

Leonardo da Vinci

The Mechanics of Man



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Leonardo da Vinci
The Mechanics of Man

MARTIN CLAYTON
RON PHILO



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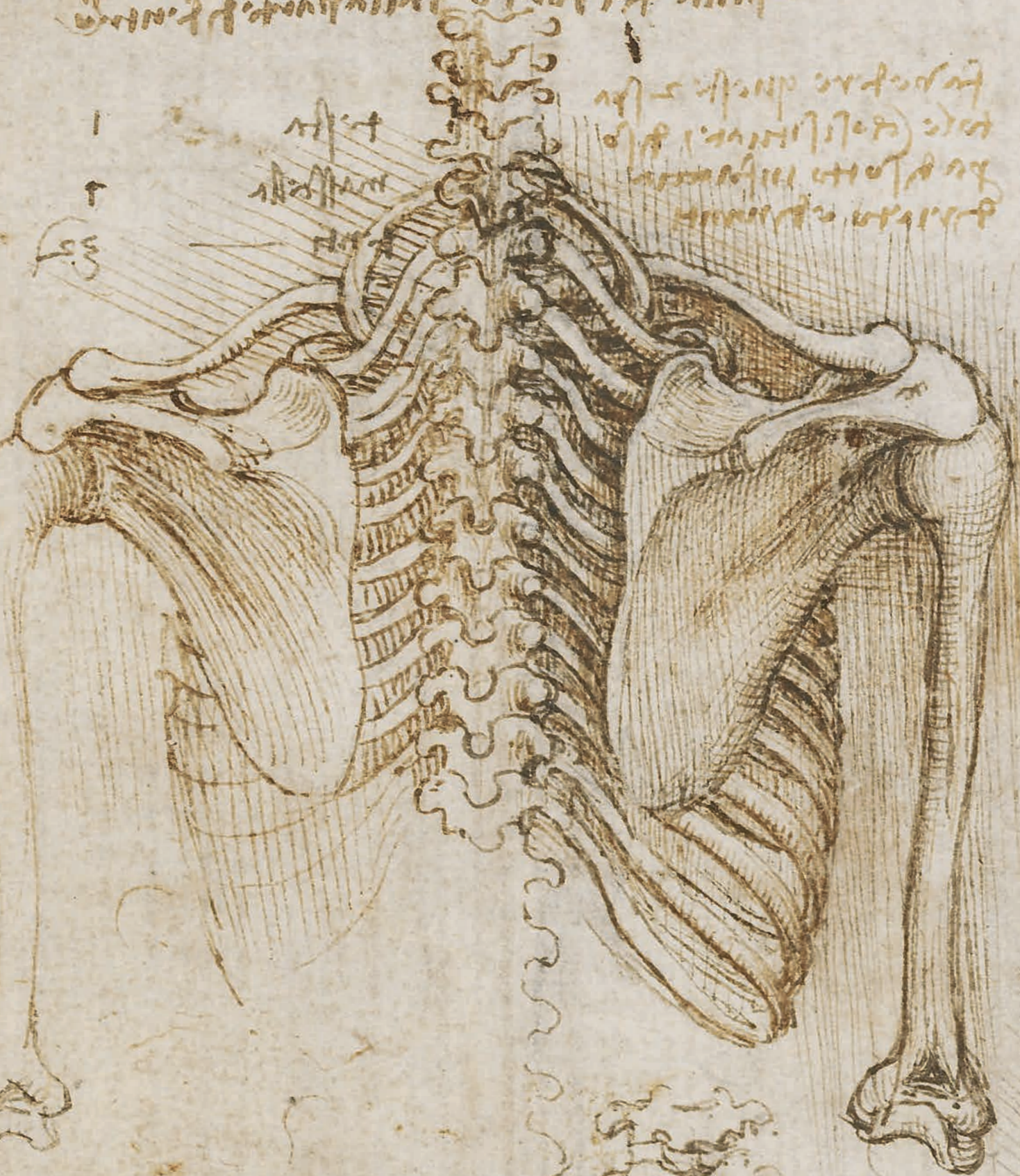
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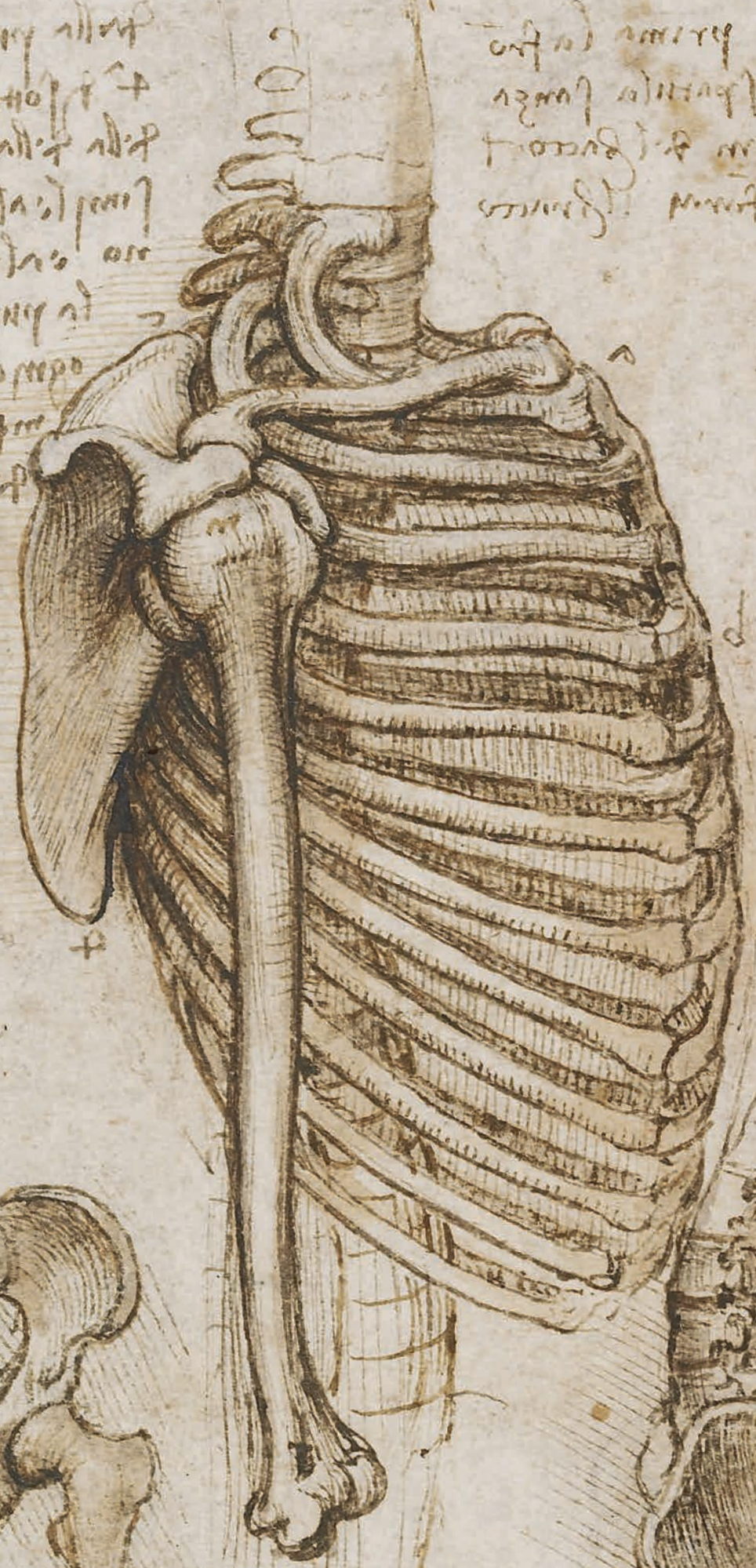


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LEONARDO IN 1510: THE ANATOMICAL MANUSCRIPT A

Martin Clayton

In the year 1510 Leonardo da Vinci was fifty-eight years old, and renowned as an artist across Italy and beyond. Less well known were his scientific researches, which in the latter part of Leonardo's life were becoming increasingly important to him—most notably his anatomical studies. Though Leonardo's early investigations had been hampered by a shortage of human material, he was now reportedly working in the medical school of the University of Pavia and had a plentiful supply of corpses. He combined manual dexterity in dissection with an acute understanding of physical structure and great skill as a draftsman to produce some of the finest anatomical studies ever made.

Leonardo intended to publish this material as an illustrated treatise, and had he done so he would have transformed the study of human anatomy in Europe. But at his death in 1519 the drawings remained among his private papers; they were essentially lost to the world, and it was not until the modern era that they were fully published and understood. This essay will examine the startling originality of Leonardo's anatomical work.

LEONARDO'S EARLY ANATOMICAL INVESTIGATIONS

Leonardo was born on 15 April 1452 near the town of Vinci, fifteen miles west of Florence in central Italy. He was the illegitimate son of a notary, Ser Piero da Vinci, and a peasant girl named Caterina, and was raised in his paternal grandfather's house. We have very little knowledge of the first twenty years of Leonardo's life. He learned to read and write, but his arithmetical skills were always shaky; and though as an adult he tried to learn some Latin, he never became comfortable with the language of most scientific writings. Leonardo's illegitimacy prevented him from following his father into the legal profession, and he must have trained as a painter, for by 1472 he had joined the painters' guild in Florence, the Company of St Luke, and was probably working in the large studio of the great sculptor and painter Andrea del Verrocchio (1435–88). Leonardo painted some works entirely

by himself, such as the *Annunciation* (Florence, Uffizi), while putting his hand to collaborative products of Verrocchio's workshop—most famously, painting an angel's head in the *Baptism* (Uffizi). Leonardo thus began his career as a conventional (if remarkably talented) painter; he may have participated in the sculptural and architectural projects that were emanating from Verrocchio's studio, but there is no evidence that he pursued any of the scientific researches that were to dominate the second half of his life.

By 1483 Leonardo had moved to the northern Italian city of Milan. There his interests steadily widened to encompass architecture and engineering, and he began to take an interest in the theoretical basis of painting, assembling notes towards a treatise on the subject. Leonardo was left-handed, and throughout his life he habitually wrote these notes in mirror-image, from right to left. This was not an attempt to keep his researches secret, as has been claimed, for Leonardo's mirror-writing is relatively easy to read with a little practice. Mirror-writing is a common developmental quirk in childhood, and what may have begun as an entertaining trick became a habit that Leonardo never had cause to discard.

Leonardo's projected treatise on painting was to encompass every subject that would enable an artist to produce works that were 'true to nature'. Its potential scope was huge, and it led him into a whole series of investigations into the appearance of the physical world, including optics, geology, botany and hydraulics, and most significantly into the principal subject matter of the Renaissance artist, the human body. Soon Leonardo conceived the idea of writing a separate treatise on anatomy; and though this, like the treatise on painting, was never completed, his anatomical studies came to be the most sustained and brilliant of his many scientific researches.

Leonardo's early anatomical studies were rather unfocused, for he wished to explain every aspect of the human body—not just structural anatomy, but also conception and growth, the expression of the emotions, the nature of the senses, and so on. An outline of his proposed treatise, drafted around 1489, captures the range of topics that he was planning to cover:

On the Order of the Book

This work should begin with the conception of man, and describe the form of the womb, and how the child lives in it, and to what stage it resides in it, and in what way it is given life and food. Also its growth, and what interval there is between one stage of growth and another; and what it is that pushes it out of the body of the mother, and for what reason it sometimes comes out of the mother's belly before due time.

Then you will describe which parts grow more than others after the infant is born, and give the measurements of a child of one year.

Then describe the grown man and woman, and their measurements, and the nature of their constitution, colour and physiognomy.

Then describe how they are composed of veins, nerves, muscles and bones. This you will do at the end of the book.

Then in four drawings you will depict the four universal conditions of man, that is: joy, with different ways of laughing, and draw the cause of the laughter; weeping in different ways, with their cause; fighting, with the different movements of killing; flight, fear, ferocity, boldness, murder, and everything belonging to such events.

Then draw labour, with pulling, pushing, carrying, stopping, supporting and similar things.

Attitudes

Then describe attitudes and movement.

