio* (biceps humeri) and what may be the antibrachial cutaneous (AnB, 23v) and the deep radial (AnB, 3v). The courses of the three principal nerves with reference to the bones of the arm are well shown on QV, 21 and 21v, and it should

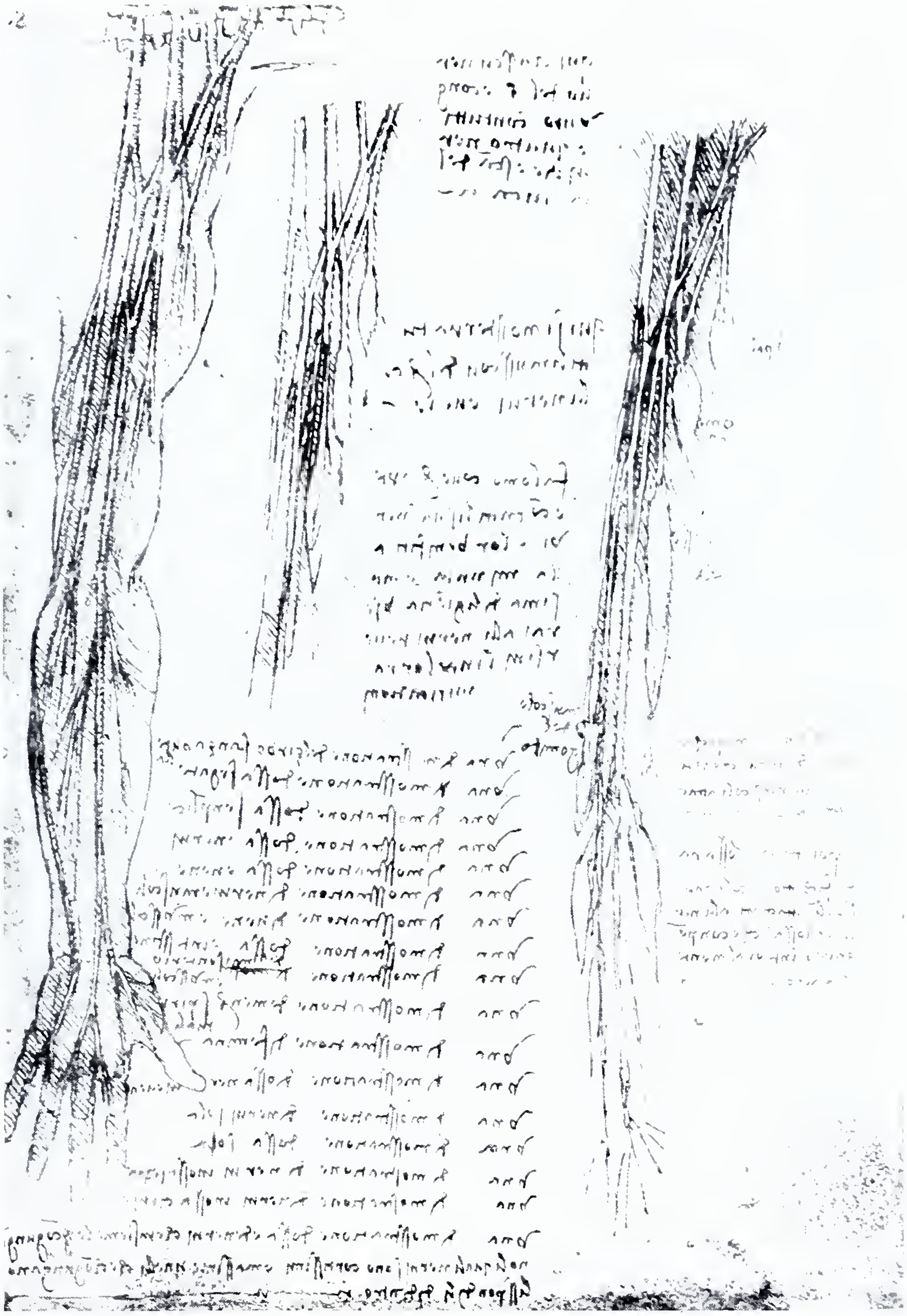

Fig. 76. Figures showing arrangement of brachial plexus. (AnB, 23v.)

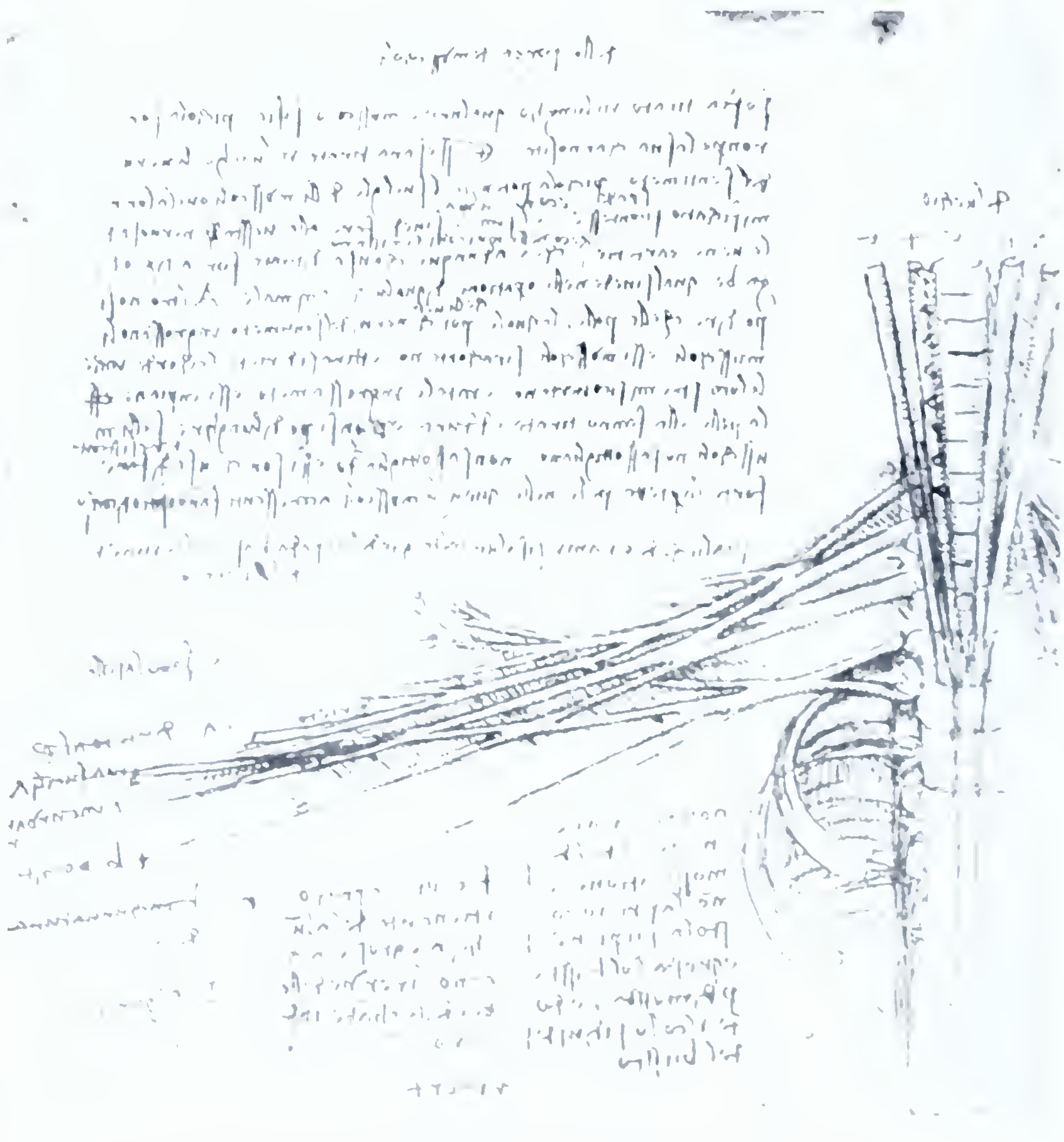

Fig. 77. Another figure of the brachial plexus. (AnB, 3v.)

Fig. 78. The lumbo-sacral plexus. (AnB, 6.)

be mentioned that the course of the ulnar nerve behind the medial epicondyle of the humerus is distinctly indicated on AnB, 23v, and that its cutaneous distribution on the volar surface of the hand, as well as that of the median, is correctly represented in the same figure and still better on AnB, 8v.

The lumbo-sacral plexus is in worse case than the brachial, the figures that represent it (AnB, 6; QV, 9 and 21) being evidently based on animal dissections and representing only four nerves participating (fig. 78). In the figure on AnB, 6 three nerves are shown arising from the plexus, one of which, passing over the pubis, being evidently the femoral, a second, the obturator, passing through the foramen so designated, while the third, passing down into the pelvis probably represents the sciatic. In the figure on QV, 21 (fig. 78), the obturator is not shown and the femoral divides into two branches, one of which is distributed to the thigh, while the other passes down behind the medial condyle of the femur and appears to represent the long saphenous, a nerve which seems to have especially attracted Leonardo's attention. On QV, 20v (fig. 79), is a figure representing the leg from the inner surface; it shows the sartorius muscle, labeled *lacerto*, and along its medial border are two cords labeled *nervo* and *vena*. Both these structures are continued downward as far as the foot, the nerve ending at the level of the medial malleolus while the vein passes to the sole of the foot. It seems probable that this nerve and vein are to be regarded as representing the long saphenous and the internal saphenous, but representing them somewhat incorrectly, since, in the thigh the nerve actually lies beneath the sartorius and the vein superficial to it, and the vein arises on the dorsum of the foot, not in its plantar surface.[3]

The long saphenous nerve is also shown in other figures, as, for example, in two silver-point drawings on QV, 19. In one the nerve, accompanied by a blood-vessel, lies under cover of the sartorius muscle; in the other the muscle is cut across and reflected and the nerve and blood-vessel are shown passing down side by side as far as the knee, where they lie behind the medial condyle. The nerve and the accompanying blood-vessel with the sartorius cut away are again shown on AnB, 18, the vessel being here probably the femoral artery, and on QV, 15 the same vessel is shown accompanied by a branch of the femoral nerve, which divides into the long saphenous and a branch to the vastus lateralis.

The great sciatic nerve is shown on QV, 15, issuing from the great sacro-sciatic foramen. It passes down the back of the thigh and divides below into a peroneal branch, which inclines laterally, and a

[3] Holl (1917) identifies the nerve in its upper part as the femoral and in its lower part as the posterior tibial. It is difficult to believe that Leonardo could have fallen into such confusion and the identification with the saphenous seems more probable, especially since the nerve is not continued into the sole of the foot.

tibial branch that continues straight downward. The same branches are shown on QV, 10, and again on QV, 9v and AnB, 5, the peroneal in these last two sending a branch to the dorsum of the foot. On AnB, 18 there is a representation of the sacral plexus, into whose formation the last lumbar and first and second sacral nerves enter and from which two nerves arise and pass down the leg parallel to one another and finally pass to the sole of the foot, bending around the malleoli (*noci dei piedi*). This may represent a high division of the sciatic, such as is occasionally seen, but even so the passage of both branches into the sole of the foot is inaccurate. A high division of the sciatic is also shown on QIV, 9 (fig. 80).

The ganglionated cord of the so-called sympathetic nervous system was known in part of its course to Galen and was regarded by him as a branch of his fourth pair of cranial nerves. Avicenna merely mentions it as a part of the fourth pair, indeed it would hardly be recognizable from his statement without reference to Galen, and Leonardo might well be pardoned if he failed to notice it. Yet it seems that he did observe it, even though he failed to perceive its correct relations. On AnB, 23 are two figures (fig. 81) that represent the cervical portion of the spinal cord and the nerves that arise from it to form the brachial plexus. On issuing from the spinal cord each nerve makes connection with a slender cord that runs upward, parallel to the spinal cord, to unite with the brain. These slender cords are again shown on AnB, 4 and 4v, and on QV, 8. One is at first inclined to identify them with the vertebral artery, since in some figures they are represented as passing through foramina in the transverse processes of the cervical vertebræ. This possibility is negatived partly by the fact that the nerves are continuous with the cords, and partly by a figure on QV, 21, in which the foramen for the cord is represented as quite separate and distinct from that for the vertebral artery, this latter foramen being labeled "passage-way for the animal virtue."

Holl (1917) and Hopstock (1919) agree that the cords can not represent the vertebral arteries and while Hopstock regards them as phantasies, Holl gives them terminological entity as the *nervi intertransversarii* and suggests that Leonardo had borrowed them for some ancient unknown source, in which prolongations of the brain substance had been described as occupying the place of the vertebral arteries. It is to be noticed that all the figures showing the cords are evidently diagrammatic; they do not represent actual preparations, though based on dissections; they are products of the study rather than of the laboratory and it is more than a possibility that the cords are portions of the ganglionated cords, the recollection of which had been more or less confused with memories of the vertebral arteries.

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Fig. 79. Figure showing course of long saphenous nerve. (QV, 20v.)

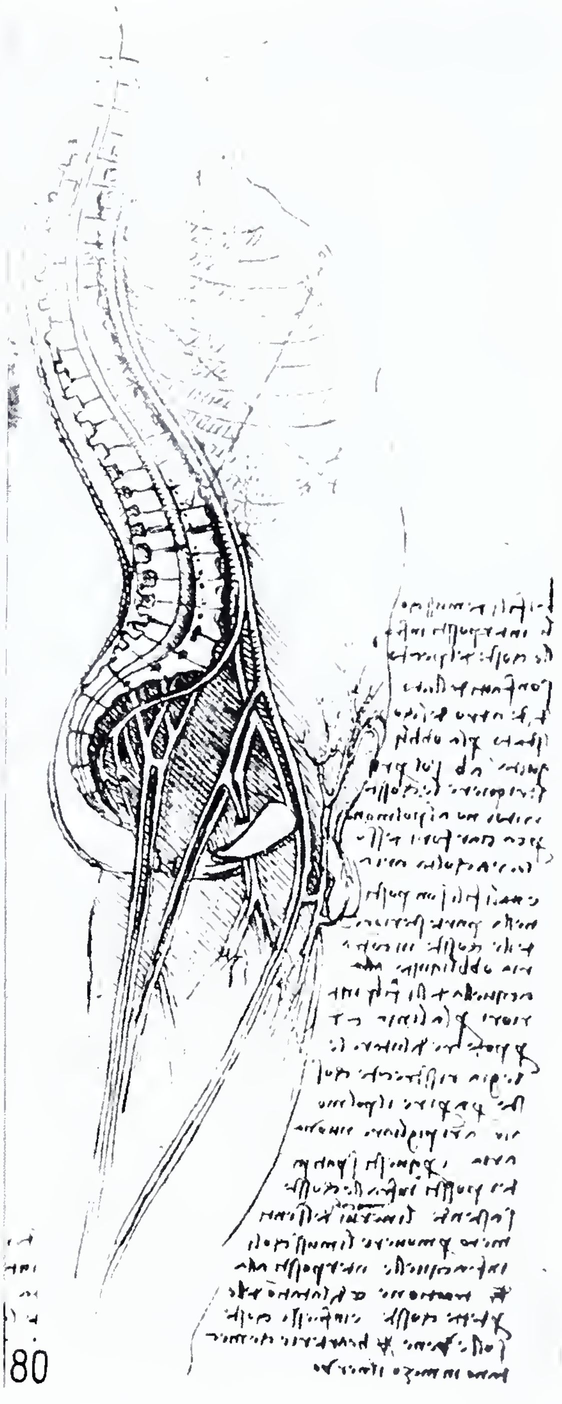

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Fig. 80. Branching of common iliac vessels and sciatic nerve. (QIV, 9.)

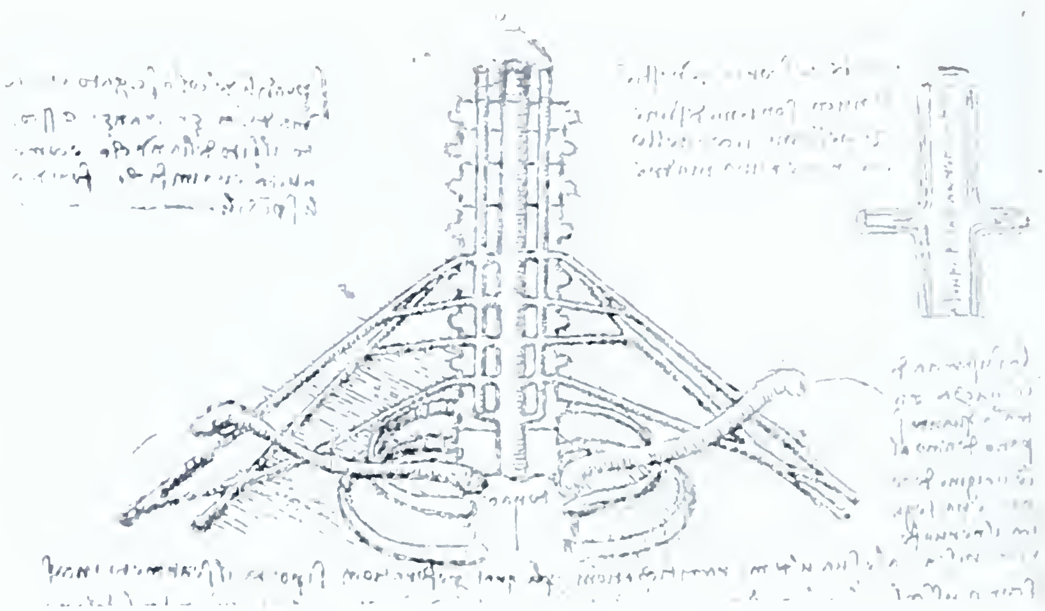


Fig. 81. Cervical portion of spinal cord, showing origins of spinal nerves and what may be a suggestion of ganglionated cord. (AnB, 23.)

CHAPTER XVIII

THE SENSE ORGANS

When it was the structure of a sense organ that was in question, and it was the structure of the eye alone that was considered in detail, the Arabian and mediaeval writers were content to rely on Galen; but when they considered the functions of these organs and how a sensation entered into consciousness they went back to Aristotle for the foundations of their theories. Consequently, to understand Leonardo's attitude toward the physiological and psychological problems presented by the sense organs it will be well to consider briefly Aristotle's psychological ideas.

Every object, he claimed, may be regarded as a combination of matter and form, this latter term being used in a very broad sense, so that it might mean the sweetness of a sapid substance, or color, or hardness, as the case might be. Sensation is the perception of objects in their forms, independent of their matter, and is the result of a change set up in the sense organ by the object, either directly or indirectly. Each sense organ reacts to only one variety of form; but an object may have several forms; in addition to color it may have, for example, number, size, motion, and for the perception of all these and for the coordination of sensations perceived by various sense-organs a *sensus communis* is predicated. By this coordination of sensations a mental representation of the object perceived, a "phantasy," is formed and such representations form the basis for thought and memory.

Aristotle's anatomy was discredited because he located the common sensorium in the heart, the source and center of the pneuma, believing the brain to be wholly destitute of sensation, and being misled by his failure to distinguish between nerves and tendons. In these views he stood alone, for older writers, and even his predecessor and teacher Plato, located sensation in the brain. The Alexandrian anatomists determined the origin of the nerves from the brain and spinal cord and later Galen's authority led to the general acceptance of the brain as the location of the sensus communis and the other mental faculties, whose supposed distribution in the brain has already been considered.

Only the five classical senses were recognized by Aristotle and, indeed, were believed to be the only ones possible; since they give information of all objects known to us, any additional ones could only be duplications and, therefore, superfluous, a condition impossible in his scheme of the cosmos. He found difficulty, however, in regarding touch as a single sense, since the sensation of temperature was associated with it, and he endeavored to avoid the difficulty by supposing that touch gave information as to the actual object, but associated with this were two pairs of contrasting qualities, fluidity and solidity, heat and cold, the qualities of the four elements that entered into the composition of the object. Avicenna added to the difficulty by recognizing in touch four pairs of discriminations, heat and cold, dryness and wetness, hardness and softness, roughness and smoothness, still adhering, however, to the doctrine of five senses, and in this he was followed by Leonardo, who does not commit himself as to the composite character of touch.

According to Aristotle's opinion, that sense was the most perfect which could most correctly perceive the form of the object as apart from its matter. Touch was, therefore, the least perfect sensation, since it required actual contact with the material object. Taste was somewhat more perfect, since, though it required contact with the sapid body, it gave more than the sensation of mere contact. Smell came next, then hearing and finally sight, none of these three requiring actual contact, but acting through a medium interposed between the object and the sense organ. This order may be followed in considering Leonardo's treatment of the sense organs, though it may be premised that it is sight alone that he considers at length.

Of touch he notes that it is distributed over the whole surface of the body (AnB, 2), instead of being located in a definite organ as are the other senses, and the impression passes[1] to the *sensus communis* by the perforated cords, *i.e.* the nerves, which are spread out with infinite ramifications in the skin enclosing the members of the body and the viscera. It has been shown (p. 208) that Leonardo was bold enough to modify the time-honored ideas as to cerebral localization by transferring the *sensus communis* from the anterior to the middle ventricle, and he also suggests (QV, 7) that since the posterior ventricle is in the region where all the nerves that give the sense of touch concur, that is to say the spinal nerves through the spinal cord, it may be that the seat of the sense of touch is in this posterior ventricle, "since Nature in all things operates in the briefest time and way possible." He notes, perhaps from observation of the results of a wound, that if the nerve to the finger is cut the sensation of the member is destroyed "even if it be placed in the fire" and states that in order that such nerves may be protected from injury they are placed between two fingers (AnA, 10v). One finds in two passages (AnA, 10 and 13v) an account of the illusion described long before by Aristotle, to the effect that if two fingers of one hand are crossed one object placed between them will seem, so far as the tactile sense is concerned, to be two. He fails, however, to understand that the illusion is a mistake in judgment, suggesting that

[1] The text reads "does not pass," but the *non* is evidently an error.

it is due to the fact that the two surfaces of the fingers concerned are supplied by different nerves, whereas when the object touches the adjacent surfaces of uncrossed fingers both of these surfaces are supplied by the same nerve; by nerve, here, he means of course nerve branches.

Of temperature sense Leonardo makes no mention, probably including it in touch, nor does he have anything to say as to taste. Smell he locates in the *sensus communis* (AnB, 2) and evidently held that it was due to the contact with the olfactory organ of particles given off from the odorous substance and transmitted through the air as a medium. He speaks of musk as always keeping a great quantity of the atmosphere charged with its substance, without, however, diminishing in quantity (CA, 270).

The structure of the ear was very imperfectly known to the classical writers, even to Galen; it was for them a cavity of more or less complicated form, excavated in the substance of the petrous portion of the temporal bone. This too was Leonardo's idea, who states that to hear the sound of a voice it is necessary that it should "resound in the concave porosity of the petrous bone, which is to the inner side of the ear," whence it is carried to the *sensus communis* (AnB, 2). A sound spreads itself out in circles through the air (A, 9v), without, however, producing displacement of the air (CA, 360), and, just as light is reflected from a mirror with the angles of incidence and reflexion equal, so will the note of an echo "strike and rebound within the hollow where it has first struck with equal angles to the ear" (C, 16). The comparison with vision suggests the query whether there may not be an aftersound in the ear, just as there is an after-image in the case of sight; whether the sound that remains or seems to remain in the bell, after it has received the stroke may be not in the bell but in the ear, but this idea is rejected since "if it were true, the sound of the bell would not cease abruptly if the bell is touched by the hand—but it does" (CA, 332).

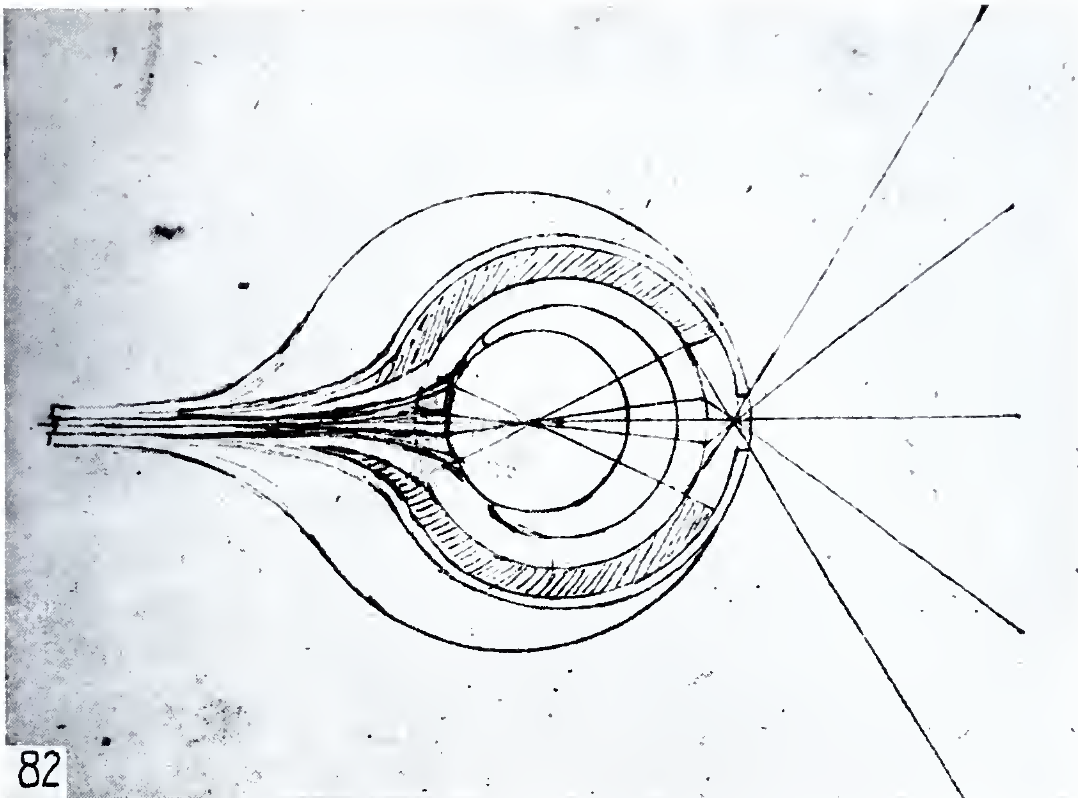
Leonardo's interest in the eye was principally and primarily that of the artist, seeking the principles that determine differences in the appearance of objects due to differences in their illumination, or those that determine the apparent size and form of objects at various distances, in order that he might more accurately portray them. But, as in other cases, he was quickly led beyond the view-point of the artist into the investigation of the problems of physiological optics, into inquiries as to the mechanism by which images of objects were conveyed to the sensorium. Unfortunately in pursuing these studies he neglected to obtain an accurate knowledge of the machine itself, but was content to rely upon the erroneous ideas as to the structure of the eye that had been handed down by earlier writers, with the result that he contributed little if anything to the knowledge of physiological optics.

The coats of the eyeball and its contents were well described by Galen and his description was satisfactorily recapitulated by Avicenna.

The membranes of the brain were supposed to form a sheath for the optic nerve and at its termination expanded to form the coats of the eyeball, enclosing its contents, the humors. In the center was the lens or crystalline humor, termed by Avicenna, likening it to a hailstone, the *glacialis*. Posteriorly is the *vitreous* humor, like liquefied glass and embracing the *glacialis* as far forward as its equator, and anteriorly is the third or aqueous humor, termed by Avicenna the *albugineus*, likening it to white of egg. At its termination in the eyeball the optic nerve expands into a membrane, net-like in texture, whence it was termed the retina, and this extends forward to the boundary between the *albugineus* and *glacialis*, where it forms a membrane, the *tela aranea*, that separates these two humors. External to the retina is the *secundina*, now known as the chorioid coat, which is interwoven with veins for the nutrition of the eyeball and anteriorly becomes converted into a membrane of a blue color, the iris, which is perforated by a foramen, the pupil. External to the *secundina* is a dense membrane, whose posterior opaque portion is termed the *tunica dura*, while anteriorly it forms the transparent cornea. Finally there is the most external coat, the conjunctiva.

From this description, read as a guide to the dissection of a bullock's eye, a fair idea of the structure of the eyeball might be obtained. But mediaeval anatomists did not dissect, and the mental picture they obtained from Avicenna's description was very incorrect, as is evidenced by the figures illustrating their treatises. In two of Leonardo's figures of the eye (QV, 6v) the conjunctiva is not represented, the lens is a spherical structure occupying the center of the eyeball, the sclerotic and choroid coats are incomplete anteriorly, a pore traverses the tela aranea and the aqueous and vitreous humors are not identified. In a third figure (CA, 1128) (fig. 82) somewhat more detail is shown, but the large spherical lens still occupies a central position. Notwithstanding Leonardo's suggestion of a method for preserving the relations of its parts during dissection (p. 87), his figures give no evidence that he had made use of the method. They rather give the impression of being copies from memory of an earlier figure, but what that may have been is uncertain; they bear some resemblance to a figure in the *Margarita Philosophica* of Gregor Reisch (1508) and may trace back to a common source with it. The supposed central position of the lens was a bar to the correct understanding of the dioptrics of the eye and, it may be noted, it continued to be so until long after Leonardo's time. Vesalius in his *De fabricâ* (1543) assigned to the lens a central position and it was not until 1583 that Felix Plater recognized its true position.

Leonardo's uncertainties as to the structure of the eye are perhaps the cause of the uncertainties of his nomenclature, all the more striking in comparison with the definiteness of that of Avicenna. The cornea is generally termed *luce*, but occasionally that word evidently means



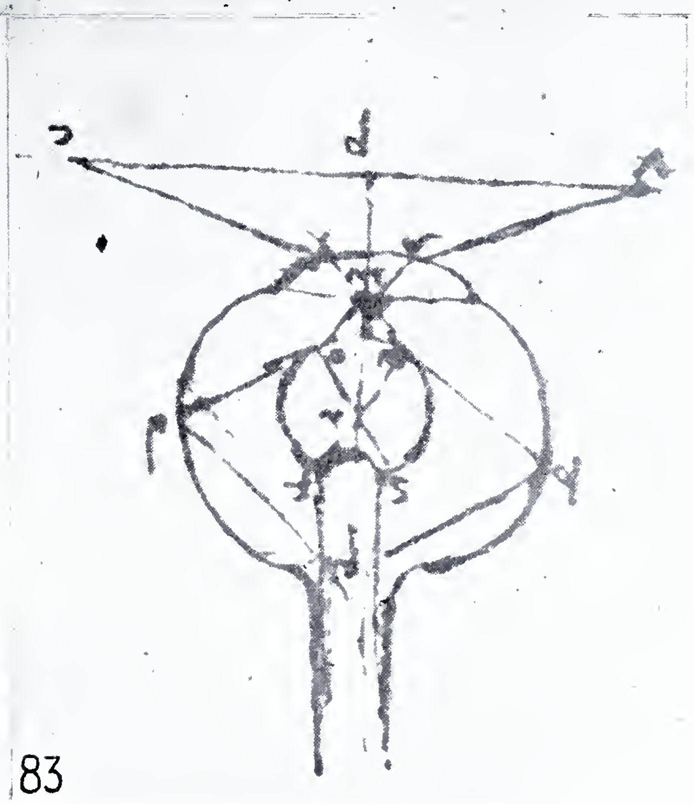


Fig. 82. Diagram of the structure of the eye. (CA, 337 R., A.)
Fig. 83. Diagram showing two possibilities of refraction within the eye. (D, 10.)

the pupil (D, 5; AnB, 13v), elsewhere termed *popilla;* the lens is usually the *spera crystallina,* but on D, 8 it is termed the *spera vitrea;* the albugineous humor has a spherical form and the lens is situated at its center, no distinction being made between the albugineous and vitreous humors (D, 3v); and, finally, the term *uvea* seems to denote the retina (D, 3v, 7v, 10).

To the ancient Greeks it seemed that sensation could occur only by the contact, direct or indirect, of the object perceived with the sense organ. With most of the senses the contact seemed obvious, but it was not so with vision. Two theories of sight contact suggested themselves. One, adopted by the Epicureans, assumed an extension of the object to the sense organ, minute particles of the object being given off to the air and being carried by it to bombard the sense organ; the other, adopted by the Stoics, assumed an extension of the sense organ to the object, the pneuma or visual virtue being projected from the eye so as to embrace or include the object seen. Plato, however, dissatisfied by both theories, suggested a modified combination of them. He assumed that visual virtue emanated from the eye, and, meeting and combining with emanations from the object, returned to the eye to produce in it an image of the object. The air acted as a medium for the transmission of the emanations, but it was air modified by these that established the contact.