Effects

Then perspective through the function of the eye; on hearing, I shall speak of music; and describe the other senses. [RL 19037v; K&P 8IV]

Leonardo was unable to get very far with most of these subjects. His status was that of a craftsman, and unsurprisingly he found human material for dissection hard to come by. Although not forbidden by church or state, as is often assumed, dissections were infrequent and (then as now) closely regulated. Those that did take place were expository, intended to 'illustrate' the canonical books (primarily the treatises of Mondino de' Luzzi, written in Bologna around 1320, and of the Persian scholar Avicenna, written around 1000; cf. p. 156), rather than investigative. Moreover, they were principally concerned with the internal organs, rather than with the bones and muscles, which would have been of more practical use to an artist.

Many of Leonardo's early anatomical observations were thus based on a blend of received wisdom, animal dissection and mere speculation. A striking example is his drawing of a hemisected man and woman in the act of coition (fig. 1), of around 1490. This is a diagrammatic rendering of traditional beliefs—a second channel in the penis carrying 'animal spirit' (loosely 'soul') from the spinal cord, and a bifurcated spinal cord in the woman to transmit her 'animal



FIGURE 1
Hemisection of a man and woman
in the act of coition, c.1490–95

spirit' to the uterus, as it was believed that conception involved both material and spiritual elements; a vessel from the testes, the source of ardour, to the heart, where the emotions are felt; and a vessel from the uterus to the breasts, so that the menses retained on conception could be converted into milk.

Leonardo was however able to dissect animals, and here we begin to see more fruitful observations. His drawings of dissections of the foot of a bear—the only large quadruped that walks on the soles of its feet, like man—are among the most impressive of Leonardo's early studies (fig. 2). He was struck by the interpenetration of the flexor tendons of its toes, and

FIGURE 2
The anatomy of a bear's foot,
c.1488–90



twenty years later, when he found the same structure in the hands and feet of man, he recalled his studies of the bear (fol. 17r). Dissections of monkeys and dogs seem to lie behind Leonardo's drawings ostensibly of the arm of man (fig. 3), which concentrate on the nerve pathways. But his drawings of legs, which deal with both nerves and muscles, are more accurate, and suggest that Leonardo did dissect a human leg in the late 1480s. In the note to fig. 4, for example, he states, 'I have lifted off the muscle *a n* [sartorius] which is half a *braccio* [30 cm / 1 ft] long, and I have uncovered *r t* [rectus femoris and adductor canal]. Now attend to what lies beneath *m o* [vastus lateralis]'. This is original, if rudimentary, research.

Leonardo's other early opportunity to investigate the internal anatomy of man came when, in 1489, he obtained a human skull. He sawed it in various sections to study the relationship between its external and internal forms, and made a sequence of exquisite drawings on the pages of a small notebook (now designated the Anatomical Manuscript B). Now armed with some knowledge of the nerve pathways to the brain, Leonardo tried to make headway in his speculations on perception. But much of his analysis of the skull was based on proportional study, and there is a mismatch between the highly accurate drawings and the simplistic observations in the related notes. For example, the note to fig. 5 states:



FIGURE 3
Miscellaneous anatomical studies,
c.1488–90

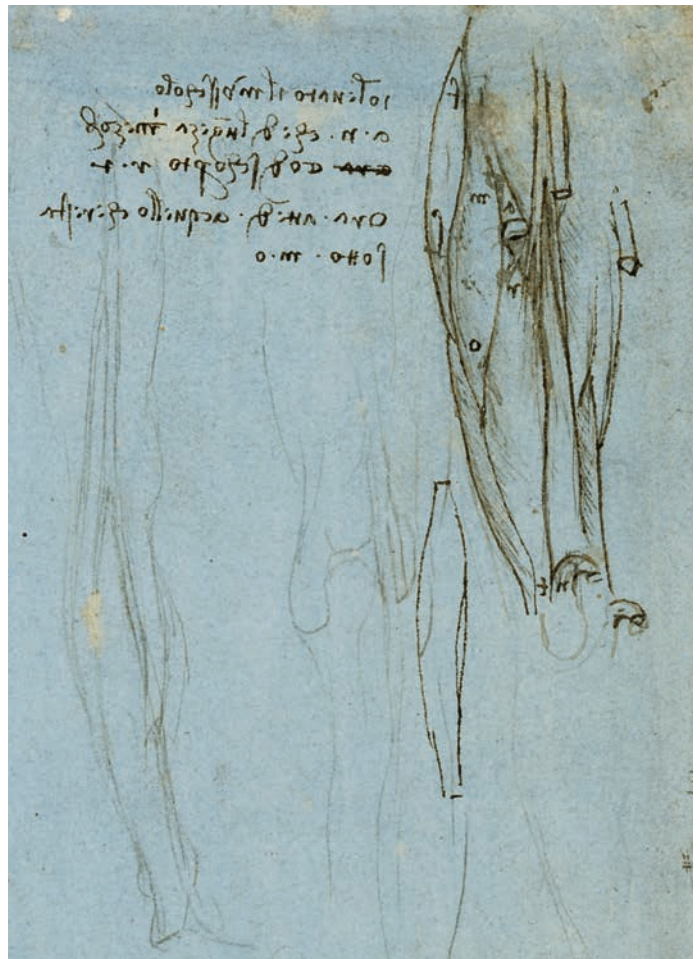


FIGURE 4
The muscles of the upper leg, c.1488–90



FIGURE 5
A skull sectioned, 1489



FIGURE 6
The proportions of the leg, c.1490

The cavity of the eye socket, and the cavity in the bone that supports the cheek, and that of the nose and mouth, are of equal depth . . . and each is as deep as the third part of a man's face, from the chin to the hairline. [RL 19058v; K&P 42v]

This concern with proportion is a major element of Leonardo's early anatomical studies, as seen in his measurements presumably of a posed studio assistant (fig. 6). But in attempting to determine the ideal proportions of man, Leonardo's observations became ever more detailed, and thus a formula for ideal beauty seemed ever further away. In the early 1490s Leonardo's researches into the human body, its structure and the phenomena of life, petered out.

In part Leonardo's anatomical interests were reflected in his two principal artistic projects of the 1490s. The mural of the *Last Supper* was a groundbreaking exploration of the effect of the emotions on the form of man, his attitudes and

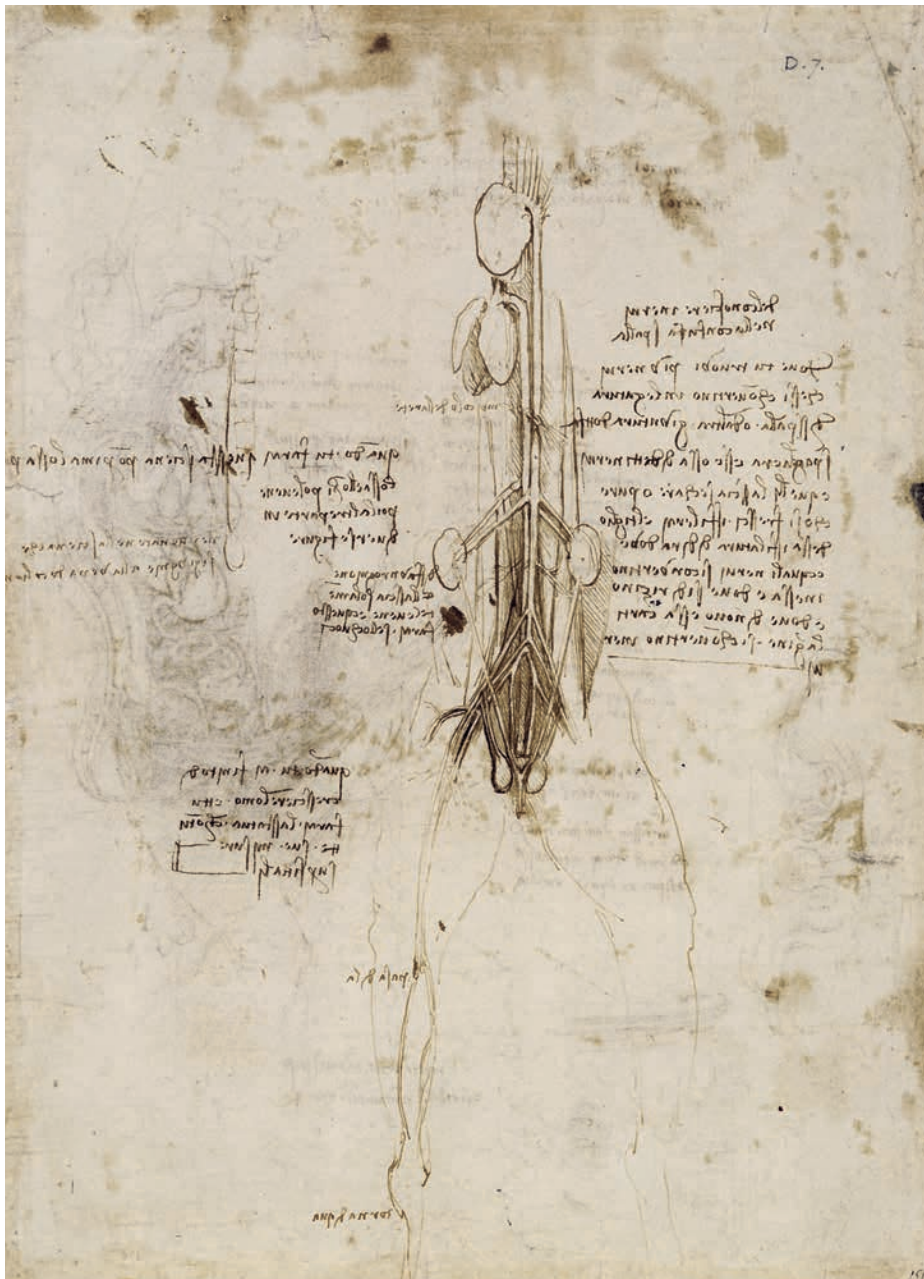


FIGURE 7
The viscera of a horse(?), c.1490–95

expressions. And a commission (received some time in the 1480s) to model and cast a huge equestrian monument to Francesco Sforza, father of Ludovico Sforza, then ruler of Milan, led Leonardo to investigate the anatomy of the horse.

Leonardo knew that different breeds of horse had different proportions, and he made many drawings of the dimensions of specific horses in the stables of the Milanese army. As the horse was not an 'ideal body', there could be no divine system of proportion to discover; this was liberating, for it allowed Leonardo to conduct his researches empirically. Writing in the mid-sixteenth century, the biographer Giorgio Vasari stated that Leonardo compiled a treatise on the anatomy of the horse. One drawing of the viscera of a large quadruped, probably a horse, does survive from this period (fig. 7), suggesting that Leonardo conducted full dissections to investigate the internal anatomy of the beast. But Vasari also stated that the treatise on the horse was lost when Milan was invaded by French forces in 1499. Ludovico Sforza was overthrown, and soon afterwards Leonardo left the city and returned to Florence.

LEONARDO'S LATER ANATOMICAL CAREER

Now aged forty-eight, Leonardo quickly re-established himself as one of Florence's leading artists—though in truth he was painting little, and it is hard to get a clear picture of his activities at that time. In 1502 he spent a few months travelling through central Italy as a military engineer and map-maker, but in 1503 he received a commission to paint a huge mural of the *Battle of Anghiari* in the council chamber of the Florentine Republic. This was the most prestigious commission of Leonardo's career, and also the most dynamic composition that he ever worked on: the only portion that he executed, known as the *Fight for the Standard*, was a wild struggle of man and horse. The size of the *Battle*, some 20 metres (65 ft) wide, required Leonardo to prepare the composition meticulously, and he returned to the study of human and equine anatomy after a gap of more than ten years.