Later authors, such as Galen and Euclid, accepted Plato's theory, but still later it was replaced by that formulated by Aristotle. His theory of vision was primarily an attempted explanation of color vision, but granting that it might account for this, it might also suffice for the explanation of form. It was obvious that the eye and the object seen were both essential to vision—either being absent it could not occur; but the third factor, the medium, was quite as essential and if it were eliminated, as by placing the object directly upon the eye, again vision failed. The eye and the object were both concrete and definite, the medium offered a greater field for assumptions, and it was upon the medium that Aristotle concentrated his attention. It was as a rule air, but it might be other material, water for example, and therefore the true medium must be something possessed by both air and water, that is to say translucency, a property due to the presence in each substance of a constituent which Aristotle termed the diaphanous. It was upon this diaphanous, an adumbration, if one may use that word, of the luminiferous ether of more recent times, that the object impressed its color and, less readily, its form, so that it carried simulacra or, as they came to be termed, *species* of the object, and vision resulted if these encountered the eye. This theory made emanations from the eye superfluous and it also obviated the difficulty of explaining how emanations from the object could penetrate the eye, since the cornea, the lens and the two humors were translucent, that is to say contained the diaphanous, and so the species could be carried to the optic nerve and by it to the *sensorium commune*.

It may be presumed that Leonardo was more or less familiar with Aristotle's theory of vision, for while he does not speak of the diaphanous medium he regards vision as due to the entrance into the eye of simulacra (species) of the objects seen.

"The senses when they receive the simulacra of things do not send forth from themselves any actual power, but the air between the object and the sense incorporates in itself the simulacra of things and by contact with the sense presents them to it." (CA, 90.)

Every object fills the surrounding air with its similitudes and the air is accordingly filled with infinite straight and radiating lines, mutually intercrossing and interlaced, but without interference (A, 2v), and it is along these lines that the species travel from the object to the eye (A, 8v), taking the shortest and most direct course in accordance with the law propounded by Aristotle that every natural action is performed in the shortest way possible (D, 10v). When one considers the wide range of one's vision and the number of objects that may be perceived at a glance, one may form a feeble conception of the innumerable lines, each bearing its own species, that must be coverging upon him. But this is but a small part of the story, for as many other lines must be converging upon every individual that perceives the same objects from slightly different angles.

"The image of the sun is single in all the sphere of water that sees it and is seen by the sun, but it appears to be divided into as many parts as there are eyes of animals seeing it (reflected) from the water. Sailors see the sun at the same time in all parts of their hemisphere." (D, 6.)

The magnitude of this concept is stupendous and it startled even Leonardo, bold as he was in conjecture, that in the eye the image of the moon in the east and that of the sun in the west might be brought together in a single picture.

"Who" he says "would believe that so small a space could contain the images of all the universe? O mighty process! What skill can avail to penetrate a nature such as thine! What tongue can unfold so great a wonder! Truly, none! This it is that leads human discourse to the consideration of things divine." (CA, 345v.)

Sometimes, indeed, he doubts whether this rectilinear emission from the object is the true explanation of vision, for, in speaking of the rays of luminous bodies, he says—

"It is necessary to determine first what these rays are and to see whether they have their origin from the eye that sees the object or from the luminous body." (D, 9v.)

This was apparently, however, but a passing suggestion; he held it to be impossible that the eye should project from itself the visual virtue (Ash[2], 1); nevertheless he maintained that subtle influences, unconnected with vision, emanated from the eyes. He disputes the opinion of those who held that such emanations would lessen the power of vision and would produce a diminution of the eye, citing in analogy the case of musk, which perfumes great quantities of air without itself being diminished, and that of a bell, which gives forth sound when struck and yet is not consumed thereby. And he then proceeds to give concrete examples of such emanations, such as the serpent luring by its fixed gaze the nightingale, the lethal glance of the basilisk, the glance of the wolf which produces a hoarse voice, the gaze of the ostrich and spider which is said to hatch their eggs, the beguiling power of maiden's eyes and finally the case of a Sardinian fish that is said to emit light from its eyes which kills other fish (CA, 270v). Mediaeval credulity, with its faith in Pliny's tales, was still strong in Leonardo's time.

These emanations were, however, something quite different from the *spetie* emitted by visible objects and passing in straight lines to the eye, where they are received by the *luce* or cornea. What then was supposed to be their fate within the eye? Where was seated the *virtu visiva* by which the "species were combined to form an image of the object from which they came?" It must be remembered that in Leonardo's time the function of the retina was unsuspected; he seems to have regarded it as a reflecting surface, comparing it to a silvered mirror (D, 7v), an idea suggested, perhaps, by the observation that if one stand between a cat and a light the animal's eye appears to be on fire (H, 109). The retina then being *hors concours*, what were the other possibilities?

In some passages Leonardo speaks as if he regarded the pupil as the seat of the *visual virtue;* he states, for example, that the pupil has all the *virtu visiva* in all parts and all in each part (D, 6v; AnB, 25). But this was either merely a passing idea or a careless method of expression, since, elsewhere, he notes that—

"The pupil is situated opposite the middle of the cornea, which has the form of a portion of a sphere. It receives the similitudes of objects and sends them by the pupil within, to the place where vision is formed." (K, 119.)

Within the pupil is the lens and this too is considered.

"Species that penetrate the albugineous humor by way of the pupil meet in the sphere of the crystalline humor, and either the *virtu visiva* is in it or at the extremity of the optic nerve, which receives the species and refers them to the common sensorium. . . . If the *virtu visiva* is in the center of the crystalline lens, this either receives the species on its surface, they being sent to it from the surface of the cornea where the objects see themselves, or they are reflected to it from the surface of the *uvea* (retina) which surrounds and covers the albugineous humor." (D 7v.)

This passage presents as an alternative for the lens the end of the optic nerve, and without further quotation it may be said that Leonardo finally decides upon this (D, 7v, 8; AnB, 2). There is a flavor of irony in the fact that he should have located the *virtu visiva* in what is now known to be the blind spot of the eye!

The decision in favor of the end of the optic nerve was based on an attempt to explain the erection of the image. The phenomena of refraction had been quite accurately described in the eleventh century by the Arabian mathematician Muhammed Ben el Hasan Ibn el Heithem, better known to the western world as Alhazen, and were known to Leonardo and his contemporaries. Leonardo recognized that the cornea and lens must produce refraction, that there must be indeed a crossing of the rays coming from an object and therefore an inversion of the image. How was it then that it appears erected? It does not seem to have occurred to him that the image is received by the *virtu visiva* inverted and that its erection is a matter of interpretation or experience and, accordingly, a function of the sensorium commune or other part of the brain. He was therefore forced to the conclusion that there was a second crossing of the rays within the eyeball.

Figure 83, a reproduction of a diagram on D, 10, illustrates two ways in which this double crossing might occur, one of the ways being later condemned. The species from *a*, *b*, *c* converge as they approach the eye and pass through a nodal point in the aqueous humor, so coming to the anterior surface of the lens, upon which the image would be inverted. The species may then follow one or other of two courses; either they may be refracted by the lens and so cross a second time, producing an erected image at the end of the optic nerve, prolonged in the diagram so that it is in contact with the lens, or they may be reflected from the surface of the lens to the retina at *p* and *q*, whence they are again reflected to the end of the optic nerve. This second path, would, however, leave the image inverted and it is therefore discarded.

"The pupil always receives the images of objects upside down and the *virtu visiva* sees them as they are. This is due to the rays passing through the center of the crystalline sphere in the middle of the eye." (D, 2v.)

It is noted that the double crossing in the eye might be open to objection and the erection of the image ascribed to the decussation of the optic nerve (D, 3v).

How far Leonardo was from a correct understanding of the dioptrics of the eye is evident from the figure. But even so he was in the line of progress in locating the seat of vision in the nerve, other structures in the eye being merely contributory to effective stimulation. For Galen had transmitted the theory that the lens was the seat of the visual virtue, basing his argument mainly on the idea that vision was a sense *sui generis*, and that since there was nothing like the lens elsewhere in the body it must be the seat of vision.

Leonardo experimented extensively with vision through a pinhole, finding in these experiments his strongest evidence for the primary inversion of the image. He figures (D, 10) a pinhole opening in the wall of a rectangular box and notes that the image thrown upon the opposite wall must be inverted. He was working with a pinhole camera obscura and evidently recognized that the eye might be regarded as such a contrivance. Indeed, the invention of the camera obscura has been ascribed to him. One pinhole experiment interested him greatly. Looking through a pinhole at a source of light and holding a pin between the perforated card and the eye, one sees the image of the pin inverted and apparently beyond the card, and if the pin is moved upward its image moves downward (D, 4v). Leonardo's argument from this observation may be supposed to be as follows. Since the camera obscura shows that there is a crossing of the rays at the pinhole and since the image of a pin beyond the pinhole appears erect, there must be a second crossing in the eye. If then one eliminates the crossing at the pinhole by holding the pin between the eye and the card, only one crossing affects the image and it should appear inverted, and so it does. Unfortunately for his argument, Leonardo failed to perceive that with the pin between the eye and the pinhole it is the shadow of the pin, interrupting rays that have already crossed, and not the pin itself that is seen, and since the shadow on the retina is that of an erect pin, it is interpreted as being inverted The same result may be obtained by bringing the perforated card so close to the eye that the shadows of the eyelashes are seen, when if the card be moved to the right, the shadows seem to move to the left (K, 125v).

How a visual estimate of the size of an object is made is a question that would naturally attract an artist, and Leonardo devoted no little thought to it, without, however, reaching any very satisfactory conclusions, since he knew little of the mechanism of accommodation. He laid down two principles governing the perception of size, (1) that that object appears largest whose species come to the eye at the greatest angle (E, 15v) and (2) that of two objects of equal size that which is the more brilliantly illuminated will seem the larger and the nearer (C, 1) In connection with the first of these principles there seems to have arisen in Leonardo's mind some confusion of the angle of vision with the angle of incidence of the visual rays, for he states in one passage that "the eye has in it an indivisible point to which the apices of all the pyramids (*i.e.* cones of visual rays) converge from different objects," this point being at the center of the eye, that is to say in the lens (A, 10). But if this point is the visual center then there is an obvious difficulty.

"If all images came at an angle they would concur in a point and all things in the Universe would appear one. We conclude, therefore, that the sense takes the images that are reflected at the surface of the eye, and then judges them within. They do not concur in a point, nor in consequence in an angle." (F, 34.)

The distinctness of an object was held to depend not only upon the brightness of its illumination, but also on the size of the pupil.

"The greater the size of the pupil the more of form and brightness will it see in the object and, conversely, the smaller it is the less and more obscurely will it see its object." (AnB, 25.)

This leads to observations on the dilation and contraction of the pupil.

"If the eye that has been in the dark is suddenly illumined, the pupil contracts so that the light will not injure too great a portion of it. In darkness the pupil dilates to its full extent to send the resemblance of obscure things to the *imprensiva*." (C, 16.)

It is noted that the power of adapting the pupil to the amount of light is especially marked in nocturnal animals.

"Nocturnal animals, like cats and owls, have a small pupil and at night a very large one. So with all terrestrial animals and those of the air and water, but more beyond compare, the nocturnal animals." (D, 5v.)

"In all animals the pupil dilates or contracts according to the amount of light. It is greatest in birds, especially in nocturnal ones, such as the owl. In this the pupil may occupy the whole eye or contract to the size of a grain of millet, remaining circular. In the lion species the pupil contracts from a circular to a triangular (*i.e.* slit-like) form. Man, less blessed with vision, is not harmed by excess of light. The eye of the owl increases so much that it sees better in the smallest light of night than we do in the full splendour of mid-day." (G, 44.)

"The *luce* or pupil of the human eye in its dilation and contraction, dilates or contracts by half its size, and in nocturnal animals it contracts and dilates more than a hundredth part of its size. And this may be seen in the eye of the owl, a nocturnal bird, by bringing toward its eye a lighted torch, or better if you make it look at the sun, for then you will see the pupil, which at first occupied all the eye, contract to the size of a grain of millet, and in this contraction it equals the pupil of man and clear and lustrous objects appear of the same color as, in such time, they appear to man, and so much the more that the brain of such an animal is less than the brain of man. Whence it happens that such a pupil increasing in the night-time a hundred times more than that of man, sees a hundred times more light than man, so that the power of vision is not then overcome by the darkness of night. And the pupil of man, which only doubles its size, sees little light and is almost like that of a bat, which does not fly in times of too much darkness." (AnB, 13v.)

"Only in the lion tribe among animals does the pupil alter its shape as it grows larger or smaller. In full contraction it is long, in moderate oval and at full expansion circular." (C.A., 262.)

"The ventricle of the brain termed *imprensiva* is more than ten times the size of the eye of man, of which the pupil (*luce*), which gives the vision, is the thousandth part. In the owl the nocturnal pupil is as large as the *imprensiva*. In man the *imprensiva* is like a large hall lighted by a small hole, but in the owl it is like a small chamber altogether open. For in the large hall it is night at mid-day and in the small open one it is day at midnight, when the weather is not cloudy." (D, 5.)

These passages tell their own story. The effect of light on the pupil was clearly perceived, but Leonardo failed to observe the movements of the iris associated with accommodation, first described by Scheiner in 1631. In one passage he speaks of changes in the lens—

"The crystalline humor which is internal to the pupil condenses to meet the things that shine and rarefies to meet obscure things." (D, 5v.)

But this supposed change was not associated with the idea of accommodation for distance, a phenomenon of which he was ignorant, the part played in it by the lens having been first suggested by Descartes (1637). Nor did he note the value of the iris in diminishing spherical aberration, for this too was unknown to him. He did recognize, however, that the species that reached the eye in the line of the axis of vision were more distinctly perceived than others. Thus he says—

"An object is less distinct if it impresses itself at a greater distance from the center of the pupil, where terminates the median line that goes straight to all the objects of the figure of which one can have a true and certain knowledge. This line is straight, without any intersections, and is the mistress of other lines." (D, 8v.)

And again—

"The eye has in it a single line placed in the middle of an infinity of others, to which it is the central line, and these others have more or less power as they are nearer or further from this central one." (D, 8v.)

He notes that if there is a number of objects in a line extending away from the observer and vision is concentrated on one, the others will appear double. Thus if there are five objects, the number seen will be nine, if two objects three, and if one hundred, one hundred and ninety-nine. So too he notes that an opaque object, smaller in diameter than the pupil, placed before the eye, does not prevent vision of a more distant object, but behaves as if it were transparent (D 6v), a statement that needs some qualification.

Again it is noted that a luminous object, such as a star seen through a pinhole, loses its rays and appears round and smaller—smaller, because with the pinhole a smaller amount of the pupil is affected, and the size of the image is proportioned by the amount of the pupil affected by its rays (F, 32); round, for a remarkable reason,

"The rays which show at the extremities of luminous bodies have their origin not in the bodies, but in their images impressed in the thickness of the eyelids. In looking at a star each eyelid receives an image and the pupil another, and the three images, being adjacent, appear one to the eye. If we raise the head the eye will lose all the lower rays of the luminous body." (D, 9v.)

And essentially the same idea is expressed in F, 30 and D, 1v, with the additional statement that the images received through the eyelids will be inverted, since the fluid that lubricates the eyelids will be concave "according to the fourth and the eighth of the Waters," and the pupil is within the concourse of the pyramidal rays of the concave mirror. Confusion also seems to prevail where the perception of the boundaries of objects is considered (D, 10v; E, 15). The eye is never able to perceive boundaries clearly, apparently because they will be confused with "the images of more distant bodies, but the nearer the object is to the pupil, the more distinct will be its boundaries."

The imperfections of vision due to the shape of the eyeball are not considered, although the use of eye-glasses was known, and it was understood that they acted by refracting the rays before they reached the eye (D, 2). In one passage (G, 90) Leonardo speaks of presbyopia, explaining it by assuming that the aged are far-sighted because an object sends less impression of itself into the eye if it is far off than if it is close. Just as changes in the lens to produce accommodation were unknown, so were those due *instanti senectæ*.

The persistence of the visual image was recognized and was regarded as an illustration of a general tendency, according to which "every impression tends to permanency or desires permanency" (G, 73). Ocular after-images were regarded as evidence that the images of objects enter the eye (CA, 204). A glowing brand moved rapidly in a circle gives the impression of a continuous line because the brand passes through infinite adjacent lines (QIII, 12v) along each of which an image passes to the eye in such rapid succession that they appear to be continuous. There is room for doubt, however, whether Leonardo saw in this phenomenon the effect of after-images, nor did he assign to them the doubled appearance of a vibrating string, which he explains by supposing that the string moves so rapidly that the eye gets simultaneously two images of the thing moved (C, 15). In one passage (G, 73) he seems to consider ocular after-images to be of the same nature as the persistence of auditory impressions after a bell has been struck by a hammer (G, 73), but elsewhere he comes to the conclusion that the continued sound impressions are due to continued vibration of the bell and are not in the ear, whereas after-images are unquestionably in the eye (CA, 332).