Leonardo's investigations were now conditioned by their practical purpose, towards a painting rather a theoretical treatise, and initially he concentrated on the topics that would be of immediate use—the superficial musculature of man (fig. 8), the horse galloping, rearing and bucking, the expressions of fury in man and horse (fig. 9). But Leonardo's scientific studies throughout his life were characterised by an urge to go ever deeper, to discover fundamental causes, and he was soon drawn back to the study of human anatomy, independently of the specific requirements of the *Battle of Anghiari*. While Leonardo's early interest in the phenomena of life remained, he was now equally concerned with the physical structure of the body. And he had evidently been trying to get to grips with the literature on the subject: a list, probably not exhaustive, of 116 books (presumably both printed and manuscript) owned by Leonardo around this date includes Johannes de Ketham's medical compendium, *Fasciculus Medicinae*; Guido de Cauliaco's manual on surgery, *Cirurgia*; Bartolomeo Montagnana's *Tractatus de urinarum judiciis*; and a *libro di notomia* which may be either Alexander Benedictus's *Anatomicæ* or, more likely, Mondino's *Anathomia*.

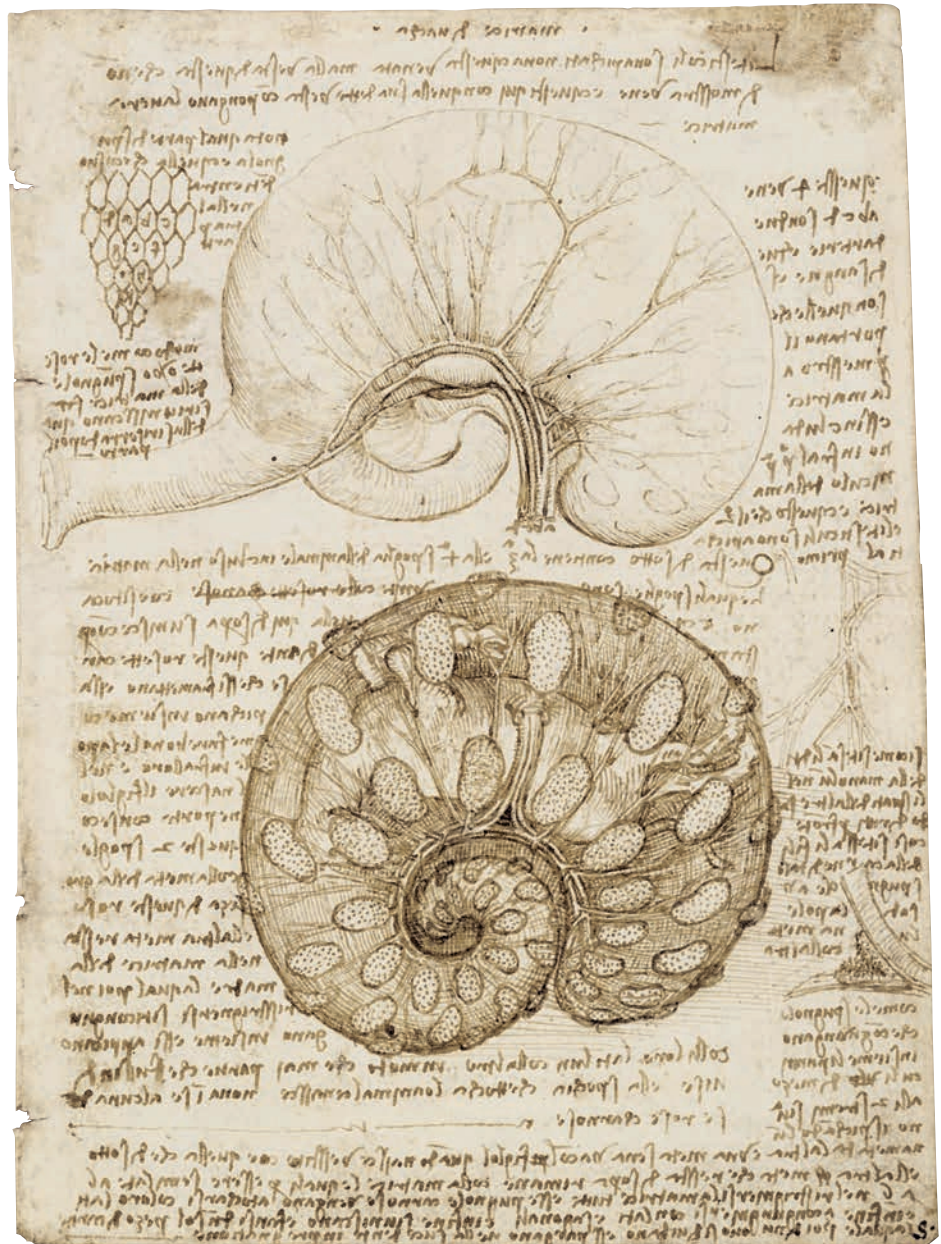
FIGURE 8
A nude man from behind, c.1504–6



FIGURE 9
Studies of horses, a lion and a man,
c.1503–4



FIGURE 10
The uterus of a gravid cow, c.1508



Reconstructing the development of Leonardo's anatomical career at this time is difficult due to the lack of datable works and the wide range of his studies. There are some explicit depictions of animal anatomy derived from dissection (such as fig. 10, showing the two-chambered uterus of a gravid or pregnant cow), and other cases where Leonardo adjusted the proportions of an animal dissection to provide a non-species-specific depiction of a structure (e.g. fig. 11, which is probably based on the dissection of a pig). But he now seems to have had regular access to human material too. In the winter of 1507–8, for example, he was permitted to conduct an autopsy of an old man, as recorded in his notebook:

This old man, a few hours before his death, told me that he was over a hundred years old, and that he felt nothing wrong with his body other than weakness. And thus, while sitting on a bed in the hospital of Santa Maria Nuova in Florence, without any movement or other sign of any mishap, he passed from this life.

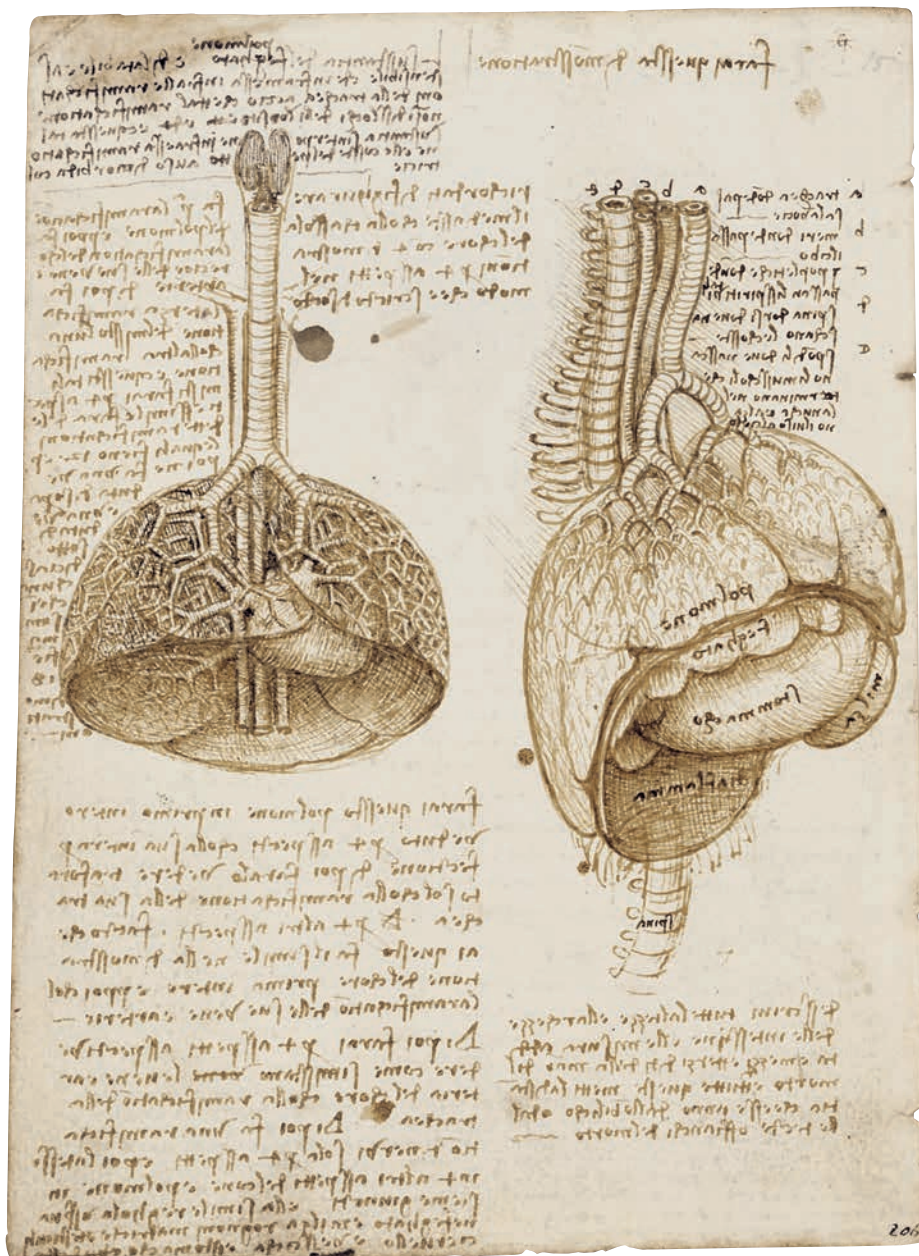


FIGURE 11
The lungs and other viscera, c.1508

And I dissected him to see the cause of so sweet a death. This I found to be a fainting away through lack of blood to the artery which nourished the heart and the other parts below it, which I found very dry, thin and withered. This anatomy I described very diligently and with great ease because of the absence of fat and humours which greatly hinder the recognition of the parts. The other dissection was of a child of two years, in which I found everything contrary to that of the old man. [RL 19027v; K&P 69v]

This passage—the first clear description of coronary vascular occlusion and arteriosclerosis in the history of medicine—indicates that by this date Leonardo was already sufficiently experienced in human dissection to identify without hesitation the pathology of this particular case. The casual reference to the ‘other dissection . . . of a child of two years’ suggests that human dissection was now almost routine for Leonardo, and indeed a year or so later he stated ‘I have dissected more than ten human bodies’ (RL 19070v). Executed criminals were the usual subjects of dissections, but the centenarian and presumably the two-year-old died in the charitable hospitals of Florence with

no relatives to claim their bodies for burial. It is plain that Leonardo had now sufficient reputation as an anatomist to be permitted by the authorities to conduct such dissections as a matter of course.

In the spring of 1508 Leonardo returned to Milan to serve the French rulers of the city, and he was to spend the next five years in and around the city. From this period date the greatest of Leonardo's anatomical researches, but again, we can do no more than sketch their circumstances and progress. The number of corpses he claimed to have dissected grew from 'more than ten' around 1509 to 'more than thirty' towards the end of his life, and the abundance of drawings based on human dissection confirms that Leonardo now had no shortage of material. Consequently, almost every drawing and statement in Leonardo's notes is based on direct investigation. The efficacy of his dissections increased exponentially: as he became more familiar with the body, so he was better able to formulate his questions, dissect the relevant part accurately and efficiently, understand what he uncovered, and synthesise his discoveries in drawings of a clarity rarely matched to the present day.

Leonardo still intended to compile and publish a treatise on human anatomy, but the potentially vast scope of the subject frequently caused him to get sidetracked into detail. The goal of a complete, coherent treatise on anatomy must have seemed, for much of this period, ever further away. Much of this period, but not all.

THE ANATOMICAL MANUSCRIPT A

The exception came during the winter of 1510–11, when Leonardo compiled a series of eighteen sheets, mostly double sided, that form the subject of this book. On these pages Leonardo crammed more than 240 individual drawings and notes running to over 13,000 words. The sheets are now collectively known as the Anatomical Manuscript A, following a facsimile edition of the sheets published in 1898 (distinguishing them from the Anatomical Manuscript B, and so on); they are referred to individually by their somewhat arbitrary foliation in that publication, from fol. 1 to fol. 18, with 'r' (recto) or 'v' (verso) to denote the front or back of each sheet.

The date is found on fol. 17r, where Leonardo commented 'this winter of 1510 I believe I shall finish all this anatomy' ('questa vernata del mille 510 credo spedire tutta tal notomia'—perhaps surprisingly, *vernata* is 'winter' rather than 'spring'; cf. modern Italian *inverno*). By 'all this anatomy' Leonardo presumably meant the compilation of material towards his proposed treatise on anatomy, and indeed the campaign of the winter of 1510 is the only period in Leonardo's whole anatomical career that he managed to survey most of the body to a reasonably consistent level of detail.

The bones and muscles were the focus of Leonardo's investigations at this time, and he illustrated in detail every bone in the body except those of the skull, and many of the major muscle groups. The nerves and blood vessels are occasionally included, but it was the mechanics of the body, rather than biochemical or 'spiritual' considerations, that primarily interested Leonardo. On fol. 10r he states: 'Provide that the book on the elements of mechanics [delli elementi machinali], with its practice, comes before the demonstration of

the movement and force of man and other animals; and by means of these you will be able to prove all your propositions.’ It does appear that Leonardo had indeed composed, or at least laid out, such a treatise, for on fol. 11v, in a note on the tendons attached to the vertebrae, he refers to ‘the fifth [chapter] of the fourth [book] on the elements of mechanics’.

The structural, mechanical perfection of the body was the guiding principle for Leonardo in this campaign of investigation. Though God is never directly invoked, on fol. 15v Leonardo lauds ‘the first composer of such a machine’ (‘il p^o conponentore di tal machina’), and on fol. 2r he attributes a feature to ‘the master’ (‘il maesstro’). More frequently however ‘nature’ (*natura*) is given as the author of a particular feature—for example ‘here you see the wisdom of nature in providing two causes of movement in each limb’ (fol. 11v; *natura* is also cited on fols. 2r, 3r, 8v, 10r, 16r, 16v and 18r). But if Leonardo’s drawings convey ‘the marvellous works of nature’ (‘l’opere mirabile della natura’), he stated that ‘if this his composition appears to you a marvellous piece of work, you should regard this as nothing compared to the soul that dwells within that architecture; and truly whatever that may be, it is a thing divine’ (fol. 2r). Perhaps one of the keys to Leonardo’s achievement in the Anatomical Manuscript A was his willingness to put to one side spiritual matters, and indeed any concern with the processes of life, allowing him to analyse the muscles and bones in purely physical terms.

To some extent this methodological shift was an inevitable consequence of Leonardo’s increasing experience, stemming from his greater access to human material. In his earlier studies, an enquiry that proceeded from effect to cause allowed Leonardo to map a way through the complexity of the body, seeking the structures that would give rise to certain physiological functions. Now much more familiar with the body, he was able to comprehend how the details fitted into the whole, and in general to work outwards from cause to effect, trying to understand the purpose of the structures that his dissections exposed.

But Leonardo may not have arrived at this methodological position alone. The physician and historian Paolo Giovio—who would have known Leonardo when both were in Rome between 1513 and 1516—wrote in a short biography of the artist, composed around 1527:

In order that he might be able to paint the various joints and muscles as they bend and stretch according to the laws of nature, he dissected the corpses of criminals in the medical schools, indifferent to this inhuman and disgusting work. He then tabulated all the different parts down to the smallest veins and the composition of the bones with extreme accuracy, in order that this work on which he had spent so many years should be published from copper engravings for the benefit of art. [J.-P. Richter, *The Literary Works of Leonardo da Vinci*, 2nd edn, Oxford 1939, I, p. 3]

This information was expanded in Vasari’s biography of Leonardo:

Leonardo then applied himself with great diligence to human anatomy, helped in this by (and in turn helping) that excellent philosopher

Marcantonio della Torre, who was then lecturing at Pavia and who wrote on this subject, and who was one of the first (as I have heard) to begin to illustrate matters of medicine by the teachings of Galen and to throw true light on anatomy, which up to then had been obscured by the great shadows of ignorance. In this he was wonderfully served by the intelligence, work and hand of Leonardo, who composed a book drawn in red chalk and finished in pen, of bodies he had dissected himself. He depicted with great diligence all the bones and to what they are joined, and then in order all the nerves, covering them with the muscles—the first that are attached to the skeleton, the second that hold it firm and the third that move it. In places he wrote his observations in crude letters, done in reverse with the left hand, which cannot be read by anyone who does not know the trick of reading them in a mirror. These papers on human anatomy are in large part in the hands of Francesco Melzi, a Milanese gentleman who in Leonardo's day was a handsome boy and much loved by him. [G. Vasari, *Delle vite de' più eccellenti pittori, scultori et architettori*, 2nd edn, Florence 1568, III, p. 7]

There are no more than a couple of passing references to Leonardo's anatomical work in the first edition of Vasari's *Lives* (1550), and it is likely that Vasari obtained the detailed information quoted above directly from Melzi, Leonardo's heir, after the publication of the first edition. While the mention of drawings in red chalk is puzzling—very few of Leonardo's anatomical drawings are in that medium—the statement that Leonardo collaborated with Marcantonio della Torre at the University of Pavia (fifteen miles south of Milan) should probably be taken at face value. There are only a few scraps of evidence in Leonardo's notes to support this, such as a sheet of embryological studies (RL 19102) that carries both a reminder to give a 'book on water to Messer Marcantonio', and—among many other notes in Leonardo's hand—a passage on the membranes surrounding the foetus, in a hand otherwise unknown among Leonardo's papers and which may well be that of Della Torre. But the strongest support for Vasari's statement is the radically different nature of the Anatomical Manuscript A from anything that Leonardo had produced before. As Vasari stated, Marcantonio della Torre was a leading figure in the revival of the teachings of the second-century Greek physician Galen; while the majority of Galen's many books (which had survived from Antiquity in Arabic translations, thence translated into Latin in the Renaissance) were not printed until the 1520s, Della Torre would have had access to a number of his works in manuscript. The abundance and range of Galen's writings make it hazardous to try to identify specific points that Leonardo may have gleaned from Galen through Della Torre, but the compelling message of works such as *De usu partium corporis humani* was that a command of detail had to precede any attempt to comprehend a system.

It is thus entirely plausible that Leonardo was working alongside Marcantonio della Torre in the medical school of the University of Pavia in the winter of 1510–11. Such a collaboration would explain both the

methodological stance inherent in the Anatomical Manuscript A and Leonardo's ready access to human material. But we must be careful not to read Leonardo's drawings as direct records of dissections—indeed we probably do not have a single sheet that was compiled as Leonardo actually carried out a dissection of soft tissue. Dissection of embalmed, fixed material, as performed today, is quite different from dissection of the unembalmed, as practised by Leonardo. Without fixatives or preservatives this is a messy process, and the paper on which Leonardo made his notes would unavoidably have become soiled with body fluids (drawings of prepared bones, on the other hand, could have been made directly, under clean conditions). Either he discarded those notes and sketches once he had processed them, or his successors did not deem them worthy of preservation.

There are some glimpses in Leonardo's notes of the gruelling nature of dissection—'break the jaw from the side so that you see the uvula in its position' (fol. 3r)—but what we have in the Anatomical Manuscript A are Leonardo's carefully considered, partly diagrammatic representations of the body's structures, synthesised from his dissection notes. It is questionable whether Leonardo would have been able to obtain sufficient information from a single dissection to create drawings of the complexity seen on some of these sheets, and he presumably combined the findings of several different dissections to arrive at these diagrams. This would explain the recurrence of certain oddities—such as the widely separated dual origin of the sternocleidomastoid muscle of the neck (see fol. 1r), and the little toe with only two phalanges (fol. 3v)—as variations seen in the anatomy of one individual were assumed by Leonardo to be normal and thus were applied to all the drawings.

We cannot know what medium Leonardo would have used for his dissection notes. The drawings that do survive, catalogued here, were mostly constructed with a detailed underdrawing in black chalk (or possibly charcoal) that was erased once the outlines had been fixed in pen and ink; in a couple of cases the drawings did not proceed beyond the underdrawing, which was consequently not erased (fols. 8r and 15r). Occasionally Leonardo worked directly in pen from his dissection notes, with scratching out and overdrawing (fol. 7v, upper right; fol. 11r, lower left); and some of his life drawings (most clearly fol. 5v, right) were constructed using compass points to record measurements taken from the model. The drawings were usually shaded using a variety of techniques: pen hatching curving around the form of a bone and muscle; lighter pen lines following the direction of the muscle fibres; delicately applied wash to capture the sheen of the fascia. In every case, Leonardo's aim was to make the drawing as clear as possible. Throughout the notes there are exhortations to depict every structure at each level of dissection in a series of different views—on fol. 10v, for example, he reminds himself to depict each bone of the hand in four views, thus requiring 108 separate drawings. But this was an ideal, born out of Leonardo's terror of 'abbreviation', and in most cases he arrived pragmatically at a set of illustrations appropriate to the structure in question.

Anatomical illustration is not a simple matter of depicting what is found upon conducting a dissection. Other than the bones, which can be shown undiagrammatically, any representation of a part of the body requires a degree

of stylisation to be legible. There is no space in the musculoskeletal system: to convey the structure of a system clearly, some space must be introduced, the muscles must be differentiated, and the nerves and vessels separated to some degree. Leonardo adopted and developed a wide range of illustrative techniques to make his drawings as clear and communicative as possible. From architecture Leonardo took the principles of elevation, plan and section, repeatedly insisting that structures should be shown from multiple directions to convey complete spatial information (fols. 8v and 13r; on fols. 6v and 9v he depicts the muscles of the arm and shoulder in eight views through 180°). From engineering he took the device of the 'exploded view', depicting the elements pulled apart to show their articular surfaces and how they connect (fols. 2r and 8v). He perceived some structures as composed of distinct layers: the structures of the palm of the hand are built up sequentially in six drawings on fols. 10r and 13v; the shoulder is progressively stripped down on fols. 14v, 4v and 2r. He tried to analyse 'complex movements' as composed of 'simple' elements, combining the engineer's or architect's orthogonal analysis of space and form with the physiologist's attempt to isolate the movements caused by each individual muscle. And having analysed the full complexity of a structure in a sequence of drawings, Leonardo then sometimes tried to convey the whole of this structure in a single diagram, reducing the muscles to threads such that the interrelationship of every muscle and bone could be seen (fols. 2r and 4v).

The intended or imaginary viewer of the drawings is in the forefront of Leonardo's mind throughout the Anatomical Manuscript A. It is futile to try to enumerate all the 'firsts' embodied in these drawings (though they are occasionally noted in the entries that follow this introduction): virtually every drawing is the finest depiction of a particular structure to that date, and in some cases for several centuries to come. With some rearrangement and amplification, and through the medium of a sensitive engraver (see fol. 8v), these drawings would have served magnificently as plates to the published treatise on anatomy that Leonardo always intended to produce.

The text is a different matter. Occasionally Leonardo began by writing at the head of a page a note presumably outlining what that page was to cover; the headings on fols. 5r and 10v do introduce the content of the page, but those on fols. 3r, 6v and 13r are unrelated to what follows. The larger drawings dictate the layout of the page, and the order in which they were made may be reconstructed with some confidence; smaller details and neat blocks of text are then fitted in around them. On each page a wide range of inks can usually be seen in the notes as Leonardo moved from sheet to sheet, adding explanations and observations over a period of time as his understanding of the anatomy evolved.