As to the question of binocular vision, Leonardo has little to say, but some of that little is very pertinent. Since the brightness or distinctness of any object was supposed to be due to the amount of the pupil affected, then it was natural to assume that an object would be less clear if seen by only one eye (AnB, 25; H91v).

"If one eye be closed and sees darkness and the other is open, the light it sees is mingled with darkness in the *virtu visiva*." (D, 9v.)

This smacks of theory rather than observation, but another memorandum shows that he had hit on the idea of stereoscopic vision, later worked out in detail by Wheatstone in 1830. On H, 49 Leonardo notes that objects seen with both eyes will appear rounder than those seen with one eye, and in the *Trattato della Pittùra* he notes that if the right eye is fixed on an object, all other objects in the same line will be hidden from it, but may be seen with the left eye. Thus the two eyes get different views of an object; they see it from slightly different angles.

Finally, as to color vision, or rather the physiological optics of color vision, Leonardo has nothing to say. As an artist he was of course deeply interested in color effects and he notes the effect of contrast on color perception, dark drapery, for instance, making the flesh seem whiter and lighter drapery making it darker. But how perception of color differs from that of form he does not discuss. Indeed it was not a problem in his day; color was included in Aristotle's category of form as distinct from substance, and the species that passed from the object to the eye were simulacra of color as well as of configuration, and color, consequently, needed no further consideration.

CHAPTER XIX

EMBRYOLOGY

The mysteries of development could not fail to incite to speculation even in the earliest times, and owing to the technical difficulties in the way of observation, speculation remained in control of the field for many centuries. One finds a brief statement regarding a human embryo in the Hippocratic writings, but the ideas of later writers were based, so far as they had a basis, on scanty observations on domestic animals and on the chick, and the facts so noted were straightway assumed to be applicable to human development. Aristotle, examining the chick, observed the embryo only when the heart began to beat and assumed that this *punctum saliens* was the first organ to form, an assumption that was an important factor in his assignment of the faculty of reason to the heart rather than to the brain. Further he assumed that the fetus was formed from the menstrual blood, the sperm contributing the element which caused it to take form, the female thus contributing the material and the male the formative element.

Galen opposed both these ideas, maintaining that the liver, on account of its predominating influence in the nutrition of the embryo, was the first organ to form, then the brain and then the heart. But the early visibility of the heart, "a palpitating bloody point, so fine that in contraction it disappeared, but reappeared on relaxation, looking like the point of a needle and of a ruddy color" in the middle of the rudiment of the chick, which had the form of "a little cloud"—the quotations are from Harvey's description (1628)—gave support to Aristotle's theory rather than to Galen's and the *punctum saliens* and the embryological primacy of the heart continued to persist in the literature until a comparatively late date. According to Avicenna the first differentiation of the embryo is that of a *locus cordis*, from which two vesicles arise, one of these developing into the heart, the other into the liver; he does not definitely give primacy to the heart, but the influence of Aristotle is evident, while Galen's theory is suggested by the association of heart and brain as the organ whose development precedes that of the umbilicus. Leonardo, however, expresses himself definitely in favor of Aristotle's theory—

"All the body" he says "has its origin from the heart in so far as concerns the first creation. The blood also and the veins and the nerves do the like, although these nerves are plainly seen to spring all from the spinal cord, remote from the heart, and the spinal cord is of the same substance as the brain whence it is derived." (AnB, 17v.)

This seems definite enough, but a further consideration of the condition under which the fetus lives led Leonardo to believe that during fetal life the heart did not beat (QIII, 7v; QV, 26). His argument was that since the fetus lies in a sac (amnion) filled with the purest water, it can not breath, for if it did it would at once be drowned. And if it can not breathe the beating of the heart would be unnecessary, and "it would be suffocated, as it can not get refreshment from the cold air that the lung draws in" (QV, 26). Such a belief does not necessarily contradict the theory that the heart is the first organ to be formed, but it detracts greatly from the importance of that organ as an essential to fetal development.

For Aristotle's theory as to the nature and significance of the maternal and paternal contributions to the formation of the embryo, Galen substituted a more correct idea, namely, that the ovary as well as the testis produced sperm, the embryo being formed by a union of the two sperms. Avicenna followed the teaching of Galen, but again with a suggestion of Aristotle in that he speaks of the male sperm as being richer in the *virtus formandi* and the female sperm in the *virtus informandi*, and furthermore he describes the female sperm as a sort of menstrual blood, slightly digested and converted. Leonardo, too, followed Galen in believing that there was female as well as male sperm, both being derived from the blood, but receiving their generative virtue in the ovaries or testes by a process of coction. The female sperm thence passed to the uterus where it was stored and its generative virtue was only aroused to activity when it became mingled with male sperm (QIII, 1v). He applies this belief to a contradiction of a supposed case of action of the environment in a passage that is worthy of quotation.

"The blacks in Ethiopia are not caused by the sun, because if a black makes pregnant a black female in Scythia the latter brings forth black, and if the black male makes pregnant a white female, she brings forth gray. And this shows that the seed of the mother has equal potency in the embryo with the seed of the father." (QIII, 8v.)

It would be easy to read into this last sentence a forecast of our modern knowledge of the process of fertilization, but of course Leonardo could have had no such prevision. He does, however, rightly interpret the facts at his disposal and with scientific acumen draws from them an important general conclusion.

Like his predecessors, Leonardo turned to the egg of the chick for information as to the processes of development, and several memoranda concerning such eggs occur among his notes. One refers to the advisability of first studying the anatomy of incubated eggs before representing the form of the liver in the child (QI, 10); another states the possibility of hatching eggs by the heat of an oven (QIII, 7); a third is a memorandum to inquire of the wife of Biagin Crivelli how capons when intoxicated may be made to hatch and rear the eggs of the hen (QIII, 7), a query apparently answered on the same folio:

> "Their chicks are given in care of a capon that has been plucked on the under side of the body and then urticated with nettles and placed on the nest (lit. under the basket). And then the chicks go under it and it feels pleased by the heat and takes pleasure in it, so that thereafter it leads them about and fights for them, jumping into the air against the hawk in ferocious defence." (QIII, 7.)

Another memorandum is a statement of what was probably a popular belief to the effect that eggs which have a rounder shape produce male birds, while longer ones produce females (QIII, 7); and still another is a note to inquire how the chick is nourished in the egg (QIII, 9v). But though these memoranda indicate clearly Leonardo's intention of studying the process of development in the chick, there is no indication that his intentions were ever carried out; one finds no descriptions and no drawings of chick embryos.

There is, it is true, one rather indistinct sketch (QIII, 8v) that might be taken as a crude representation of a chick embryo lying in the center of the area pellucida. Across it is written "yellow crystalline in large quantity," apparently a reference to the amniotic fluid; surrounding the embryo is a membrane, from which a leader extends to the label *anima* (*i.e.* amnion); surrounding the posterior half of this is another membrane labeled *alanchoidea* (*i.e.* allantois); surrounding all these is a third membrane labeled *secondina* (*i.e.* chorion); while enclosing everything is the *matrice* (*i.e.* uterus). The representation of these last two investments indicates that the sketch is intended as a diagram of the membranes surrounding a mammalian embryo, and two excellent figures on AnB, 38 (fig. 84) show that Leonardo had made a study of the pregnant uterus of a cow. In one figure he shows such a uterus with one of the ovaries and four blood-vessels supplying its walls, "these four veins *a*, *b*, *c*, *d* are two of arteries and two of blood," while the cotyledons show through indistinctly. In the second figure the fetus is shown still enclosed within the chorion, over whose surface the cotyledons, now plainly seen, are scattered and blood-vessels ramify in it, coming from the umbilical cord which is seen issuing from the ventral abdominal wall of the fetus.

It is evident, then, that Leonardo recognized the membranes which enclose the fetus, but it is equally clear that he knew them as they occur in the lower animals and not as they are in the human species. The amnion with its enclosed fluid is described; the fetus floats in the amniotic fluid and its weight is accordingly distributed over the whole

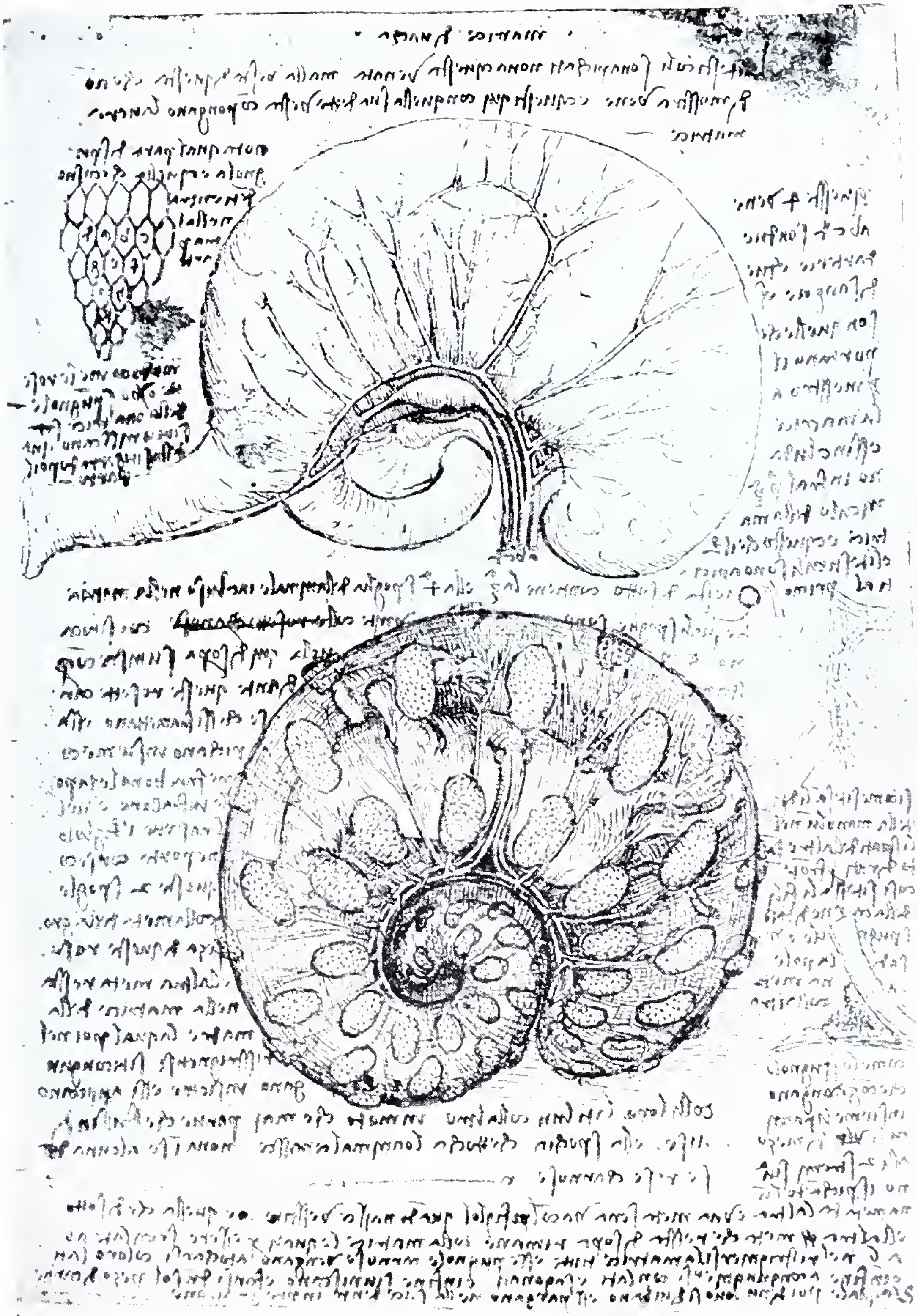


Fig. 84. Two figures of membranes and circulation of fetal calf. (AnB, 28.)

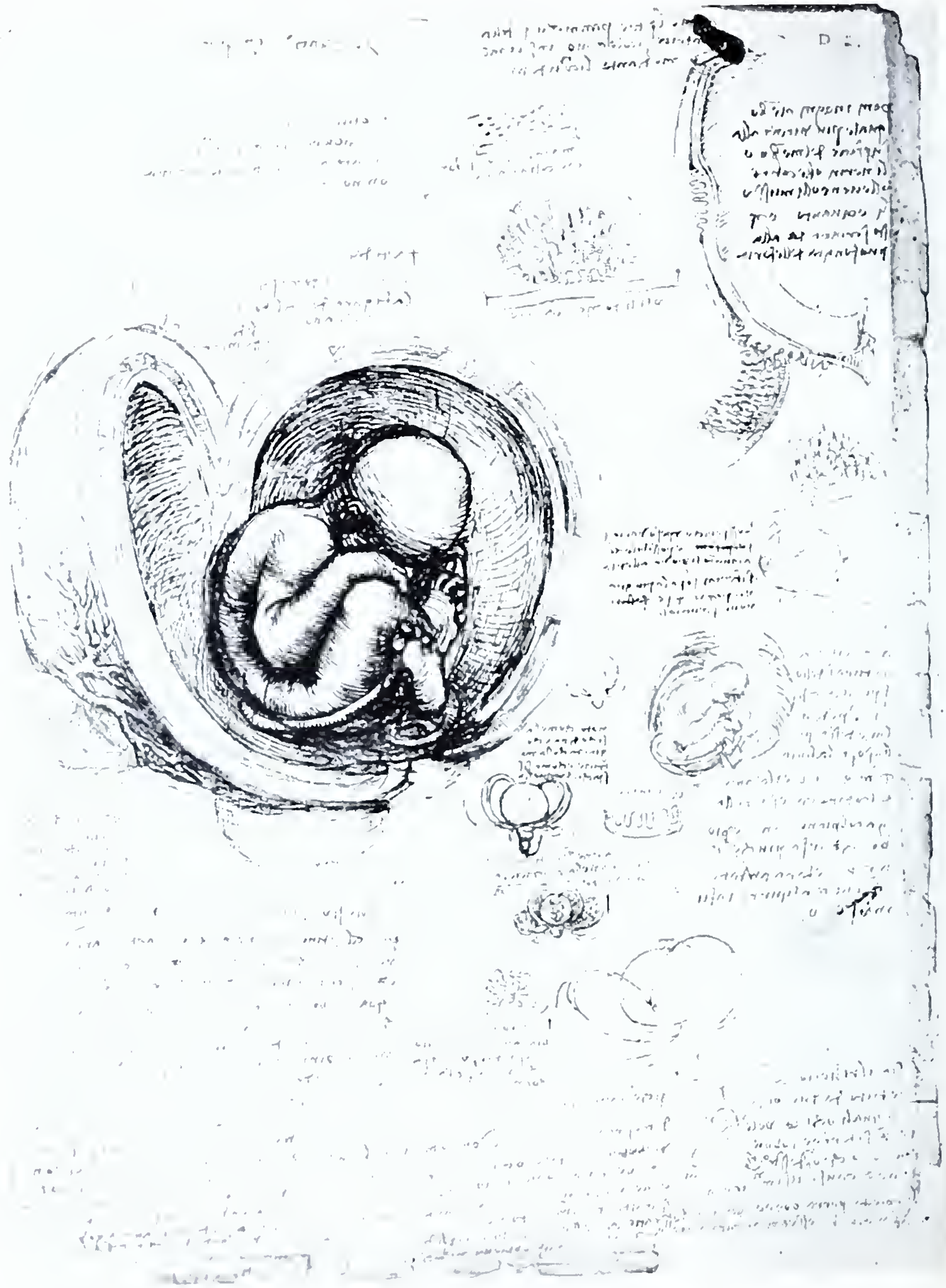


Fig. 85. Representations of human fetus at term and of ungulate placenta. (QIII, 8.)

inner surface of the uterus (QI, Iv). A second membrane is the allantois, which is described as passing—

"between the hands and knees of the child as it lies curled up, and it passes between the arms and the inner (*silvestra*) part of the thigh as far as the flanks and ties and encloses, making itself an investment for the child from its flanks downward." (QIII, 9v.)

The description is not very clear, but notwithstanding that the fetus is spoken of as the "child" (*putto*) it is evident that it was not the very rudimentary human allantois that was being described, but the more highly developed allantois of a ruminant.

So too it is the chorion of the fetal calf that is described, and it was upon this that Leonardo, following the example of his predecessors, based his ideas of human placentation, assuming that it also was of the cotyledonary type. In the wonderful drawing (fig. 85) of the fetus still within the womb (QIII, 8) it is curious to note cotyledons of the ungulate type on the wall of the uterus, while the discoidal placenta is entirely overlooked, even although there is a memorandum to "Note well the umbilical vein where it ends in the uterus" (QIII, 7v). It is evident that Leonardo had examined a pregnant human uterus at term—he gives a number of drawings of the fetus as it lies curled up within the womb (QIII, 7, 7v, 8, 9v)—but in none of them is a placenta shown. Where the uterus is also shown there is usually no indication of how the fetus is connected with it; only in QIII, 8 are the cotyledons represented, on the assumption that what he had seen in the cow occurred also in the human pregnant uterus.