In some cases the notes explain a feature of an adjacent drawing; in others they deal with a related anatomical issue but are not directly relevant; in many instances they are Leonardo's comments to himself on how to depict a certain structure, or on a feature that required further investigation. Only rarely is there evidence that Leonardo acted on these memoranda. On fol. 5r he reminded himself to 'see what purpose the gibbosity of the arm at f serves', followed by 'I have looked at it, and find that the gibbosity f serves as the attachment of the

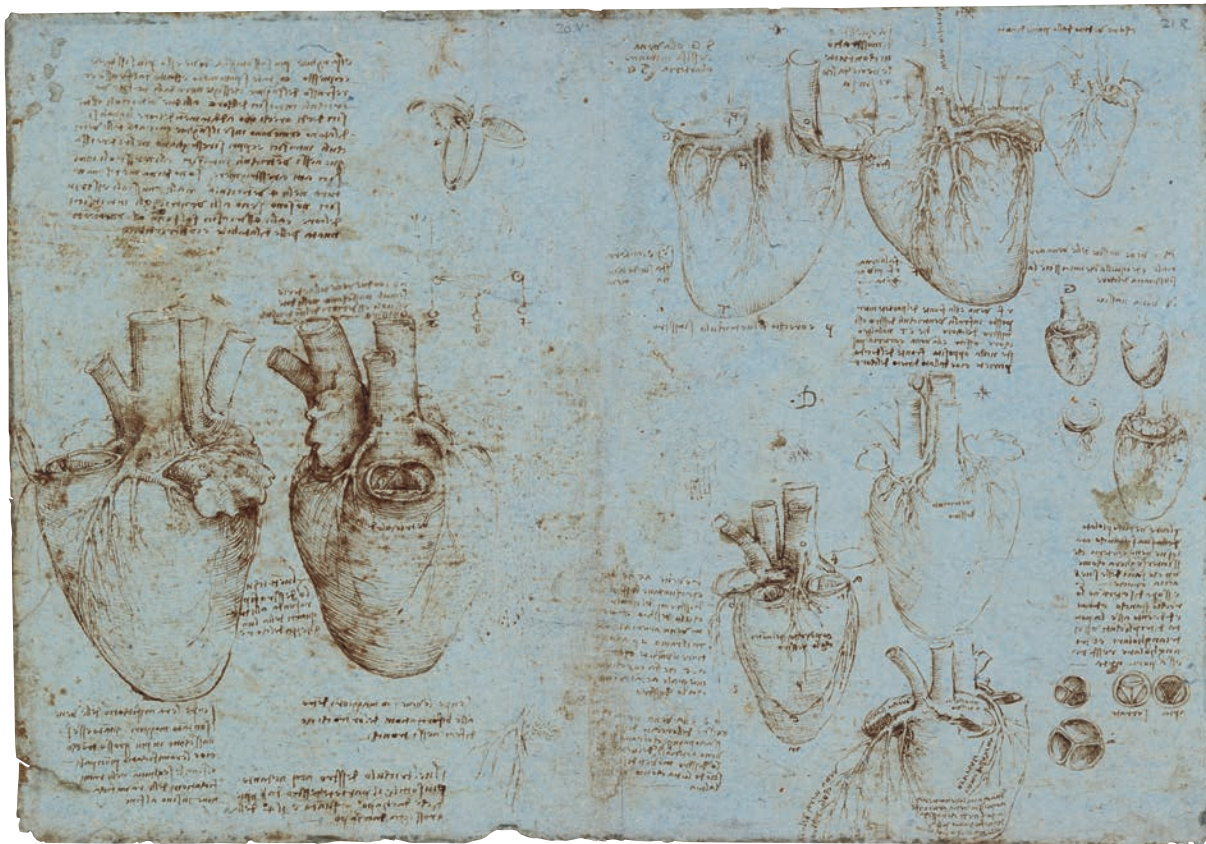


FIGURE 12
Studies of an ox's heart, c.1511–13

muscle that raises the humerus', but this is exceptional. Relatively few of the notes comprise definitive statements on a particular structure of the body—the majority were Leonardo's attempt to keep track of a flood of partially resolved information. The lucidity of the drawings may convey the impression that these are final expressions of Leonardo's understanding, but this is belied by the notes, which emphasise the fact that the Anatomical Manuscript A was a work in progress.

The name 'Anatomical Manuscript A' is in fact somewhat misleading, as it implies a bound notebook. While the sheets are mostly uniform in paper and size (excepting fols. 15–16, which are on a different paper, and fols. 17–18, which are double sheets), it appears that they were loose when Leonardo compiled them, and it is impossible to discern any structure to their content. Leonardo probably did not conceive of them as running in a fixed order—drawings of the shoulder and the foot, in particular, are scattered throughout. A few of the drawings are conspicuously poor (e.g. fol. 12r, upper centre) and were presumably made at an early stage; some others, notably the two large studies of the foot (fols. 17–18), have an air of finality about them, and were probably executed towards the end of this campaign of dissection and illustration. But the hope, expressed on fol. 17r, that Leonardo would conclude his anatomical work in the winter of 1510 was to be confounded.

THE AFTERLIFE OF THE ANATOMICAL MANUSCRIPT A

Marcantonio della Torre died of the plague in 1511, aged around thirty, and whether or not this loss affected Leonardo's methodology directly, he never again attained the balance between coverage and detail that is found in the Anatomical Manuscript A. Towards the end of the same year the French

occupiers of Milan, Leonardo's employers, were partly ousted by Swiss forces. The city remained in turmoil for many months, and for much of the period Leonardo stayed at the Villa Melzi at Vaprio d'Adda, fifteen miles east of Milan. He continued to pursue his anatomical interests, with dogs, birds and the hearts of oxen as his material, and his study of the bovine heart (fig. 12) was perhaps the most brilliant of all of Leonardo's many scientific investigations.

In September 1513, Leonardo and his assistants left Milan for Rome, where they lodged in the Vatican palace under the patronage of Giuliano de' Medici, brother of Pope Leo X. Leonardo seems to have attempted to continue his anatomical researches at the hospital of Santo Spirito, close to the Vatican, but in a draft letter he complains of having been 'hindered in anatomy, denounced before the Pope and likewise at the hospital' by a troublesome German mirror-maker with whom he was forced to work. Leonardo's three years based in Rome were generally unproductive, and after the death of his patron he probably welcomed an invitation to move to the French court. By the end of 1516 Leonardo had settled at Amboise, one of the chain of royal residences in the Loire valley, where he held a privileged position as painter, engineer and architect to King Francis I. Leonardo worked on a few artistic projects, advised on technical matters, provided designs for entertainments, and generally served as an ornament to the court.

There is no evidence that Leonardo pursued his anatomical researches during these last years in France, but he had with him the hundreds of sheets of drawings and notes on the subject that he had compiled over the previous three decades. A diary entry by Antonio de Beatis records a visit to Leonardo's studio by Cardinal Luigi d'Aragona on 10 October 1517. After describing some paintings that Leonardo showed the party, Beatis (the cardinal's secretary) noted that:

This gentleman has written in great detail on anatomy, with illustrations of the members, muscles, nerves, veins, joints, intestines, and of whatever else can be discussed in the bodies of men and women, in a manner that has never yet been done by anyone else. All this we have seen with our own eyes; and he said that he had dissected more than thirty bodies, both male and female of all ages. He has also written on the nature of water, on diverse machines and on other things, which he has set down in countless volumes, all in the vulgar tongue, which if they are published will be profitable and very delightful.

[L. Beltrami, *Documenti e memorie riguardanti la vita e le opere di Leonardo da Vinci*, Milan 1919, p. 149]

But Leonardo's researches were not to be published for several centuries. He died on 2 May 1519, a couple of weeks past his sixty-seventh birthday, at the chateau of Cloux, and bequeathed his notebooks and drawings to the young Francesco Melzi. Though periodically Leonardo had stated his intention to put his notes into order, Melzi returned to Italy with a mass of undigested material, dense, repetitive and disorganised.

Melzi settled at his family home at Vaprio, and over the next fifty years he attempted to make sense of this daunting legacy. His ownership of Leonardo's

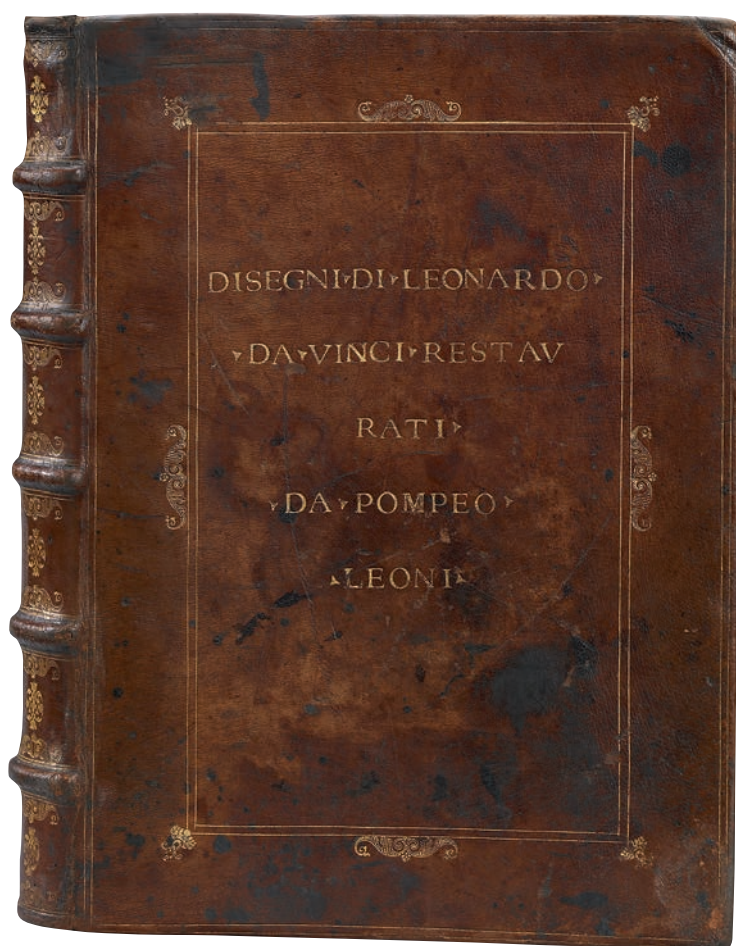


FIGURE 13
The Leoni Binding, Milanese,
c.1590–1600

anatomical studies was no secret, as Vasari's account quoted above demonstrates, and a few early copies of the anatomical drawings show that artists did have occasional access to them. Melzi copied out passages from the theoretical writings in Leonardo's notebooks in an effort to construct the treatise on painting that Leonardo himself had never completed; abridged copies of Melzi's resulting manuscript circulated in Italy in the sixteenth and seventeenth centuries, and a version was first published in 1651. But there is almost nothing on the subject of anatomy in Melzi's version of the treatise, beyond generalities on the dynamics of the body in motion, and indeed no evidence that he made any sustained attempt to investigate the anatomical papers. Beyond the walls of the Villa Melzi fresh anatomical enquiry gained pace, culminating in Andreas Vesalius's *De humani corporis fabrica* of 1543, the most important book in the history of anatomical study, and a model of what Leonardo's projected treatise could have been.

Melzi died around the year 1570, and by 1590 his son had sold the majority of Leonardo's papers to the sculptor Pompeo Leoni, who preserved the notebooks intact and mounted the loose drawings into several large albums. Among the contents of one of these albums (fig. 13) were almost all the anatomical studies now known to us, which suggests that those drawings had been acquired by Leoni as loose sheets, not bound as notebooks. Leoni spent much of his later career in the service of the King of Spain and divided his time, and his art collection, between Milan and Madrid. Peter Paul Rubens saw Leonardo's papers while they were in Leoni's possession, probably in 1603 in Madrid; he was reported to be particularly interested in Leonardo's anatomical drawings, though there is no direct reflection of them in the anatomical studies that Rubens himself made a few years later.

Inventories of Leoni's estate compiled after his death in Madrid in 1608 list (among a great many other items) the Leonardo volumes that he had had with him in Spain. By 1630 one of these was in England, in the possession of Thomas Howard, 2nd Earl of Arundel, one of the great collectors of seventeenth-century Europe. While the album was in Arundel's possession, a few of the anatomical drawings (including details of fols. 3v and 13v) were reproduced in etchings by Wenceslaus Hollar, but they seem to have been regarded as curiosities rather than repositories of knowledge. Arundel left England for the Low Countries shortly before the outbreak of the Civil War, travelling on to Italy, where he died in 1646, and it is not known whether he took the Leonardo album with him into exile. The album is next recorded in 1690, when it was seen in London in the possession of William III and Mary II. The means by which the volume entered the Royal Collection is unknown but it is probable that, along with many other Renaissance drawings, the Leonardos had been acquired, by purchase or gift, by Charles II (reigned 1660–85).

There was only sporadic interest in the album of Leonardos during the eighteenth century, and it was forgotten about and 'rediscovered' at least twice. But by 1773 the physician and anatomist William Hunter had examined the anatomical drawings in George III's library, and recommended in a letter to Albrecht von Haller that they should be included in his great work on the history of anatomy, *Bibliotheca anatomica*. Hunter seems to have been the first person to appreciate fully the content and significance of the drawings since Leonardo's death two and a half centuries before, and in one of his lectures he noted that Leonardo's drawings enabled him:

to carry the history of the improvement of Anatomy farther back than has been generally done by our own writers; and to introduce into the annals of our art, a genius of the first rate, Leonardo da Vinci, who has been overlooked, because he was of another profession, and because he published nothing upon the subject. I believe he was, by far, the best Anatomist and physiologist of his time . . . and Leonardo was certainly the first man we know of who introduced the practice of making anatomical drawings . . .