The structure of the cotyledons interested him greatly. He recognized that at birth each cotyledon divides, part remaining connected with the uterus and part adhering to the chorion (QIII, 8; AnB, 29v), and gives figures (fig. 87) showing the separation (QIII, 8; AnB, 29v, 38), but is somewhat uncertain as to their actual structure. Sometimes he figures and describes both maternal and fetal cotyledonary villi interlocking as the fingers of one hand may do with those of the other (AnB, 38; QIII, 8, 9v), and at other times he describes the villi as developed on only one of the two contributing structures, chorion or uterus, and fitting into depressions on the other half-cotyledon (AnB, 29; QIII, 8). The villous constituent he terms the male cotyledon and the other the female, and raises the question, without answering it, whether it is the male or the female cotyledon that remains attached to the uterus at birth. But, however that may be, he perceived that half of each cotyledon remains with the fetus "When it is born covered" (AnB, 38), that is to say in a "caul," and the other half remains with the uterus. When this contracts after parturition the maternal cotyledons, widely separated on the uterus at term, are brought closer together, eventually come into contact, assuming by mutual pressure an hexagonal form, and finally fuse together to form a continuous membrane, separating again if a succeeding pregnancy occurs (AnB, 38). This seems to indicate that Leonardo had observed the discoidal human placenta and was endeavoring to explain it as a derivation from the diffuse cotyledonary type found in the cow and generally believed to be the functional type in the human species.

Leonardo's adherence to the traditional ideas as to the movements of the blood and the significance of the arteries and veins made an understanding of the relation of the maternal and fetal blood-vessels impossible for him, even though he had gained a knowledge of the vessels concerned in the fetal circulation. On AnB, 29v there is a figure representing these vessels as he observed them in the fetal calf (fig. 86). A number of branches are shown passing from the fetal membranes, some represented as almost vertical and others as almost horizontal, the accompanying text stating that the former come from the chorion and the latter from the amnion, though it is more probable that the allantois was meant. These branches open into four main stems that pass to the umbilicus, where they converge to a single umbilical vein that passes up the inner surface of the anterior abdominal wall to the under surface of the liver. In the substance of that organ, it breaks up into numerous branches and is not continued further. From the umbilicus four other vessels pass downward to open into the right and left iliac arteries and veins; the arteries are evidently the hypogastrics, the veins are imaginary.

Another figure, on QI, 1, is of interest because it represents the supposed human conditions (fig. 87). The lower portions of the aorta and inferior vena cava and their division into the iliac arteries and veins are shown and below is an oval structure, apparently representing the uterus, within which is a mass which is presumably meant for the discoidal placenta. To this an artery and vein (uterine) pass from each of the iliac vessels—for the vessels passing upward from the iliacs, see p. 176—and from the placenta there passes a single structure, evidently the umbilical cord. This extends to the fetal umbilicus and there gives off the ascending umbilical vein and the fetal hypogastric arteries. It seems probable that Leonardo believed the hypogastric vessels to carry vital spirit to the fetus, while nourishment was carried by the umbilical vein, since in another passage (QIII, 7v) the blood is said to pass from the fetal liver to the stomach, where it is converted into chyle; this passes to the intestine where a portion is absorbed by the meseraic veins, the rest remaining in the intestine and forming the meconium or fetal feces.

From the text on An, 29v one might gather that Leonardo believed that there was a complete separation of the maternal from the fetal blood, for he asserts that the umbilical vein of the fetus does not extend beyond the liver and, furthermore, that the umbilical vein is the origin

Fig. 86. Diagram of the umbilical and hypogastric vessels. (AnB, 29v.)

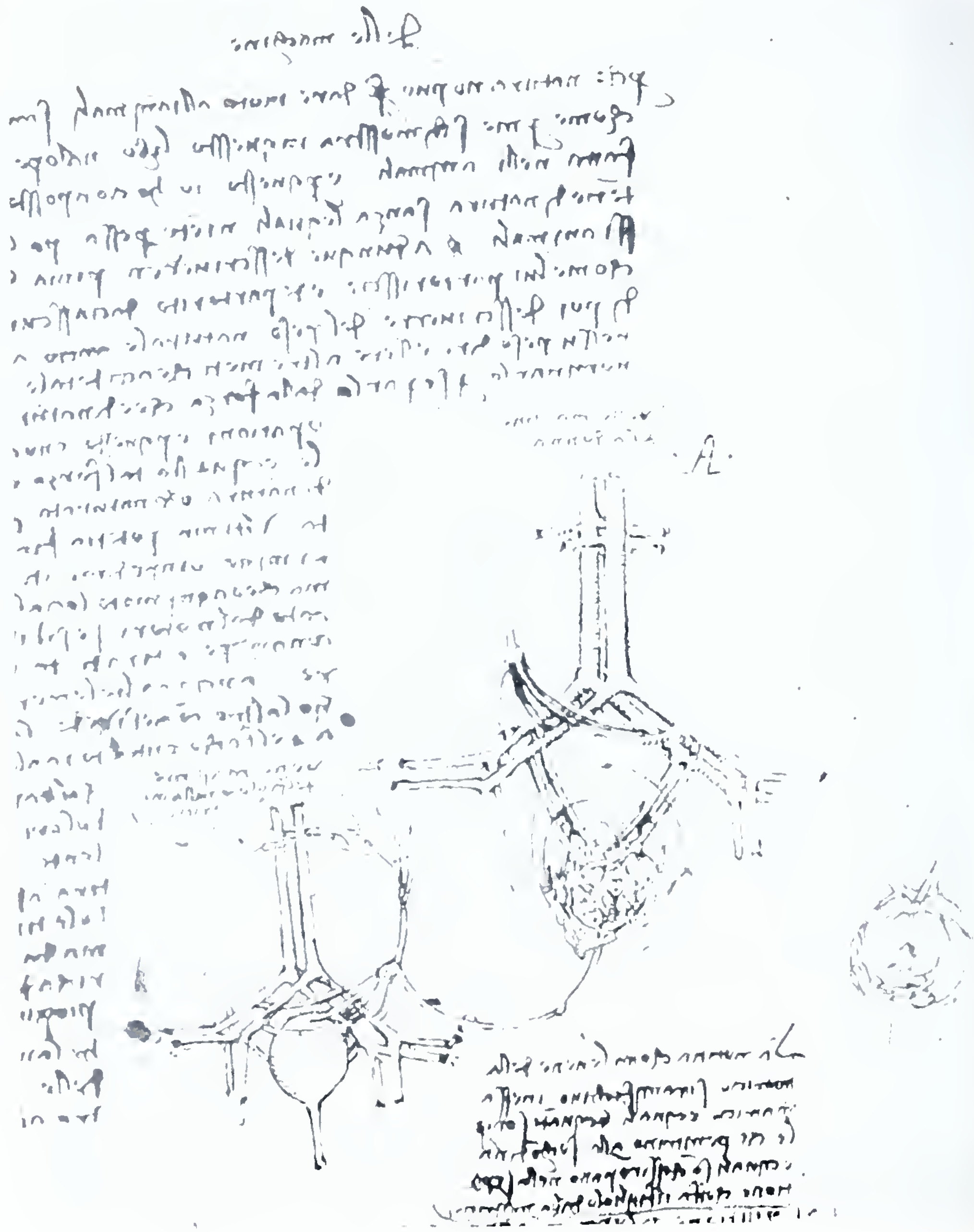


Fig. 87. Diagram of the human fetal circulation. (QI, 1.)

of all the veins of the child and does not have its origin from any vein of the mother, "since each of these veins (*i.e.* the veins of the child) is entirely separate and divided from the veins of the gravid woman." And the same condition is implied by the statement that the veins of the child do not ramify in the substance of the uterus but in the *secondina* (chorion), which is, as it were, a shirt in the interior of the uterus that invests it and is connected, but not united, with it by the cotyledons (QI, 1).

Other passages, however, speak even more definitely in favor of a continuity of the two bloods, that of the mother passing directly into the child. A strong argument for this view was Leonardo's belief, already mentioned (p. 229), that the fetal heart did not beat since the fetal lungs could not function.

"The beating of the heart and the breathing of the mother serve also for the child joined to her by the umbilical cord." (QII, 11.)

The child in the womb can not weep or speak.

"Where there is no breathing there is no voice" (QIII, 7);. . . "If women say that the child may sometimes be heard to weep within the womb, it is the sound of the wind." (QIII, 7v.)

If then there was no breathing and no beating of the fetal heart the only source for the vital spirits of the child is the blood of the mother and in discussing this point the word *anima* is used in its theological as well as its biological meaning. Thus he says—

"And the same soul governs the two bodies and the desires and fears and pains are common to this creature as to all the other animated members, and hence it results that the things desired by the mother are often found impressed on the members of the child which the mother carries at the time of the desire. So it is concluded that one and the same soul governs the bodies and that the same body nourishes both." (QIII, 8.)

Another interesting passage with the same purport occurs on QIV, 10.

"Although human genius (reveals itself) in various inventions, corresponding with various instruments to one and the same end, it will never find an invention more beautiful, easier or shorter than that of Nature, since in her inventions nothing is lacking and nothing superfluous. She does not make use of counterpoises when she makes members suitable for movement in the bodies of animals. But she places therein the soul (*anima*), the producer of the body, that is to say the soul of the mother that first produces in the womb the form of the human being and in due time awakens the soul that is to be the inhabitant thereof and that at first remains dormant and under the tutelage of the soul of the mother, which nourishes and vivifies through the umbilical vein with all its spiritual members. And this it continues to do so long as the umbilical cord is joined to it by the chorion (*secondina*) and the cotyledons, by which the child is united to the mother. And this is the cause that one will, one supreme desire, one fear that the mother has, or other mental pain, has more power over the child than over the mother, since frequently the child loses its life thereby."

Here Leonardo breaks off to remark—

"This discourse does not belong here but will be necessary in the (chapter on) the composition of animal bodies, and the rest of the definition of the soul I leave to the understanding of the friars, fathers of the people, who by inspiration know all secrets."

With this remark, which has something of a sarcastic flavor, he breaks off again, and, as if to counteract the sarcasm, finishes the passage with a declaration of his belief in the inerrency of the Scriptures, "Let the crowned writings stand, since they are supreme truth."

In both these passages Leonardo finds evidence of a community of soul in mother and unborn child in the supposed inheritance of maternal impressions, a well-known belief vouched for by the Scriptures in the story of Jacob and his ring-straked cattle. It is referred to again in a third passage, where it is noted "how one soul governs two bodies as is seen by the mother desiring a food and the child remaining marked (*segnato*) by it" (QIII, 3v). Another ancient belief, tracing back, however, only to the Hippocratic writings, was also accepted by Leonardo, namely, the belief that an eight-months child could not survive, while that born after only seven months of gestation might. He does not discuss the belief, merely making a memorandum to enquire why the child of eight months does not live (QIII, 3v).

Little is recorded regarding the development of the individual organs, but passages on QIII, 8v contain some remarks on the liver and spleen. It is stated that so long as the umbilical vein is functional, it occupies the chief position in the middle of the body both as regards length and breadth, but when it ceases to be of use it is drawn aside, together with the liver, which is created and nourished by it. At first the middle of the liver is below the center of the heart and above the umbilicus, that is to say its right and left lobes are of equal size, and at this time the spleen is a viscous aquosity, pliable and flexible, and does not occupy its proper place. Later, however, it condenses to assume its necessary form and place and in so doing encroaches upon the left lobe of the liver, which withdraws toward the right lobe, pressing upon it, condensing it, and apparently being taken up into it, so that as much as seven-eighths of the left lobe seems to be lacking and the middle of the liver, together with the upper part of the umbilical vein, lies to the right of the median plane of the body.

While the fetal nourishment, respiration and supply of vital spirits is cared for by the mother, the fetal excretion was carried on by the fetal kidneys. Exit of the urine by way of the urethra was, however, prevented by the position assumed by the child in utero, its right heel lying between the anus and the virile organ and thus compressing the passage. Nature therefore provided for its passage a canal which passed from the apex of the bladder to the umbilicus and from the umbilicus the urine passed in some unexplained way to the mouth of the uterus (QIII, 7). Clearly the canal that Leonardo saw was the urachus, but he evidently failed, even in the calf embryo, to trace its continuity with the allantois.

Leonardo's observations on the bodily proportions of the child have already been mentioned (p. 110), but in addition to these he has left a few memoranda as to the rate of growth and a statement to the effect that the length of the umbilical cord is the same as the length of the child (QIII, 7v), expanding this in another passage to an assertion that the length of the cord is the same as that of the child at all stages of growth and that this is not true of any other animal. The statement is fairly accurate as an average, but the length of the cord is subject to considerable variation.

As to growth, it is noted that the child at birth is generally one-third the average adult height (QIII, 7), and that the fetus at four months is half the length and one-eighth the weight of the child at term (QI, 10v). The growth in utero as well as in after life proceeds at a constantly diminishing rate until it ceases. The weight of the child nine months after birth is not double that of the infant after nine months gestation, nor is it so even after eighteen months (QIII, 7v).

CHAPTER XX

COMPARATIVE ANATOMY

It was the anatomy of the human body that especially interested Leonardo. Approaching it from the standpoint of an artist, he became more and more absorbed in its details until he came to study it as an anatomist, striving to obtain a correct idea of the structure and relations of the parts of the body that he might better understand their mode of action. In default of human material he did not disdain, however, the study of the parts of animals, and a number of his notes and drawings are evidently based upon animal dissections. Attention has already been drawn to some of these cases, as when he describes as if it were human the heart of the ox with its os cordis and well-developed moderator band, the larynx and hyoid bone of, probably, a dog, the brain of an ox with its rete mirabile, the mode of origin of the great vessels from the aortic arch in the ox, the placental cotyledons of a calf.

Leonardo fell into the same mistake as did Galen and the Salernitans in supposing that he could get an accurate idea of human structures by the study of those of animals. Thus he asserts that all terrestrial animals have similitudes of members, such as muscles, nerves and bones, the only differences being in length or width, as will be shown in the *Notomia*. In aquatic animals, however, there is great variety, so that a type for them can not be established; and so too it is with insects (G, 5v). But he also was aware that in many cases animal structures differed from human and there are many notes suggesting the dissection of animal forms, partly out of curiosity to learn in what they differed from man, partly, one may believe, in the hope that a study of their differences might throw light upon their form and function in Man. Thus on AnB, 9v are sketches of the arm skeleton and biceps muscle of a man and an ape, and it is pointed out that the nearer the insertion of the muscle is to the hand, the greater the weight that may be raised by it, "and this makes the ape more powerful in its arms than is man, according to its proportions." It must be confessed, however, that there is no evidence that he carried out many of his proposed comparative studies. Indeed, the scope of his suggestions was too wide to be covered by one who had as many interests as Leonardo; but, nevertheless, while one can not, with Bottazzi (1910), regard him as the founder of the comparative analytical method of anatomy, for that was the method pursued by Aristotle, he was,

Fig. 88. Dissection of the foot of a bear. (QV, 11.)

before Pierre Belon (1555) the reviver of that method after it had lain fallow for many centuries.

Leonardo clearly perceived the anatomical similarity of man to the lower animals, speaking of him as "prima bestia infralli animali" (AnA, 1), and in an interesting sketch of the classification of familiar mammals he groups man with (1) "those that are almost of similar species, and as the baboon, the monkey and the like, which are many." His other groups are (2) lions and their like, as panthers, lionesses, leopards (cats), lynxes, Spanish cats (?), genets and common cats; (3) horses and their like, as the mule, ass and the like that have teeth both above and below; (4) bulls and their like, that have horns and are without teeth above, as the buffalo, stag, fallow deer, roe-deer, sheep, goat, ibex, mucheri (?), chamois, giraffe (AnB, 13). One wonders whether Leonardo's generalization as to the teeth and horns of the Ungulate groups was based on his own observations or was a reminiscence from Aristotle's *De partibus*, perhaps through Albertus Magnus.

He makes a memorandum to discuss the similarities that the bones and muscles of animals have to those of man (QV, 22) and he has left a sketch of the carpus and hand of a monkey (*scimmia*) (QV, 21v). In the outline of a mode in which he hoped to discuss and figure in his proposed treatise the anatomy of the lower limb (AnA, 17) one reads—

"Figure here the foot of a bear and monkey and other animals, as to how they differ from the foot of man. And also represent the feet of some birds."