Those very drawings and the writing, are happily found to be preserved in his Majesty's great collection of original drawings. Mr Dalton, the King's librarian, informed me of this, and at my request procured me the honor of leave to examine them . . .

In due time, as I doubt not of being honoured with the permission of the King, who loves and encourages all the arts, I hope to engrave and publish the principal of Leonardo's anatomical designs. They will be a curious and valuable acquisition to the history of Anatomy.

[Two Introductory Lectures, Delivered by Dr William Hunter, to his Last Course of Anatomical Lectures, at his Theatre in Windmill-Street, London 1784, pp. 37–9]

Hunter died in 1783, before he could carry out his plan; but in 1796 John Chamberlaine published his *Imitations of Original Designs by Leonardo da Vinci*, including good etchings by Francesco Bartolozzi of fols. 4v, 13r and 14v, with

the notes on the first two transcribed and reliably translated; subsequent editions added etchings of fols. 13v and 14r. For the first time the beauty and accuracy of Leonardo's anatomical drawings could be witnessed by a wider public. The following year the artist James Barry attempted to persuade the Committee of the Royal Academy to revive Hunter's intentions. This initiative came to nothing, and a detailed understanding of Leonardo's anatomical work had to wait another century.

Many passages from Leonardo's anatomical notes feature in J.-P. Richter's *Literary Works of Leonardo da Vinci* of 1883, which (with later editions) remains the best general compendium of Leonardo's writings; but Richter's work was sparsely illustrated, and few of Leonardo's anatomical notes can be appreciated without the related drawings. Finally, in 1898 the whole of the Anatomical Manuscript A was published, with all the notes transcribed by Giovanni Piumati, in *I manoscritti di Leonardo da Vinci della Reale Biblioteca di Windsor. Dell'anatomia: Fogli A*. Facsimile publications of Leonardo's other anatomical drawings followed, and since then, scholars (including many anatomists and physicians specialising in particular aspects of the body) have attempted to come to terms with the legacy of Leonardo's anatomical researches. Particular mention should be made of C. D. O'Malley and J. B. Saunders's *Leonardo da Vinci on the Human Body*, first published in 1952 and still in print—reproducing 215 of Leonardo's anatomical drawings and translating most of the notes, this remains the most widely available edition of his anatomical work. More comprehensive still was Kenneth Keele and Carlo Pedretti's *Leonardo da Vinci. Corpus of the Anatomical Studies in the Collection of Her Majesty The Queen at Windsor Castle* (two volumes plus facsimiles, 1979–80), but this is available only in specialist libraries.

Most of these publications have translated Leonardo's notes alongside the reproductions of the drawings. The reader must work hard to retain a sense of the interrelationship of text and image, and the essential unity of Leonardo's thought is frequently lost. In this book we have attempted to remedy this, after a faithful reproduction of the drawing, by replacing Leonardo's blocks of text with translations of those notes, 'dropped in' to the page. By this method it is hoped that the lay reader will be able more readily to follow the progress of Leonardo's anatomical understanding as it evolved on the pages of the Anatomical Manuscript A, five hundred years ago.

NOTES ON THE TRANSLATIONS

The meticulous transcription and translation of Leonardo's notes in Keele and Pedretti's facsimile edition of 1979–80 is unavoidably the basis of the translation given here. Leonardo's writing style varies from the spare and unadorned—which can usually be translated in only one way—to the convoluted, either when he is struggling with a complicated situation, when the necessary vocabulary for a structure is lacking, or occasionally when he allows himself to compose a more self-consciously 'literary' passage. In these cases, Keele and Pedretti's unravelling of Leonardo's opacities usually cannot be bettered. But there is a degree of personal 'style' in translation, and the versions given

here frequently differ—rarely so much as to alter Leonardo’s meaning, but often affecting the formality of his expression, or the degree to which he was struggling with anatomical vocabulary.

Leonardo’s notes—written from right to left in perfect mirror image—tend to run on with minimal punctuation, and it can sometimes be difficult to follow his arguments. I have tried to break up these passages for ease of reading, but the translations do then lose something of the inexorable force of Leonardo’s reasoning. And there are decisions to be made about how to translate certain key words in Leonardo’s notes. *Notomia* means ‘anatomy’ in general terms, but it is sometimes better translated as ‘dissection’ (e.g. ‘io ne feci notomia’, literally ‘I made an anatomy of him’, but more felicitously ‘I dissected him’); and when Leonardo states ‘this winter of 1510 I believe I shall finish all this anatomy’ (fol. 17r) or ‘begin the anatomy at the head and finish it at the soles of the feet’ (fol. 3r), he should be taken to mean ‘the treatise on anatomy’.

Leonardo often begins a note on how to depict a structure with the word *farai*, literally ‘you will make’, but better understood in the imperative; and by ‘make’ he means ‘draw’. The next element is frequently *una dimostratione*—literally ‘a demonstration’, by which Leonardo means a didactic drawing (he rarely uses the words *disegno*, *disegnare* etc.), and I have used the term ‘diagram’ here without intending this to convey the idea of something excessively schematic or reduced to components. *Dimostrare* has however been retained as ‘to demonstrate’, meaning ‘to show to the reader’. A closely related term, used less often, is *una figuratione*, which I have rendered as ‘a depiction’ (and likewise *figurare*, ‘to depict’); *la figura* is the shape or form, usually of a bone. When intending to use words rather than images Leonardo often begins *scrivi . . .*, literally ‘write [on] . . .’, but rendered here as ‘describe . . .’.

Leonardo was aware that nerves are involved in both sensation and muscle control, but the latter function caused him some confusion, and he often used the word *nervi* indiscriminately for both nerves and tendons (which connect muscle to bone). The word has been translated here according to the context. *Corde*, on the other hand, are always tendons in the Manuscript.

Most of the larger superficial structures of the body had, of course, terms in common daily use. Leonardo adopted some technical terms from anatomical and medical textbooks, derived either from Greek (*basilica*, *diaframma*, *mesopleuri*, *trachea*) or Arabic (*alchatin*, *meri*, *nucha*) via Latin translations, and used descriptive terms for the shapes of bones (*ale*, *briglia*, *rosto*, *scuto*, *sprone*) and muscles (*pesce*, *lacerto*; see fol. 15r). But there was no vocabulary for the smaller bones and most of the muscles, nerves and vessels, and Leonardo thus used key letters when annotating his diagrams.

The following is a complete glossary of the anatomical terms used by Leonardo in the Anatomical Manuscript A. His spelling is regularised, for example removing the frequent double consonants, and the redundant ‘h’ after a hard ‘c’ (except in the case of words derived from Arabic).

GLOSSARY OF ANATOMICAL TERMS IN THE ANATOMICAL MANUSCRIPT A

- aiutorio* — ‘assistant’ — humerus
alchatin — pelvis
ale — ‘wings’ — transverse processes of the vertebrae
anca — iliac crest
arteria — artery
basilare, osso — trapezium bone of the hand; cuboid bone of the foot
basilica — basilic vein
bocca — mouth, but also any opening (e.g. of the larynx)
braccio — arm (and also a unit of measurement, around 60 cm but varying from city to city)
briglia della lingua — ‘bridle of the tongue’ — frenum
calcagno — heel
cartilagine — cartilage
codrione or *osso della coda* — coccyx
collo — neck
colon — colon
corda — tendon (cf. *nervo*)
coscia — thigh, upper leg (cf. *gamba*)
costa — rib
diaframma — diaphragm
dimestico — the medial, inner, smooth, ‘domesticated’ side of a limb (cf. *silvestro*)
dito — finger
dito del piede — toe
dito grosso del piede — big toe
dito massimo — thumb
dito medio — middle finger
dorso — back of the hand, upper surface of the foot
fecce — faeces
focile — literally the striking-steele for a flint (another term for which is *acciauolo*, as written by Leonardo at the top of fol. 9r) — any of the long bones, usually the ulna, tibia (*focili maggiori*), radius and fibula (*focili minori*), but occasionally the humerus or femur
forcula, forcola (sometimes *forcula del pecto*) — clavicle
foro — hole, foramen
gamba — leg, often specifically the lower leg (cf. *coscia* for the upper leg)
gengie — gums
gibbosita — gibbosity, tubercle (see also *gobbo*)
glandula — usually gland, but can be any small bulbous structure (cf. *osso glanduloso*)
gobbo — lump, bump, hump
gomito — elbow
guancia — cheek
indice — index finger
intestine — intestines, but more generally the passages of the body, including the blood vessels
labri — lips, and also the edges of the socket of a joint
lacerto — ‘lizard’ — a long thin muscle, especially sartorius
legatura — ligament
lingua — tongue
linguella — ‘little tongue’ — epiglottis
mano — hand
mascella — jaw
mascellare — molar
membro — limb, or in general any distinct part
meri — oesophagus
mesopleuri — intercostal muscles
monocolo — caecum
muscolo — muscle
nari — nostrils (of a horse)
natiche — buttocks
nervo — nerve or tendon (cf. *corda*)
nucha — spinal cord
omero — from the Latin (h)umerus, shoulder, which was subsequently applied (rather misleadingly) to the bone of the upper arm; Leonardo uses the word to refer both to the acromion and to the portion of the trapezius muscle that inserts on the acromion (cf. *spalla*); the humerus he usually calls *aiutorio*
omero — humour (mucus etc.)
osso — bone
osso glanduloso, osso petroso — sesamoid bone
padella — ‘frying pan’ — scapula or patella
paletta della spatola — body (‘blade’) of the scapula, excluding the acromion and coracoid process
palma della mano — palm of the hand
panicolo — membrane, connective tissue
patella — patella (see also *padella, rutola*)
pesce — ‘fish’-shaped muscle, with two heads of origin, e.g. biceps brachii, rectus femoris
pettine — ‘comb’ — the metacarpals and phalanges together (cf. *rasetta*)
petto, pecto — chest, and by extension, other prominences, e.g. *petto del piede*, ball of the foot
piede — foot
polise — thumb (cf. *dito massimo*)
polmone (in the singular) — lungs
polo — ‘pole’ or fulcrum, and thus any axial joint, such as the transverse axis of the ankle
polpa della gamba — calf
polso — wrist
polso delli piedi — ankle
poppa /o — breast
pugno — fist
rasetta — ‘little ray’ — wrist (-bones) (cf. *pettine*)
reni — kidneys, but also the lower part of the back (cf. *schiena*)
rosto della spatola — ‘beak of the scapula’ — coracoid process
rutola — ‘little wheel’ — patella
scia — hip joint, eminence of the greater trochanter at the top of the thigh
schiena — back, often specifically the upper back (cf. *reni*)
scuto — ‘shield’ — acromion
sella — ‘saddle’ — axilla, armpit
silvestro — the lateral, outer, hairy, ‘wild’ side of a limb (cf. *dimestico*)
spalla — shoulder, but also the deltoid muscle (cf. *omero*)
spatola — scapula (cf. *padella*)
spondile — vertebra, but also any knobbly protuberance or process, such as the lesser trochanter
sprone — ‘spur’ — spinous process
testa — head
torace — the front part of the ribcage, and specifically the sternum
trachea — trachea
tramezzo — ‘partition’ — palate
uvola — uvula
vena — vein
ventriculo — ventricle



It is observed that the muscles of the back and shoulder are connected to the arm and hand. The muscles of the back are the trapezius, latissimus dorsi, and rhomboids. The muscles of the shoulder are the deltoids, pectorals, and serratus anterior. The muscles of the arm are the biceps, triceps, and forearm muscles. The muscles of the hand are the intrinsic muscles of the hand. The drawing shows the relationship between these muscles and the bones of the skeleton.

THE ANATOMICAL MANUSCRIPT A

Martin Clayton and Ron Philo



THE BONES OF THE FOOT, AND THE SUPERFICIAL ANATOMY OF THE SHOULDER

FOL. 1R

Most of the page concentrates on the sesamoid bones of the foot. Sesamoid bones are found within the tendons of several muscles where those tendons pass over a joint, and serve both to protect the tendon and to increase its effectiveness by holding it further away from the joint—the patella or knee-cap is the most familiar example, and is described as a sesamoid bone by Leonardo on fol. 12r. Our term derives from their passing resemblance to sesame seeds, but Leonardo called them *ossi glandulosi* or just *glandule*, from their ‘glandular’ (i.e. bulbous) form, or *ossi petrosi*, ‘stony bones’ (fol. 7v).

The two sesamoid bones of the foot are found in the tendons of the two heads of the flexor muscle of the big toe (*flexor hallucis brevis*), as shown in the diagrams at centre and below (inexplicably upside-down in relation to the remainder of the sheet). In the notes at lower centre and lower left Leonardo discusses the mechanical function of sesamoid bones in general terms, stating that the further a given force (or tendon) is from the axis (or joint) it acts around, the greater will be its effectiveness (in physical terms, its ‘moment arm’). At lower left Leonardo observes that the sesamoid bones of the foot also serve to protect the tendon, allowing it to move unimpeded by pressure from the weight of the body during walking. He thus understood perfectly both functions of the bones.

The drawing at the bottom of the sheet shows one of the sesamoid bones in place at n. The bones of the foot are well illustrated, though the groove within the neck of the talus (the bone of the foot that forms the lower part of the ankle joint) may be slightly exaggerated.

In the drawing at upper left, the distal phalanges—the last bones of the toes—are diverted to the side. The tarsal bones and their processes or projections are beautifully shown; the division between the talus and the bone in front of it, the navicular, is indistinct, but without careful observation these can appear fused into one bone. The ankle joint is again taken apart to show its articulation, with the processes known as malleoli (‘little hammers’) at the ends of the tibia and fibula forming a ‘mortice’ sitting squarely on the ‘tenon’ of the talus. But Leonardo has failed to differentiate sufficiently between the tibia and fibula: the drawings on fol. 9r give a much better impression of their relative sizes. The sustentaculum tali (the portion of the calcaneus or heel-bone that extends under the talus) is rather too small in the upper two drawings—the lateral view at the bottom of the sheet is more accurate in this respect.

Handwritten text in a cursive script, likely Latin or Greek, located on the left side of the page, adjacent to the first anatomical drawing.

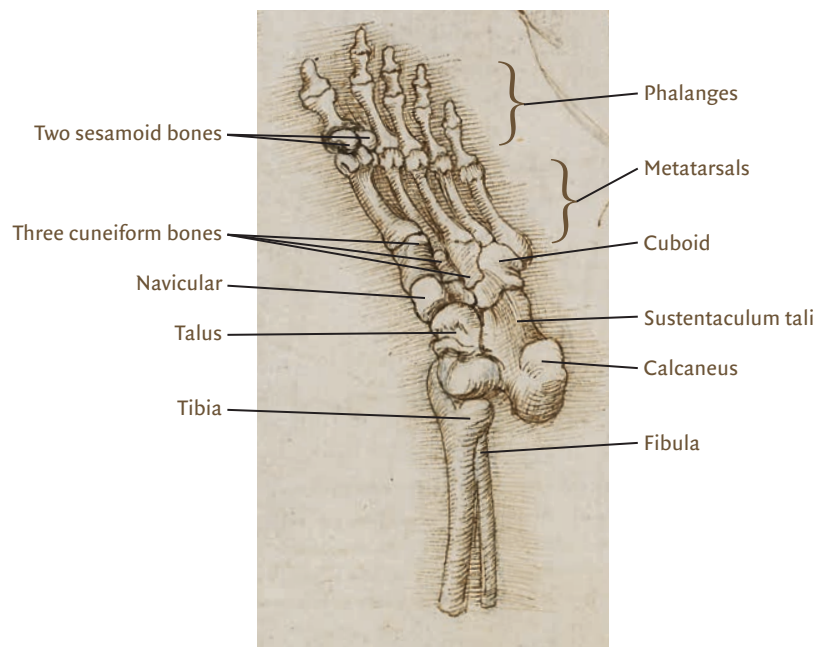


Second block of handwritten text, positioned between the first and second anatomical drawings.



Handwritten text at the bottom left of the page, below the fourth anatomical drawing.

Handwritten text at the bottom right of the page, below the fourth anatomical drawing.



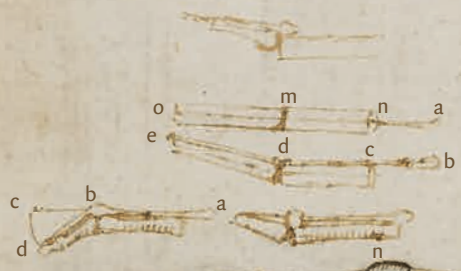
At the centre of the sheet (see key diagram) Leonardo correctly depicts the groove on the cuboid bone caused by the tendon of the peroneus (fibularis) longus muscle, but he also shows a deep groove in the back of the head of the talus. There is a long tendon nearby, that of the tibialis posterior muscle, but it does not indent the talus. If, however, one rotates the talus laterally about 90° out of normal position, it closely resembles the way Leonardo has drawn it. His notes frequently discuss the need to take apart and reassemble the bones diagrammatically, and the implication is that he frequently did this in reality with his prepared material; it is thus possible that here he mispositioned the talus on reassembling the foot.

The drawing at upper right is unrelated to the remainder of the sheet, being one of a sequence of similar studies on fols. 5v, 8r, 12v and 14r. In general the muscles are accurately displayed, and the proportions of the chest, back and arm have been manipulated in order to show more of the front and back than could be seen in a simple side view. Leonardo has portrayed a wide separation between the two heads of attachment of the sternocleidomastoid muscle (which as its name indicates originates on both the sternum and clavicle and ends at the mastoid process, the large bump behind the ear)—a recurring feature throughout the manuscript.

Draw these two feet with the same outlines turned to the same aspect, and do not care if one is the right and the other the left, because drawn thus they will be more intelligible

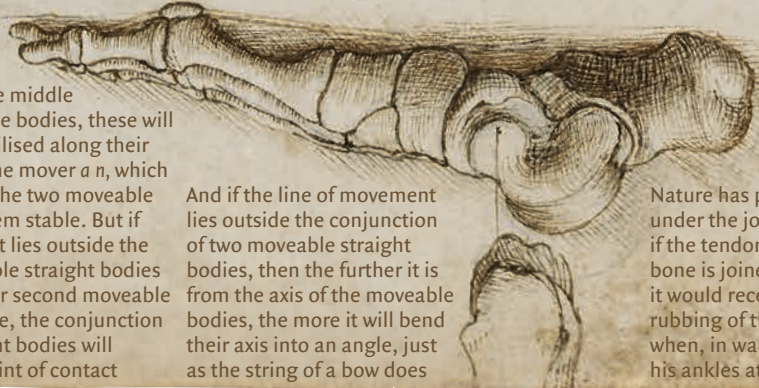


First draw all these bones separated from each other, placed such that each part of each bone faces or is turned towards the part from which it has been separated, and to which it will be rejoined when you rejoin all the bones of this foot together in its original state—and this diagram is made to know better the true shape of each bone by itself, and you will observe likewise in each diagram of each member to whatever aspect it is turned



When the line of power of movement passes through the middle of the conjunction of moveable bodies, these will not be moved but will be stabilised along their primary axis, as is shown by the mover *a n*, which passes through the centre of the two moveable bodies *n m*, and *m o* makes them stable. But if the line of power of movement lies outside the central line of the two moveable straight bodies then, as the head of the first or second moveable body is hemispherical in shape, the conjunction of the two moveable straight bodies will become angular at their point of contact

And if the line of movement lies outside the conjunction of two moveable straight bodies, then the further it is from the axis of the moveable bodies, the more it will bend their axis into an angle, just as the string of a bow does



Nature has placed the glandular bone under the joint of the big toe because if the tendon to which this glandular bone is joined were without this gland, it would receive great damage by the rubbing of the great weight of a man when, in walking, he raises himself on his ankles at each step

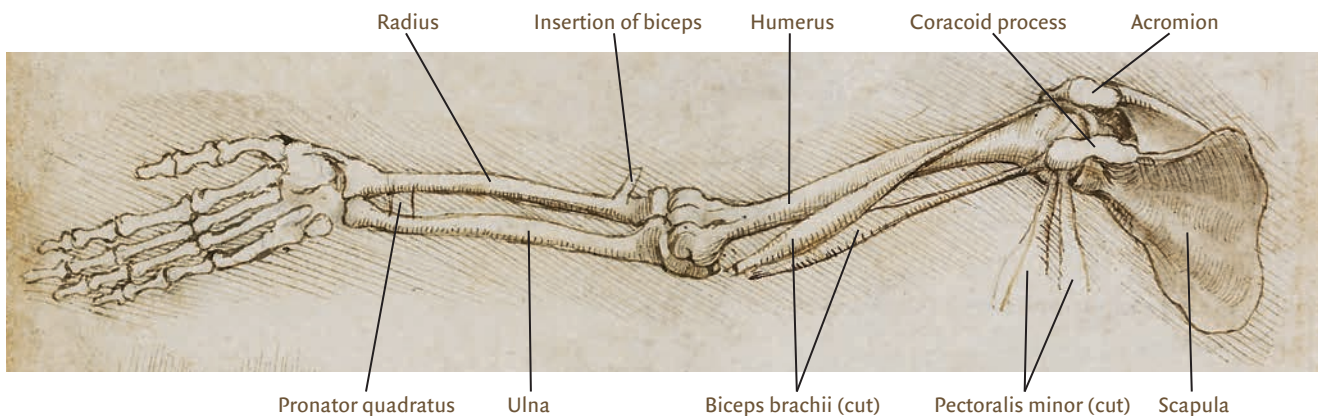
THE BONES AND MUSCLES OF THE ARM

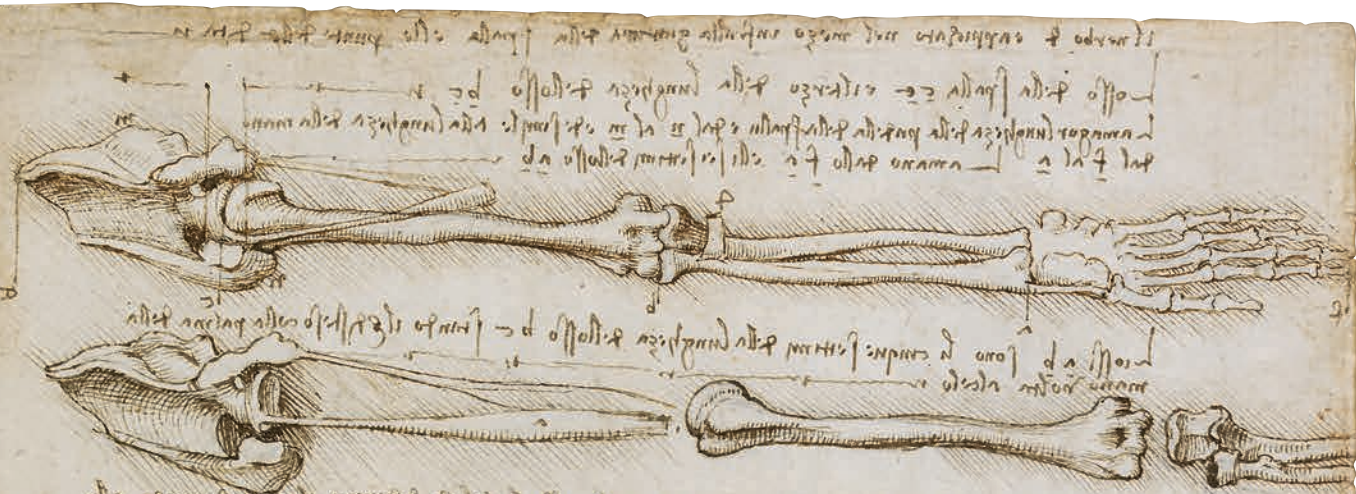
FOL. 1V

The page is primarily concerned with the mechanism by which the arm turns to direct the palm upwards (supination) or downwards (pronation).