It has been seen that he had made dissections of a monkey and, probably, four beautiful drawings in silver-point (QV, 11 to 14) (fig. 88) represent dissections of the foot of a bear, there being further evidence in a remark concerning the tendons of its fore-paw that he had made a dissection of that animal (QI, 2).

So too one must conclude that he had studied the brain and nasal cavity of the lion. Speaking of his belief that the senses of man are more obtuse and grosser than those of animals, he refers this condition to man's sense-organs being less ingenious and less capable of receiving the sensory virtue. For he found that in the lion for the sense of smell the brain sent portions of its substance into a rather capacious receptacle, divided into a large number of cartilaginous saccules, between which were sufficient passageways to allow the stimulus to reach the brain; evidently a description of the highly developed nasal conchæ of a carnivore. And furthermore he notes that the orbits of the lion occupy a large part of the head and its optic nerve joins the brain quickly, whereas in man the orbits are relatively small and the optic nerves are slender, long and weak (AnB, 13v). Of the dog, in addition to the probability that the larynx and hyoid bone figured on QV, 16, 17 (fig. 66) is that of a dog, he has a memorandum to study its lumbar region, the diaphragm and the motions of the ribs. Further, on QI, 96 there is a sketch showing certain proportions of a dog's head, but these are more interesting from an artistic than from a scientific standpoint.

Leonardo makes no statements as to the sources from which he obtained the material for his comparative studies. It may be conjectured that some of the animals mentioned, such as monkeys, were kept as pets by members of the ducal courts, while others may have been made available as the results of hunting expeditions. In the case of the lions, the Florentine Diary of Luca Landucci (1450–1516) gives the information that accordng to ancient custom lions were kept in cages behind the Palazzo del Capitano, later incorporated in the Palazzo Vecchio. The custom was discontinued toward the end of the seventeenth century, but the street on which the cages fronted is still known as Via de Leoni.

Among other suggestions of comparative studies may be mentioned a comparison of the intestines of man with those of the monkey, the lion group, the ox and birds—a special discourse to be made of these investigations (AnB, 37). He notes that animals without feet have a straight intestine, since they are always prone; but in man, on account of his erect position, the stomach would immediately empty itself were it not for the coiling of the intestines, which aids in digestion and absorption (AnB, 14v). He planned the dissection of the eye of various animals to discover the muscles that open and close the pupil (G, 44); the study of the facial muscles and their innervation in the horse, because in that animal they are large and very evident (AnA, 13v); the tongue of the wood-pecker is suggested as an object for study (QI, 13; QIV, 10), as is also the jaw of the crocodile (QI, 13), probably in connection with the ancient belief that the crocodile was the only animal in which the upper jaw was movable. The leg of the frog was to be figured for comparison with that of man, for it was supposed to be very similar both as regards the bones and the muscles, and with this there was to be a representation of the hind-legs of the hare, which are very muscular and with speedy muscles, because they are not impeded with fat (QV, 23). Nor did he confine his investigations to the vertebrate group of animals, invertebrates, though rarely, also claiming his attention.

> "That the flies have their voice in the wings you will see by cutting them a little or, better still, by anointing them a little with honey, so that they are not altogether hindered from flying. And you will see that the sound made by the movement of the wings is made raucous, and so much the more will the voice change from high to low, the more their wings are hindered." (AnA, 15v.)

He also refers (K, 81) to the old legend which regarded the Gordian worms, occasionally to be found in fresh-water streams or pools and still popularly known as hair worms, as the hairs of cattle that had fallen into the water and acquired the power of twisting and writhing as if endowed with life.

Leonardo's experimental study on the central nervous system of the frog and his observations on the development of the chick and on the fetal membranes of the cow have already been mentioned in Chapters XVII and XIX and need not be further considered here. But just as his desire to depict accurately the human form stimulated him to the study of human anatomy, so also two other interests led him to special studies of the anatomy of the horse and of that of birds, but in neither case were his investigations carried so far as were those in human anatomy.

The founder of the fortunes of the Sforze was the Condottiere Muzio Attendolo, who, from his great strength, was nicknamed Sforza, and who became commander-in-chief of the Neapolitan forces under Queen Joanna II. His son, Franceseo, married Bianca Maria Visconti, natural daughter of the Duke of Milan, and, on the death of her father without heirs (1466), Francesco succeeded to the Duchy, establishing the short-lived dynasty of the Sforze. As early as 1473 Francesco's son, Galeazzo Maria, had conceived the idea of perpetuating his father's memory by the erection of a bronze equestrian statue, but the political exigencies of the times prevented the fulfillment of his intentions before his death in 1476. The Duchy then passed into the hands of Gian Galeazzo, a mere child, for whom his uncle Ludovico acted as regent, succeeding to the Duchy on the death, whether naturally or by design, of his nephew. Once established in power, Ludovico revived his brother's idea of a statue of Francesco, and, according to Solmi's account (1919) applied to Lorenzo di Medici for advice as to a competent artist. Leonardo was recommended, and in his remarkable letter to Ludovico, offering his services, one of the items which he states he is prepared to undertake is this equestrian statue.

> "Also" he wrote, "I can undertake the work on the Horse, which will be to the immortal glory and eternal honor of the happy memory of my lord your father and of the illustrious house of Sforza."

Leonardo went to Milan in 1483, but it was not until ten years later that a colossal plaster model of the horse was set up in the grand square before the Castello. It may well be supposed that during these years Leonardo was, amidst other things, perfecting his knowledge of the surface anatomy and proportions of the horse, by the same methods as those he had used earlier in the study of the human body. But in the case of the horse his studies were almost entirely from the artistic standpoint; he did not carry them to a thorough investigation of the various parts and organs. It was the artist rather than the scientist that was at work.

The majority of the sketches of the horse are in the Windsor collection and have been reproduced in the Rouveyre edition of the Windsor folios, forming volume 15 of that edition, with reproductions of no less than 67 folios. The title given to this volume is *Notes et croquis sur l'anatomie du cheval* and it awakens expectations of much of anatomical interest. The figures, however, are largely postural studies or notes on proportions, or, at best, sketches of the surface anatomy of the limbs. Scattered through the other collections there are, however, a few figures that compare certain of the thigh muscles of the horse with those of man. Thus on QV, 22 (fig. 12) there is a drawing of the skeleton of the hind-leg of a horse placed alongside one of the skeleton of a human leg, certain of the muscles descending from the pelvis, such as the rectus, the tensor fasciæ latæ, the adductor magnus and the glutei being represented in each by bands or cords. Accompanying the figures are various memoranda, one to the effect that, to insure more exact comparison, the knee of the man should be figured bent as is that of the horse, another noting that for the same purpose the man should be represented as standing on tip-toes. Somewhat similar figures are to be found on AnB, I, and on K, 102 and 109.

The figures illustrating the proportions of the horse's body have but little scientific interest, nor are they sufficiently definite to allow of the establishment of a canon of proportion. They are mostly sketches with lines drawn across them, labeled with numbers or letters indicating the dimensions of the part. Thus, to take an example from elsewhere than the Windsor collection, there is on A, 62 a sketch of a horse's head enclosed within an oblong, which is divided into three parts by transverse lines. There are no labels in this case, but accompanying memoranda give the following data. From the base of one ear to the other equals the interval from the eyebrows to the chin (*i.e.* the angle of the mandible); the size of the mouth equals from the division of the lips below the chin (not quite clear); from one ear to the other is equal to the length of the ear; the length of the ear is one-quarter the length of the face. The author of the preface to Rouveyre's *Notes et Croquis*, Colonel Duhousset, believes that Leonardo took as his canon of proportion for the horse the length of the head and indicated it on his sketches by the Symbol T, the measurement of the neck at the withers for instance being labeled I T and the distance of the hock from the ground T I. The sketch and memoranda mentioned above may be taken as supporting the contention that the length of the head was adopted as a canon, but there are others from which it is difficult to ascertain that any definite standard for comparison had been selected. A prolonged discussion of the question would be out of place here, seeing, as has already been stated, that the studies, so far as Leonardo was concerned, were of purely artistic interest and had not been carried out sufficiently to have become of scientific value.

The second interest that led Leonardo into special comparative anatomical studies was his desire to invent a flying machine. He claimed to have already invented a submarine, whose construction he refrains from revealing on account of its enormous possibilities for destruction, and his inventive genius stimulated him to the further conquest of the air. It was, of course, a heavier-than-air machine that he had in view, and he turned to the bird, the most perfect of all such machines, to discover the principles that governed its flight. It was natural that he should do so; that was his method, the modern method—in attacking any problem to seek an understanding of the fundamental principles that lay behind it. And so he proceeded to study the flight of birds, their soaring, hovering and swooping, their manner of changing direction and of adapting themselves to varying wind currents, the differences in the flight of kites, sparrows and thrushes, differences in the movement of the wings of magpies, doves and rooks, the use of the tail as a rudder and control. And it is surprising how much he was able to discover by keen observation, without such modern aids as instantaneous photography. He had it in mind to write a treatise on these topics.

"I have divided," he says, "the Treatise on Birds into four books; the first of which treats of their flight by beating their wings; the second of flight without beating the wings and with the help of the wind; the third of flight in general, such as that of birds, bats, fishes, animals and insects; the last of the mechanism of this movement." (K, 3.)

But, as was the case with the Anatomy, this intention was never fulfilled, though many notes dealing with the topics mentioned are to be found scattered through the *Codex Atlanticus*, the Windsor folios and the volumes in the Institut de France (especially E, K and L) and, furthermore, there is a small volume of thirty pages, with sketches and notes written *à rebours*, almost entirely pertaining to the flight of birds. This last has been published in facsimile by Sabachnikoff, with transcription and notes by Piumati, under the title *Codice sul volo degli Ucelli e varie altre materie* (Paris, Rouveyre, 1893) (see p. 68).

The moving idea that led to the observations recorded in these memoranda was the possibility of the construction of a machine by which man would be able to navigate the air like a bird. It was, accordingly, a problem in mechanics with which Leonardo was confronted and questions of anatomical structure were of subordinate interest. There is therefore, little that need be discussed here in connection with the studies on birds; merely one or two points of anatomical interest need be considered. As to the mechanics of flight it will suffice to say that Leonardo had discovered their essential principles; but there was lacking then and until comparatively recent times a suitable source of motive power to give these principles practical effect.

"A bird" he says "is a machine working according to mathematical law, which machine it is within the capability of man to reproduce with all its movements, but not with a corresponding degree of strength." (C. A. 161.)

As Beltrami (1910) has pointed out Leonardo had understood that—

"Weight, instead of being an obstacle, was an essential condition of flight and that the bird can fly because, being heavier than air, it does not remain in the power of this, but succeeds in profiting by the resistance which this very weight can oppose to it."

There are, however, three points of anatomical import that may be briefly mentioned. On QIV, Iv there is an admirable study of a bird's wing (fig. 89) showing the bones, the attachment of the feathers and certain tendons. It is a study of the behavior of the feathers during the action of the wing in flight, an accompanying memorandum indicating that one of the tendons shown acts on the feathers in such a way as to draw their tips "toward the elbow of the wing" when the wing is being folded, but when it is extended by another tendon "the feathers direct their length toward the tip of the wing."

The great development of the pectoral muscles of birds is noted, the statement being that they are heavier than all the rest of the body (AnA, 12v), but in the *Codice sul volo dei Uccelli* it is argued that the excessive development of these muscles is not necessary for flight—comparatively little power is necessary to sustain the bird in the air, but the extra power is furnished to give rapid motion, so that enemies may be avoided or prey secured, and, further, to allow the bird to carry heavy burdens in its talons, as when a falcon carries a duck or an eagle a hare. These exigencies made needful the doubling or trebling of the power required for flight and explain not only the large pectoral muscles, but also the one-piece breast bone, the wings—

"all interwoven with large sinews (*nervi*) and other very powerful ligaments of cartilage and the very strong skin with various muscles." (Sa., 16.)

Leonardo was probably the first to describe the so-called bastard wing or *alula*, that portion of the wing whose feathers are attached to the pollex of the bird's hand and may, therefore, have some independent movement. He speaks of the pollex as *il dito grosso* and regards it as that part of the wing that meets with the greatest resistance from the air and is therefore strong, provided with very strong tendons and short feathers of greater strength than those of any other part of the wing. It is that part of the wing that especially propels the bird forward, and in this respect he compares it to the claws of a cat climbing a tree, although he also speaks of it as a rudder, just as is the

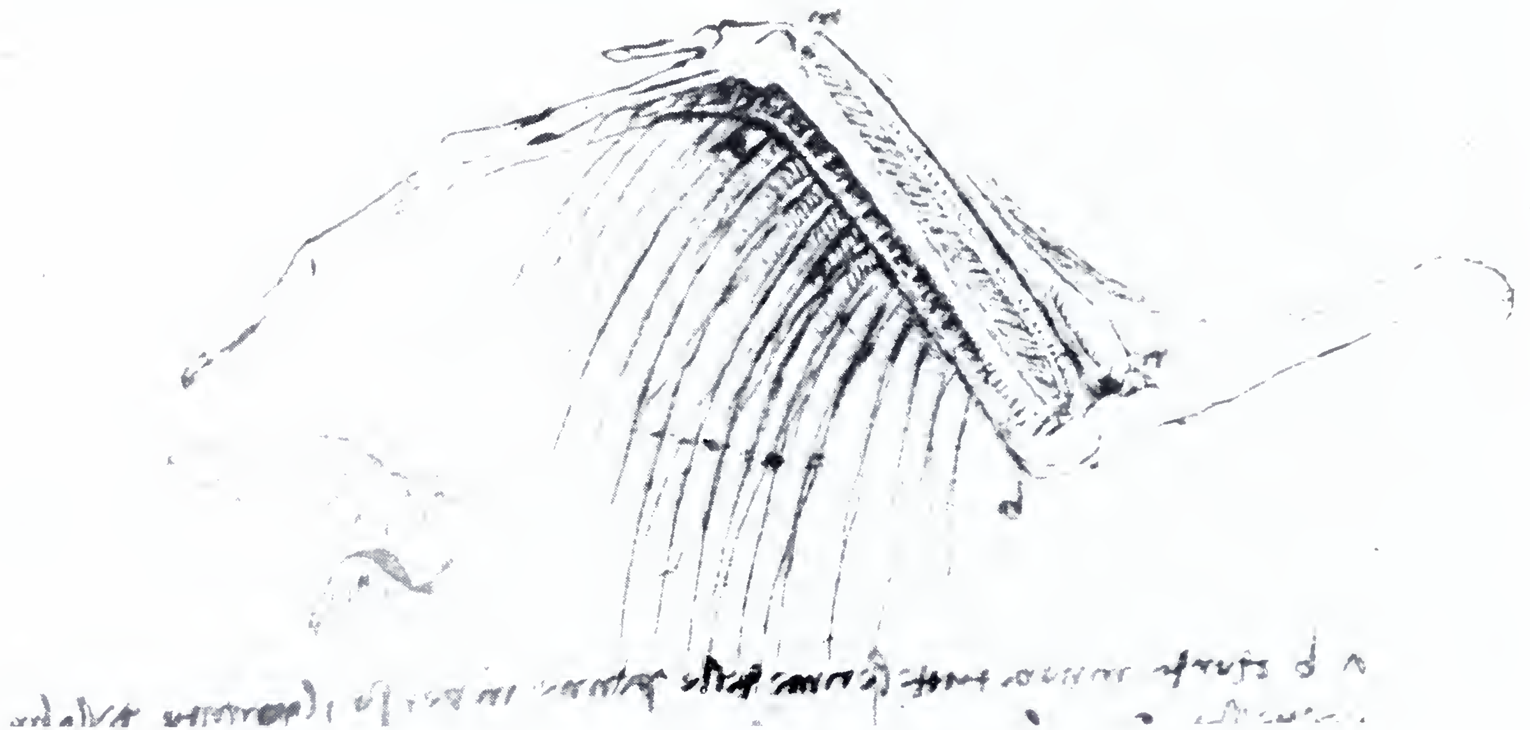


Fig. 89. Dissection of a bird's wing. (QIV, 1.)

tail (Sa, 14v). The manner in which his rudder acts is described on K, 7v, but the passage is not of anatomical interest.

But after all Leonardo saw clearly that his flying machine could not be constructed on the plan of the bird with feathers.

"Remember" he says "that thy bird should not imitate anything else than the bat, since its membranes make an armature or a building together of the armatures, that is to say of the framework of the wings. And if you imitate the wings of the feathered birds, these are much more bone and sinew (*nervatura*), since they are penetrable, that is to say, their feathers are separate and the air may pass between them. But the bat is aided by its membrane that binds the whole and is not penetrable." (Sa, 16.)

Further there is a memorandum to dissect a bat, study it carefully and on this model to construct the flying-machine, but there is no evidence that such a dissection was made (F. 41v).

CHAPTER XXI

BOTANY

In considering Leonardo as an Anatomist one thinks of him as an investigator of the structure of the human body, accepting what has become the popular significance of the word anatomy. But, as has been seen, in his search for light Leonardo extended his studies to other animals and, further, he included in the scope of his observations the other great group of living organisms, the plants. Like animals, they too had vital spirits, contributed in their case by the sun, and they too required nourishment, derived in their case from the earth's humidity (G, 32v; TP, 823). He found, too, other interesting analogies between plants and animals. He compares, for instance, the coverings of the brain, scalp, cranium and membranes, to the coats enclosing the germ of an onion (QV, 6); he likens the arrangement of the blood-vessels to a tree (QV, 1) and finds an analogy between the heart with the great vein and a germinating nut with its ascending plumule and descending radicle (AnB, 11). It seems fitting accordingly that his botanical observations should find some brief consideration here.

Numerous beautiful drawings of trees and flowering plants indigenous to Italy are to be found in his manuscripts. These, however, are not of present concern; his observations on plant structure and plant physiology are the matters of interest. The chemistry of the day could give him little insight into the processes of nutrition in plants and he seems to have regarded the rain, the dew and the moisture contained in the soil as the source of the plant's food.

"Plants are nourished in summer through their leaves by the dew and the rain, and in winter by the contact they have with the soil by means of their roots." (TP, 856.)

But it was the moisture of the soil and not its mineral constituents that was of importance, for he states explicitly that it is the moisture of the soil that constitutes their nourishment (G, 32v). Further he describes an experiment in which he left a gourd (*zucha*) with only a very small root and it was nourished only with water and yet it brought to perfection all its fruits, about sixty.

"And I gave diligent attention to this great vitality and recognized that it was the nightly dew that with its moisture penetrated at the attachment of its large leaves to nourish the plant and its progeny." (G, 32v; TP, 823.)

The concluding sentence of this quotation implies that Leonardo had observed the relation of the buds to the leaves, namely, that they occur in the axils of the leaves. But the observation is recorded more definitely in the statement that each branch and fruit arises above a leaf, which serves as a mother in bringing the rain and the dew and in protecting from the sun (G, 33v). And he speaks of the leaf, not only as the mother of the bud, but also as its teat or udder (G, 32v; TP, 823). The significance of the relation is more fully expressed as follows:

"Because the branch or fruit arising in the following year from the bud veinlet of the eye which is above the contact of the attachment of the leaf, the moisture that bathes the branch can descend to nourish the bud by the drop being held in the concavity of the origin of the leaf." (TP, 822.)

With this idea as to the meaning of the axillary position of the buds it was not a great step to inquire how far the arrangement of the leaves favored the access of moisture to the buds and thus Leonardo took the first step in the determination of the laws governing the arrangement of leaves, the laws of phyllotaxis, later further worked out by Grew and Malpighi in the eighteenth century and by Sachs in the nineteenth. He noted that in many plants the sixth leaf was above the first (G, 16v; TP, 828), that is to say the leaves were arranged in a spiral along the branch or stem, so that in passing from any leaf to the next directly above it, through the points of attachment of intervening leaves, two turns would be made around the stem, and the angle of divergence of one leaf from the next succeeding one would be two-fifths of the circumference of the stem. This he regarded as the most frequent arrangement and mentioned the vine, canna and *pruno de more* as examples of it; in the white jasmine (*Vitalbo gelsomino*), however, the leaves are arranged opposite one another in pairs, successive pairs being at right angles (G, 16v; TP, 828). In another passage it is stated that there are four modes of arrangement, but only three are mentioned: (1) that in which the sixth leaf is above the first, (2) that in which the two-thirds above are over the two-thirds below, and (3) that in which the third above is over the third below (G, 33; TP, 828). The first, of course, is the two-fifths arrangement; the third is probably the one-third although it might be interpreted as the one-half; but what is meant by the second arrangement is by no means clear, perhaps it was the three-eighths. If it were, then Leonardo had discovered the principal varieties of phyllotaxis, and in the manner of his time he finds a teleological explanation for the arrangements in that they allow the free access of air, light and moisture to the leaves; the alternation—

"Serves (1) to allow intervals for air to pass between; (2) that drops falling from the first leaves may fall on the fourth and sixth of other branches." (TP, 905.)

"(1) That the branch or fruit coming from the bud that is above in contact with the attachment of the leaf may be nourished by the water that moistens the branch, (2) that the leaves do not overshadow one another." (G, 16v.)

Since the branches arise from buds in the axils of the leaves, they too will show a phyllotactic arrangement in an untrimmed tree, provided, of course, that every bud develops, and it may therefore be possible to determine the age of a tree by counting the series of branches (TP, 820). It is stated that branches are arranged in two ways, either above one another or not (TP, 819), and in another passage (TP, 813) eleven principles affecting the arrangement of branches are laid down; (1) Every branch of a tree, if not prevented by its weight, curves its tip toward the sky; (2) the lower branches are larger than the upper; (3) all the branches at the center of the tree are soon killed by being in the shade; (4) the branches nearest the top of the tree will be more vigorous on account of their access to the air and sun; (5) the angles at which the branches form are all equal; (6) but they become more obtuse as the branches thicken in growing old; (7) the width of the angle is more oblique in slender branches; (8) the branches of a bifurcation are together of equal size with the branch from which they arise; (9) the twistedness (*tortura*) of the large branches is proportional to the development of their branches that do not interfere with one another; (10) the twistedness of that branch is greatest which has its branches most equal in size; (11) the attachment of a leaf always leaves a mark below its branch, growing with the branch until the bark cracks and fissures from the age of the tree. What Leonardo meant by items 9 and 10 is not clear; 2 and 3 he expands somewhat in other passages, which are interesting as examples of Leonardo's search for natural explanations of natural phenomena.

"Always the largest branches are those that grow from the part that looks toward the ground and the lesser those that grow from the upper part. Because the moisture (*omore*) of the branches, when it is not percussed by the heat of the sun, flows down to the lower parts of the branches and the moisture nourishes more where it is in greater abundance. And such a branch always has its bark thicker below than above." (T P, 832.)

"The branchings of the larger branches do not occur toward the middle of the plant. And this is so because naturally every branch seeks the air and avoids the shade and the shade is greater in the lower parts of the branches that look toward the earth than in those that are turned to the sky. In these the water that rains and the dew that abounds at night flows down and keeps the lower parts more moist than the upper, so that the branches have more nourishment in those parts and thus grow more." (TP, 831.)

The growth in diameter of an exogenous stem or branch was ascribed to—

"the sap that forms between the bast (*camicia*) and the wood, in the month of April, at which time the bast is converted into bark, which acquires new fissures at the bottom of those already there." (TP, 833.)

The number of branches that may be produced from a branch depends on the quantity of bast between the bark and the wood (TP, 829), "the thing nourished is as its nourishment" (TP, 830). If a branch be cut off and another branch from the same tree be inserted in its place, the graft will in time become somewhat larger than the branch that nourishes it, since the nourishment and vital spirits succor the injured place. If many eyes of plants be inserted in a circle as grafts on a cut trunk they will acquire in the same year a greater size than had the trunk that was cut away (TP, 830). Other things being equal, however, the nourishment would be equally distributed, so that when branches are opposite one another they will be of equal size (TP, 837), and, furthermore, the sum of the sizes of the branches of any year will be equal to the size of the branch grown the year before and so on in the future (TP, 817).

Not less striking than the discovery of phyllotaxis was the observation that the age of a tree or branch might be determined by counting the growth rings on a cross-section. And not only so, but by observing the relative widths of the rings, whether they are broad or narrow, the nature of the season, whether it was wet or dry, might be ascertained. Furthermore, the surface of the tree that faced the south might be distinguished by the greater breadth of the rings on that portion of their circumference, since in the northern hemisphere the southern surface is that most exposed to the sun and therefore better supplied with nourishment. This difference in the widths of the individual rings brings it about that the axis of the tree lies a little nearer the southern than the northern surface (TP, 820).

The roughness of the bark is also explained by the exogenous mode of growth. In young shoots the bark is smooth, but in older branches it becomes corrugated and is roughest on the oldest branches (TP, 820), and rougher on the southern surface, where growth is most active than on the northern (TP, 835). The roughness is due to the splitting or cracking of the bark as the stem or branch increases in diameter, and the splitting is always lengthwise, except in the cherry (*ciliego*) in which it occurs in circles (TP, 819).

The favoring influence of the sun on growth has been already noted and is definitely indicated in the statement that plants which see the sun set seed, those that only see its reflexion do not (G, 37v). Its influence resulted in increased growth activity, such as that witnessed by the supposed greater width of the growth rings and the greater fissuration of the bark on the southern side of a tree. And it was such phenomena that led to the statement that plants always curve with the convexity toward the south (G, 36v), a statement that has gained for Leonardo the credit of having observed the phenomena of heliotropism in plants. As a matter of fact heliotropism bends the plant toward the source of light, not away from it; the effect of exposure to the sun is rather to inhibit than to increase growth. Leonardo regarded the sun as the source of the vital spirits of plants, and if this were so it followed that those parts of the plant most fully exposed to the sun would have the greater vitality and therefore greater growth. That this was his train of thought is indicated by the continuation of the passage just mentioned (G, 36v), as it states that the branches on the south side are stronger and longer than those on the north side, and he explains both this and the supposed curvature on the ground that the sun attracts the humor toward that surface of the plant which is nearest to it.

But, nevertheless, Leonardo did record the occurrence of heliotropism when he stated that the branch of a tree, if not prevented by weight, curves its tip toward the sky (TP, 813), a statement in direct opposition to that on G, 36v. Furthermore he records what may be regarded as an example of negative heliotropism when he notes that old trees cover the bark of the north side of their trunks with a greenish featheriness (*verdicante piumosità*) (TP, 834), meaning thereby, of course, the moss which, in the northern hemisphere, grows most abundantly on the north side of trees.

In his studies of plants, then, Leonardo showed the same keenness of observation as has been seen in his animal studies, and in these too he was sometimes led astray by faulty physiological theories. Further he applied the experimental method in his plant studies as has been seen in the experiment with the gourd mentioned on p. 244, but a more pretentious one is described in the *Codex Atlanticus*. He bored a small hole in the trunk of a tree and poured in arsenic and sublimate dissolved in spirits of wine, expecting either to make the fruit poisonous or to destroy it. When the fruit was ripening the hole was deepened until the pith was reached and the poison forced in by a syringe. Unfortunately the results of the experiment are not recorded.

CHAPTER XXII

CONCLUSION

In the preceding pages an attempt has been made to set forth without prejudice Leonardo's achievements as an anatomist, record being made of his failures as well as of his successes. There has been an endeavor, also, to provide an historical background against which those achievements may be judged, and there remains to be added a brief consideration of the position to be assigned to him in the development of modern scientific anatomy.

The Renaissance in art, when conventionalism began to give way to naturalism, may be traced back to Giotto and through him to Cimabue; it had already, in Leonardo's time, been in progress for some two centuries. Indeed, it may be said to have reached its height when three such artists as Leonardo, Michel Angelo and Raphael were giving to the world their masterpieces at the same time. To depict objects naturally, that is to say accurately, required accurate observation, and for two centuries the artists had been cultivating that faculty, raising the standard of accuracy as time went on. Leonardo's note-books abound in records of observations made for their bearing on a better technique, for improvement of his artistic accuracy; one finds, for example, notes on the changes of color tones in light and shadow, the effects of contrast in colors, the lighter tone of foliage blown by the wind, the effect of distance on the contour, and so on. The faculty of minute observation was one of the important factors in making him a great artist, and when his studies for Art's sake led him to anatomy it was his habit of observation that made him a great anatomist. He combined in himself the two faculties, artistic ability and keen observation, which in later times cooperated for improvement in anatomical illustration and so for improved description. The artist undoubtedly played an important part in the advancement of anatomical knowledge (see p. 51).

No one will dispute Leonardo's right to be termed a great artist, indeed, one of the greatest, and he also has a right to the title of great anatomist. True, he might be classed as an Arabist; he was undoubtedly greatly influenced by Avicenna and Mondino; his nomenclature is Arabistic and his physiology was largely so, but his Arabism was merely the foundation on which the artist and observer was building. The Arabists did not observe, they relied entirely on tradition or dogma; they either did not use illustrations in their treatises, or, if they did, they were conventional and crude. Leonardo initiated a new movement in anatomy, one destined in time to replace piece by piece the old foundations by more substantial ones. One may perceive strivings toward the new movement in the works of Phryesen and Reisch, but Leonardo's artistic ability and the wider scope of his observations mark him as its true initiator.

This achievement alone, the inauguration of a revolution in descriptive anatomy, ranks him as a great anatomist and his right to that title is confirmed by the many important discoveries he made in following out his methods. He is guilty of many errors both of omission and commission, but these may be ascribed in part to his preoccupation in many other interests and in part to the influence of his Arabistic foundation. On the opposite page are to be placed to his credit important discoveries, the harvest of his reliance on observation. These have already been discussed and it will suffice to mention here merely his observation of the correct inclination of the pelvis, his discovery of the frontal and maxillary sinuses, of the moderator band of the heart, of the bronchial arteries, of arterial sclerosis, and his rediscovery of the thyreoid gland and of the unilocular structure of the uterus.

Even more striking than these, perhaps, is his emancipation from belief in the theory of innate heat, striking because it was the denial of one of the fundamental tenets of antiquity, accepted by the Arabists, and also because it illustrates a characteristic striving to explain phenomena on the basis of a natural rather than a supernatural causation. This is a very modern trait, the trait that led Newton to the discovery of the law of gravitation and Darwin to the formulation of the doctrine of evolution. It was the bourgeoning of the modern spirit of scientific investigation, contrasting with the prevalent reliance on tradition.

What distinguishes Leonardo from his mediaeval predecessors and his contemporaries in anatomy was his greater desire for thoroughness. The mediaeval anatomists dissected in order to demonstrate Avicenna's teachings, the artists contemporary with Leonardo were satisfied with the study of the surface modeling of the body as revealed by flayed cadavers. But Leonardo, having seen a skeleton, must not only study and accurately portray each bone, but must inquire into its structure; having seen a muscle he must inquire as to its individual action, as to its intimate structure and as to how it functions. And then, not content with having more than covered the ground thought necessary for an artist, he extends his studies to the heart and its mechanism, to the digestive system and its functions, to the activities of the brain, to the organs that subserve generation and to the growth and being of the child within the womb. In short, the scientist predominates over the artist and he strives for knowledge for the sake of knowledge and seeks for a solution of the mysteries of life and death.

And yet Leonardo was not unpractical, merely a dreamer. To appreciate him as a scientist one must bear in mind his extraordinary fertility in invention, less evident in connection with his anatomy than with his studies in mechanics and hydraulics. These resulted in a wheel-barrow and armored cars, in a lamp chimney and a lifting crane, in plans for water mills and for extensive canals, for temples and cathedrals and for entire cities. These and many other inventions that might be mentioned were the products of a vivid imagination working on fundamental scientific data. Imagination was not lacking in the fourteenth and fifteen centuries; on the contrary it was most active, producing, for example, the marvelous Gothic cathedrals that excite our wonder and admiration. But for the most part mediaeval imagination was not based on scientific foundations, it found its field for play in metaphysics rather than physics. Some of Leonardo's contemporaries may have equalled him in artistic ability, in keenness of observation, in imagination, or in diligence, but he combined all these qualities in an exceptional degree and added to them a searching curiosity to discern the fundamental laws of Nature and a conviction that natural phenomena were to be explained by natural rather than supernatural causes. He had—

> The faith, the vigor, bold to dwell
> On doubts that drive the coward back,
> And keen through wordy snares to track
> Suggestion to its inmost cell.

To Leonardo the individual, then, may be assigned high rank as a scientist and as an anatomist, but what is his status in the history of anatomy? The fact that his discoveries were not published and so given to the world at large lessened undoubtedly his influence on the progress of anatomical knowledge, but it can not have been entirely lacking. His studies were no doubt known to many of those frequenting the Florentine and Milanese courts, and among these were many of the then leaders of scientific thought in Italy, such as Pacioli, the Marliani and the Cardani. His fellow artists must have known of them and so too his fellow members in the Florentine guild of physicians and apothecaries, and there are reasons for a belief that his anatomical drawings were known far beyond the confines of Italy. For K. Sudhoff (1908) has pointed out that certain anatomical drawings in Albrecht Dürer's sketch books were undoubtedly copies of drawings by Leonardo, but when and where Dürer saw the originals is unknown. Some of the drawings are dated 1517, but at that time Leonardo was in France; Dürer probably heard something of Leonardo's activities during his residence in Venice (1505–1507), five years after the visit to that city of Leonardo and his friend Pacioli.

Leonardo's influence, then, may not have been as limited as has been supposed and it is worthy of note that the foundations for modern descriptive anatomy were laid in northern Italy, where his influence would be most readily felt. However, after all, great advances and great discoveries do not come as bolts from the blue; each has its period of preparation, of incubation, before it is given to the world. It was the *Zeitgeist* of the literary and artistic Renaissance that led to the advance in descriptive anatomy. It glimmered in Berengario da Carpi (1550) and Guinterius (1503–1579), more strongly in Estienne (1503–1564) and burst into flame in Canano (1515–1579) and Vesalius. But it shone with yet brighter luster in Leonardo even earlier than in any of these; through him it shed light on many fields of science and made him a conspicuous and typical figure of the scientific Renaissance.

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The list is arranged in two portions, the first of which contains the facsimile reproductions of Leonardo's manuscripts together with the Forster manuscript and for these the customary reference symbols are employed. The second portion contains essays, critiques, etc., reference to which is made by date number.

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GLOSSARY OF ARABISTIC AND CERTAIN OTHER TERMS USED BY LEONARDO

In preparing this glossary much use has been made of the two glossarial works of Hyrtl, *Das Arabische und Hebräische in der Anatomie*, Wien, 1879, and *Onomatologica Anatomica*, Wien, 1880; of Professor Fonahn's *Arabic and Latin Anatomical Terminology, chiefly from the Middle Ages*, Kristiania 1922; and of the glossary contained in P. de Koning's *Trois traités d'anatomie arabes*, Leiden, 1903.

Additamenti del core—QII, 3v. The term *additamentum* was in common use in anatomical terminology in the Middle Ages to denote a process or projection. Thus the great trochanter, the coracoid process of the scapula and even the olfactory lobes of the brain were termed *additamenta*. The term *additamenta del core* denotes the auricular appendages of the heart and is an exact translation of *additamenta cordis* used by Mondino.

Aiutorio—AnA, *passim*. An Italianized form of *adjutorium*, which, in turn, is a literal translation of the Arabic *al-'adhid*, derived from the verb *'adhada*, to support. Strictly it denotes the upper arm or brachium and is so used by Leonardo, but sometimes it means the humerus. In one passage (AnB, 16v) it appears as *aiutorio di sopra*, as if the term might also be used for the forearm or its bones.

Alanchoidea or *Alantoydca*—QIII, 8v. Variations from *allantoidea*, allantois.

Alcatin. Sometimes denotes the pelvis (AnA, 16v) and sometimes the sacrum (QII, 16; QIII, 7v). In Mondino it is the concavity of the sacrum, but in Avicenna *al-qatan* stands for the lumbar vertebræ.

Anca. The Italian word for the hip or hip bone, from the same root as the English word haunch. Leonardo uses it for the ilium.

Animus, Animo—QIII, 8v. Erroneous spellings of amnios, now amnion.

Arteria venalis—QII, 2v. Probably the left atrium of the heart regarded as a part of the pulmonary veins, these then opening directly into the ventricle. See p. 153.

Ascia—AnA, 15v. Apparently the great trochanter of the femur. It suggests *ischium*, but may have its origin in *scia*, used frequently by the mediaevalists for the acetabulum or the head of the femur.

Astalis—QI, 13. A corruption of *extalis*, rectum. See p. 32.

Bellico—QIII, 3v. A modification of umbilicus.

Burella—QV, 3v. Patella.

Caleere—QII, 12. A fanciful term (*calcere*, capstan) proposed for one of the chordæ tendineæ of the left ventricle.

Camicia—TP, 833. The bast or meristem of plants.

Caro. Flesh. Used in a somewhat indefinite manner to denote muscle, or the substance of which muscle is chiefly formed, or glandular tissue.

Caroncle—AnB, 35. Carunculi, used to denote the olfactory bulbs of the brain.

Catena—QIV, 15. Used for a moderator band of the heart, as it were a chain to prevent over dilation.

Catino—AnB, 20. Pelvis. The same as *alcatin*, *q.v.*

Celabro—AnB, 13v; *Ciclabro*—QV, 6v. The brain, for cerebro.

Cervello—QI, 3v. The brain.

Chassa (*del polmone*)—QI, 7v. The pleura.

Chassula del core—QI, 2v. The pericardium.

Cholatorio del chore—QII, 4v, 10. The interventricular septum of the heart, so named from the belief that it was traversed by minute pores through which the more subtilized blood might pass from the right to the left ventricle.

Coda—QIII, 4v. The coccyx.
Codrione—AnA, 8v. The sacrum and coccyx.
Colatorio—AnB, 40. The cribriform plate of the ethmoid bone.
Corda. Used variously for tendon or nerve.
Corde forate—AnB, 2. Nerves, these being supposed to be hollow so that the vital spirit might flow through them.
Coscia—AnA, 15, 17, 18; AnB, 8. The thigh, *coxa*.
Coste mendose—AnB, 13v. The false ribs.
Ddjoflama—QI, 7v. Diaphragm.
Degiuno, Deiuno, Djguno. Various spellings for jejunum.
Emicicli—QII, 13v. The concavities formed by the semilunar valves and the sinuses of Valsalva.
Epigloto—QI, 5v; QIV, 10. The larynx. Epiglottis was the common mediaeval term for the larynx, what is now termed epiglottis being known as *linguella*, *coopertorium*, etc.
Epiglottide scutale. The epiglottis.
Fistola—QIV, 10v. The larynx.
Forcula, Forchola, Furchula. The clavicle. Hyrtl has pointed out that strictly *furcula* (dim. of *furca*, a two-pronged fork, yoke) denotes both clavicles and it is so used for the united bones in birds. Leonardo, however, usually follows the Latin Avicenna in using it for either of the two bones. Mondino uses it for the sternum and it has been used for the suprasternal notch.
Fucile. A modification of *focile*, the usual Arabistic translation of the arabic word *zand*, used for the bones of the forearm and crus. According to Blumenbach (quoted by Hyrtl) the Arabic word denoted a wand or rod of wood which could be rubbed against another to produce fire, hence the word *focile* (*focus*, a hearth). The words *focile majus* were used for the ulna and tibia and *focile minus* for the radius and fibula.
Fuso del gamba—AnA, 9. The tuberosity of the tibia.
Inbelliche—QI, 7. Umbilicus.
Ipopletiche—AnB, 37v. The carotid artery. See *venæ apoplecticæ*.
Lacerta. Used for a long and somewhat slender muscle.
Lacrimatori—AnB, 38v; *Lacrimatoio*—AnB, 41, 42. The eyelids.
Linguella—AnA, 3. Epiglottis.
Lombi—QII, 16v. The psoas muscles.
Luce—D *passim*. Employed sometimes for the pupil of the eye, sometimes for the cornea.
Maestre—AnB, 24, 41v. The canine teeth. Avicenna and Mondino both use the term *canini*. *Maestre* probably refers to their greater length (*magister*, *magis*).
Mascellari—AnB, 24, 41v. The molar teeth (*Maxillares*). Not unusual in mediæval authors, though not used in the Latin Avicenna nor in Mondino. It is probably not directly from *maxilla*, but from the common stem-root seen in *macero*, to soften or crush.
Meri. The usual Arabistic term for the œsophagus, the arabic *mari*.
Mesopleuri—AnA, 7; AnB, 27v. The Galenic term for the intercostal muscles.
Mirac. The Arabistic term for the anterior abdominal wall, the Arabic *maraqq*.
Monocolo—AnA, 15v; AnB, 14v. The cæcum. "The Arabs found it inappropriate that a portion of the intestine that really possessed one opening should be termed *blind* (cæcum). Consequently they named it: *al-a'war*, *one-eyed*, which the translators plainly enough expressed with the Græco-Latin hybrid *monoculum*" (Hyrtl).
Muscolo del chore—QI, 11v. Papillary muscle of the heart.
Musculi dilatanti—AnB, 27v. Name suggested for the serratus anterior from its action in dilating the thoracic cavity.
Muscolo del dolore—AnA, 13v. The frontal portion of the occipito-frontalis.
Muscolo del ira—AnA, 13v. (1) The corrugator supercilii (?). The zygomaticus minor.
Muscoli latitudinali—AnB, 15; QI. 16. The obliqui abdominis.
Muscoli longitudinali—AnB, 15; QI, 16. The recti abdominis.
Muscolo massimo della spalla—AnA, 2. The infraspinatus.

Muscoli tiranti—AnB, 27v. Proposed for the serratus posterior superior to indicate its action in drawing the ribs upward.

Muscoli trassversali—AnB, 15; QI, 16. The transversi abdominis.

Nervo. The mediaevalists continued to be influenced by the Aristotelian confusion of nerve and tendon. The word *nervo* is used for a nerve, a tendon, a ligament, or even a small artery.

Nervi reversivi—AnA, 16; QIV, 7. Properly the term is applicable to the recurrent laryngeal nerves, and Leonardo sometimes uses it in that sense (QI, 13v). In other passages it is used for the vagus nerve as a whole.

Nuca or *Nucha.* The history of this word has been fully worked out by Hyrtl, who shows that it has an Arabic origin and is a modification of two quite different words. Consequently it has two quite different meanings, (1) as a modification of the arabic *nuqra* it means the back of the neck (AnA, 8v, 16v), in which sense it is still used in ligamentum nuchæ and in nuchal. (2) As a modification of the Arabic *nukha'* it means the spinal cord (AnB, 23).

Omore albuginea or *albusinio*—D, 7v. Aqueous humor of the eye.

Omore crystallina—D, 7v. The lens of the eye.

Orca—QII, 12. A fanciful name suggested for one of the chordæ tendineæ of the left ventricle of the heart. *Orca,* a brace or stay, nautical term.

Orecchio. Literally an ear, but used to denote the auricular appendages of the heart or the vermiform appendix of the caecum.

Ossi glandulosi—AnA, 1, 12. The sesamoid bones of the great toe.

Ossi petrosi—AnA, 7v. The sesamoid bones of the great toe.

Osso dell' aiutorio—QIII, *passim.* The humerus. See *aiutorio.*

Osso basillare. This term is applied to three different bones. (1) The bone at the base of the skull, probably the occipital, AnA, 3; (2) the cuboid bone of the tarsus, AnA, 3v; and (3) the trapezium of the carpus, AnA, 10v.

Osso del coda—AnA, 5. The coccyx.

Osso del coscia. In AnA, 15 and 15v, this denotes the femur (see *coscia*), but it is also used for the os innominatum, AnA, 9.

Osso della forcula—AnA, 3. The clavicle. See *Forcula.*

Osso del pettine—QV, 24. The pubic bone.

Osso della schiæna—AnA, 8v. The spinal column, back bone.

Osso della spalla—AnA, 1v. The scapula.

Padella. A misspelling of patella and may indicate that bone, AnA, 9, or the scapula, AnA, 1v, 3, 4, 13.

Paletta. Also a misspelling of patella, denoting the scapula, AnB, 23.

Panniculi. Used for membranes in general, but also specially applied to the atrio-ventricular valves of the heart, QI, 3; QII, *passim,* on account of their membranous character.

Penule—AnB, 11v. A mediaeval term applied to the lobes of the liver. Probably from the Latin *pænula,* a mantle or cloak, in allusion to the manner in which the lobes of the liver were supposed to cover the stomach (see figs. 7 and 9). Leonardo extended the use of the term to the lobes of the lungs, QII, 1.

Pesce del'brachio—AnA, 14v; AnB, 22. M. biceps brachii.

Pesce della coscia—AnA, 9. M. rectus femoris.

Pettignone—TP. 338, 341. Mons veneris.

Pettine—QI, 6v; QIII, 4v, 7; AnB, 15v, 6v. Used by Leonardo most frequently in the sense of pubes. It also denoted the hand, especially with the fingers extended, *pecten manus,* and from this it came to be applied to the palm of the hand. Leonardo uses it in this sense on AnA, 10v.

Polpa or *Pompa della gamba*—AnA, 11v. The calf of the leg.

Pomo granato—AnA, 18; QIII, v; TP, 338, 341. The xiphoid process of the sternum. See p. 33.

Pori (*Poli*) *ureterici*—AnB, 14, 37. The ureters.

Porta. Most frequently used in the sense of *porta hepatis,* but sometimes for the atrio-ventricular orifices of the heart, QII, 12.13v, and for the opening of the inferior vena cava, QI, 2v.

Portinario—QIII, 1. The hymen.
Portinaro—QII, 16; QIV, 11v. The pylorus of the stomach.
Punta della spatola—AnA, 14v. The coracoid process of the scapula.
Rasetta—AnA, 14. The Arabistic term for the carpus, corrupted from the Arabic *rusgh*, which denotes either the carpus or the tarsus.
Rete—QIII, 3. The great omentum.
Rostro della spalla—AnA, 14v. The coracoid process of the scapula.
Rotula (*Rotella*)—AnA, 9; TP, 340. The patella.
Scutola—AnA, 3. The thyreoid cartilage.
Secondina—According to Hyrtl *secundinæ* is a barbarism, the classical Latin word for the afterbirth being *secundæ*. Leonardo uses the term with various spellings, sometimes for the chorion, QIII, 8v, sometimes for the placenta, QII, 1; QIII, 8.
Sifac.—The usual Arabistic term for the peritoneum, from the Arabic *sifaq*.
Spalla—Literally, the shoulder, as in *osso della spalla*, but Leonardo uses it, AnA, 2, for the deltoid muscle.
Spatula, *Spathula* or *Spatola*. The Scapula.
Spera albuginea—D. 7v. The aqueous humor of the eye.
Spera crystallina—D, 7, 10. The lens of the eye.
Spera vitrea—D, 8v. The lens of the eye.
Spetie—The particles or simulacra supposed to be emitted by objects and which, reaching the optic nerve, give the sensation of vision.
Spina del dorso—AnB, 37v. The spinal column.
Spondili—From *spondyles*, the Latinized Greek term for vertebræ. It was used in the Latin Avicenna and hence was the term in common use by mediaeval writers, eventually being replaced by vertebræ when Celsus, who uses that term, became popular. In addition to using it in this sense Leonardo also uses it, AnA, 5, to denote the lesser trochanters of the femora. See *vertebrum*.
Tallone—QII, 24. The usual meaning is heel, but the word is derived from the Latin *talus*, which meant heel or ankle or ankle bone. Leonardo seems to use it in this place for malleolus.
Testiculi—Applied to both testes and ovaries, AnB, 13.
Trachea—Denotes not only what is now termed trachea, but all its branches (bronchi and bronchioles) as far as they could be followed.
Usscio, *Uscioli*—QII, *passim*. These might be expected to denote the openings guarded by the valves of the heart, but they are used for the valves themselves.
Uvea—D, 7. The retina of the eye.
Vena—Frequently used in the modern sense, but also in the general sense of a blood-vessel.
Venæ apoplecticæ—AnB, 32v. The carotid arteries. The term is used by Mondino and is explained by the belief commonly held during the Middle Ages that if these arteries were compressed the individual would fall insensible. The belief dates back to classical times, being stated by Aristotle; Galen, however, did not accept it.
Vena arteriale—QII, 2v, 17v. The pulmonary artery. On QII, 4, it denotes the aorta.
Vena cilis—QV. The ureter.
Vena chili or *del chilo*. The Arabistic designation of the vena cava. It may be noted that the word *chilo* has nothing to do with chyle, but is the Latin transcription of the Arabic transliteration of the Greek word *koile*-cava.
Vena magiore—QI, 10. The vena cava.
Vena massima—QI, 1. The vena cava.
Vena meseraica—QI, 1; QIII, 7. The mesenteric vein.
Vene mulgenti—QII, 7; QIII, 7v. The renal veins
Vena nera—QII, 4. A cardiac vein.
Vergha—QIII, 1. The penis.
Verme—QI, 3v; QIV, 11. A problematical structure in the brain, supposed to contract and expand and so close or open the communication between the third and

fourth ventricles. It may be the vermis of the cerebellum, though Hyrtl argues that primarily it meant the chorioid plexus of the lateral ventricles.

Vertebrum—AnB, 37v. Not vertebra, for which Leonardo used *spondili* (*q.v.*) but seemingly the spinous process of a vertebra, recalling the use of spondili for the lesser trochanter, both words implying etymologically a turning movement. Mondino uses vertebrum for the spherical head of the femur.

Zirbo—AnB, 3, 11v, 34v. The Arabistic term for the great omentum. A corruption of the Arabic *tarb*.

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Sans Tache

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