The upper two drawings show the arm and shoulder from above, held directly away from the side of the body (abducted) with the palm facing upwards (supinated). In the first drawing the bones are in their natural positions, and in the second they are separated out to demonstrate their articulation. The biceps brachii muscle is beautifully illustrated, with its double origin (the name means ‘two heads of the arm’) on the scapula or shoulder-blade, and its insertion on the radius marked at *d*. Leonardo discovered that biceps has two actions, both bending the arm at the elbow and supinating the arm (turning the palm to face upwards). Indeed, while there are muscles whose sole purpose is supination, the biceps brachii is the strongest supinator of the forearm. It would be two centuries before Leonardo’s observation was repeated.

The third drawing (see key diagram) gives a front view of the arm, with biceps cut away from its insertion on the radius (marked as *a*) and thus out of position. Two slips of the pectoralis minor muscle also dangle from the coracoid process of the scapula. The small square marked between the ulna and radius near the wrist represents pronator quadratus (cf. fol. 10r, lower right), one of the two muscles primarily responsible for pronation (rotating the radius over the ulna to turn the palm downwards)—the position of the arm in the fourth and fifth drawings on the page. Leonardo concluded that





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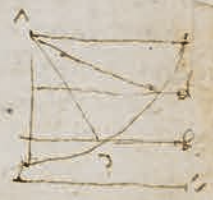


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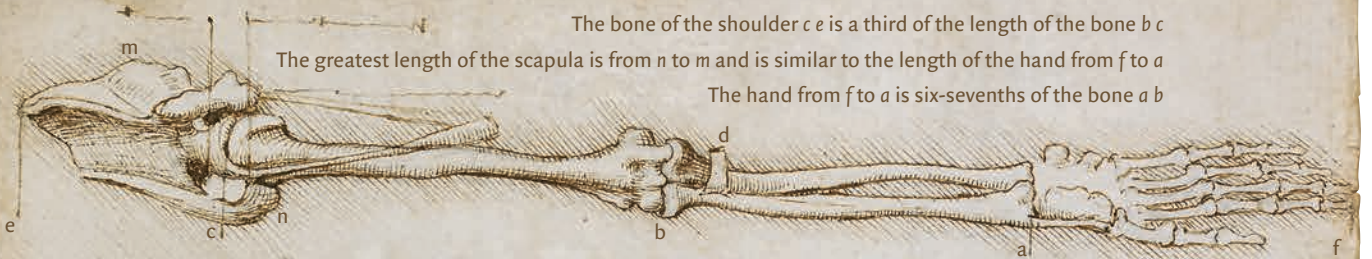


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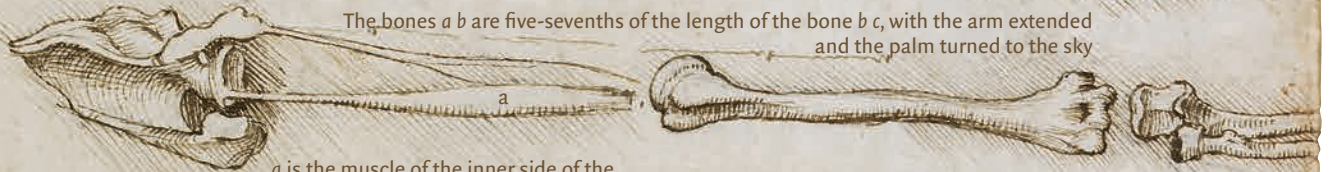
as the bones cross and thus become oblique during pronation, the forearm must shorten a little (as illustrated in the small geometrical diagram in the right margin), though this is difficult to observe in practice. The other primary muscle of pronation is pronator teres, which is seen on the forearm in the final drawing. Like biceps, pronator teres has two heads, on the humerus and the ulna, though the latter attachment is not clearly shown.

In his notes Leonardo discusses the need to saw the bones in cross-section and longitudinal section to observe the differences in cortical (dense) bone and trabecular (spongy) bone, though there are no surviving drawings that indicate that he carried out this task.

The tendon *d* is attached midway between the joint of the shoulder and the tips of the fingers
 The bone of the shoulder *c e* is a third of the length of the bone *b c*
 The greatest length of the scapula is from *n* to *m* and is similar to the length of the hand from *f* to *a*
 The hand from *f* to *a* is six-sevenths of the bone *a b*



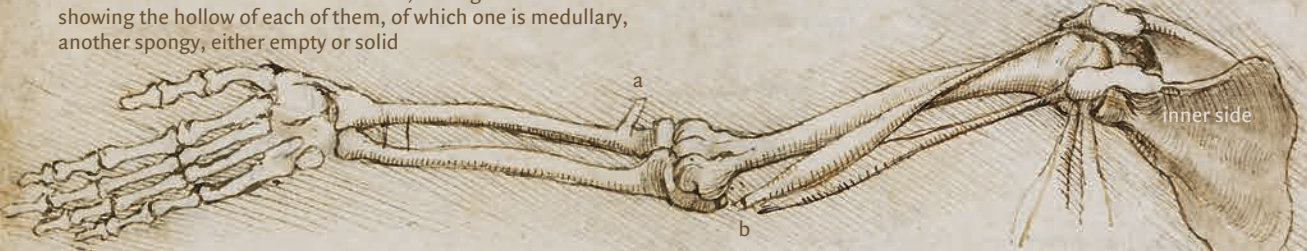
The bones *a b* are five-sevenths of the length of the bone *b c*, with the arm extended and the palm turned to the sky



a is the muscle of the inner side of the arm, which is attached to the scapula

First draw these bones sawn along their length and then transversely, so that one may see where the bones are thick or thin; then depict them united and separated, as above, but in four aspects so that one may understand their true shape; then clothe them step by step with their nerves, veins and muscles

True knowledge of the shape of any body consists of seeing it from different aspects; therefore, to give knowledge of the true shape of any member of man, first beast among animals, I will observe the aforesaid rule, drawing for each member four diagrams from four sides. And of the bones I will make five, sawing them in half and showing the hollow of each of them, of which one is medullary, another spongy, either empty or solid

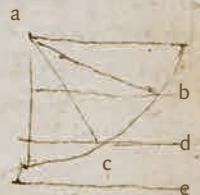


a, nerve or rather tendon, is joined to *b*, muscle

First draw this diagram with the clavicle, and then draw it again alongside without the clavicle, that is, like this



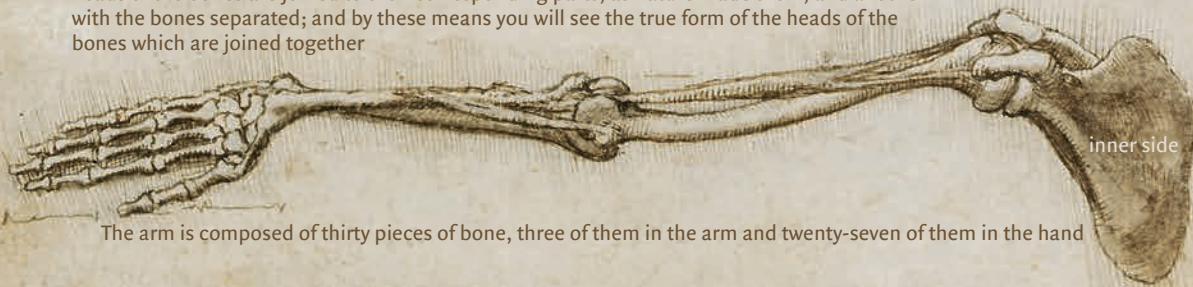
The arm, which has two bones between the hand and the elbow, will be somewhat shorter when the palm faces the ground than when it faces the sky, with the man standing and his arm extended. And this happens because these two bones, in turning the hand towards the ground, come to be crossed in such a way that the bone that arises on the right part of the elbow goes to the left part of the palm, and the bone that arises on the left part of the elbow ends on the right part of the palm



The bone *a b* makes exactly half a turn when the palm, which was turned towards the sky, is turned towards the ground

A line loses depth when it is placed in a position of greater obliqueness

Draw each of these four diagrams duplicated, such that you draw one of each sort in which the heads of the bones are joined to their corresponding parts, as nature made them, and another with the bones separated; and by these means you will see the true form of the heads of the bones which are joined together



The arm is composed of thirty pieces of bone, three of them in the arm and twenty-seven of them in the hand

The usual position of the palm is to be turned towards the horizon, and the usual extremes are to be turned towards the sky or towards the ground, that is, towards the head or towards the feet of whoever bears it

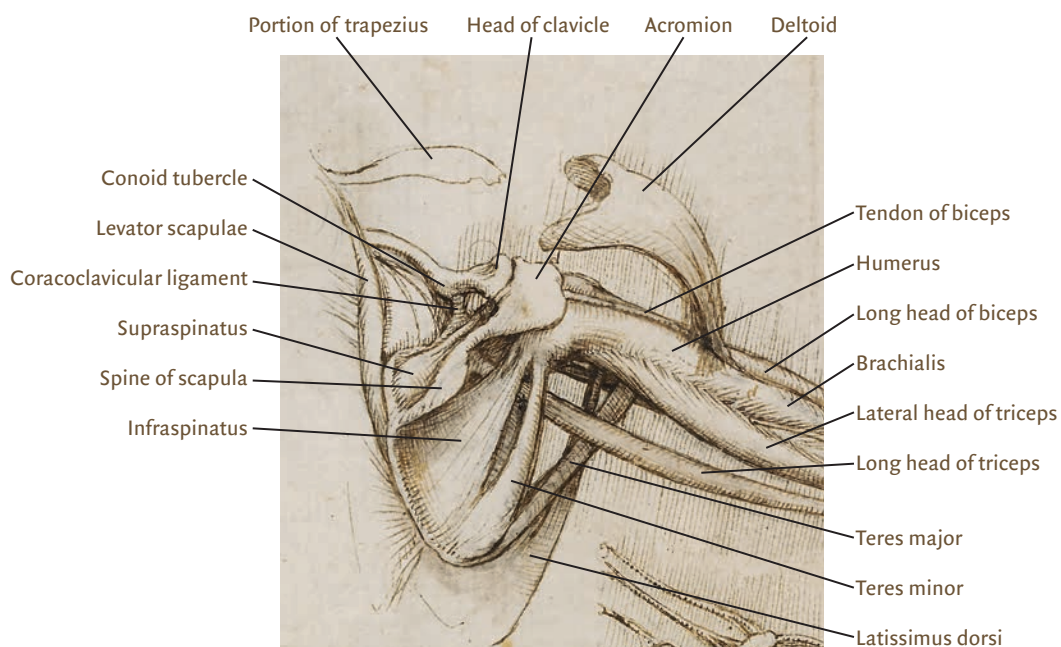
THE BONES AND MUSCLES OF THE SHOULDER

FOL. 2R

Most of the page is concerned with the complex of muscles around the shoulder joint. The largest drawing, at upper centre, is a view from above and behind (see key diagram). Two muscles are shown lifted away: the deltoid (labelled *spalla*, 'shoulder'), detached from its origins on the posterior border of the spine of the scapula (a) and the acromion (b, the process of the scapula that articulates with the clavicle to form the summit of the shoulder); and a portion of the trapezius (labelled *omero*, a name that has changed its meaning and is now applied to the humerus), also detached from an attachment on the acromion (n). To the left, the levator scapulae muscle is shown, passing from its attachment along the superior angle of the scapula upwards towards the cervical vertebrae, and the tendon of the long head of biceps brachii can be seen within a groove on the upper surface of the humerus.

Leonardo understood the structure that we refer to as the rotator cuff, the group of muscles and tendons that act to stabilise the shoulder during movement. Three of the muscles are depicted here—supraspinatus, infraspinatus and teres minor—and in the notes he alludes to their fused attachments that 'clothe' the head of the humerus. Leonardo has also depicted teres major and latissimus dorsi, brachialis at r h, and the long head of triceps brachii passing along the underside of the arm (though he seems to show it attached to the spine of the scapula, rather than to its lateral edge).

Leonardo's anatomical acuity is demonstrated by his illustration of part of the coracoclavicular ligament, just next to the conoid tubercle of the

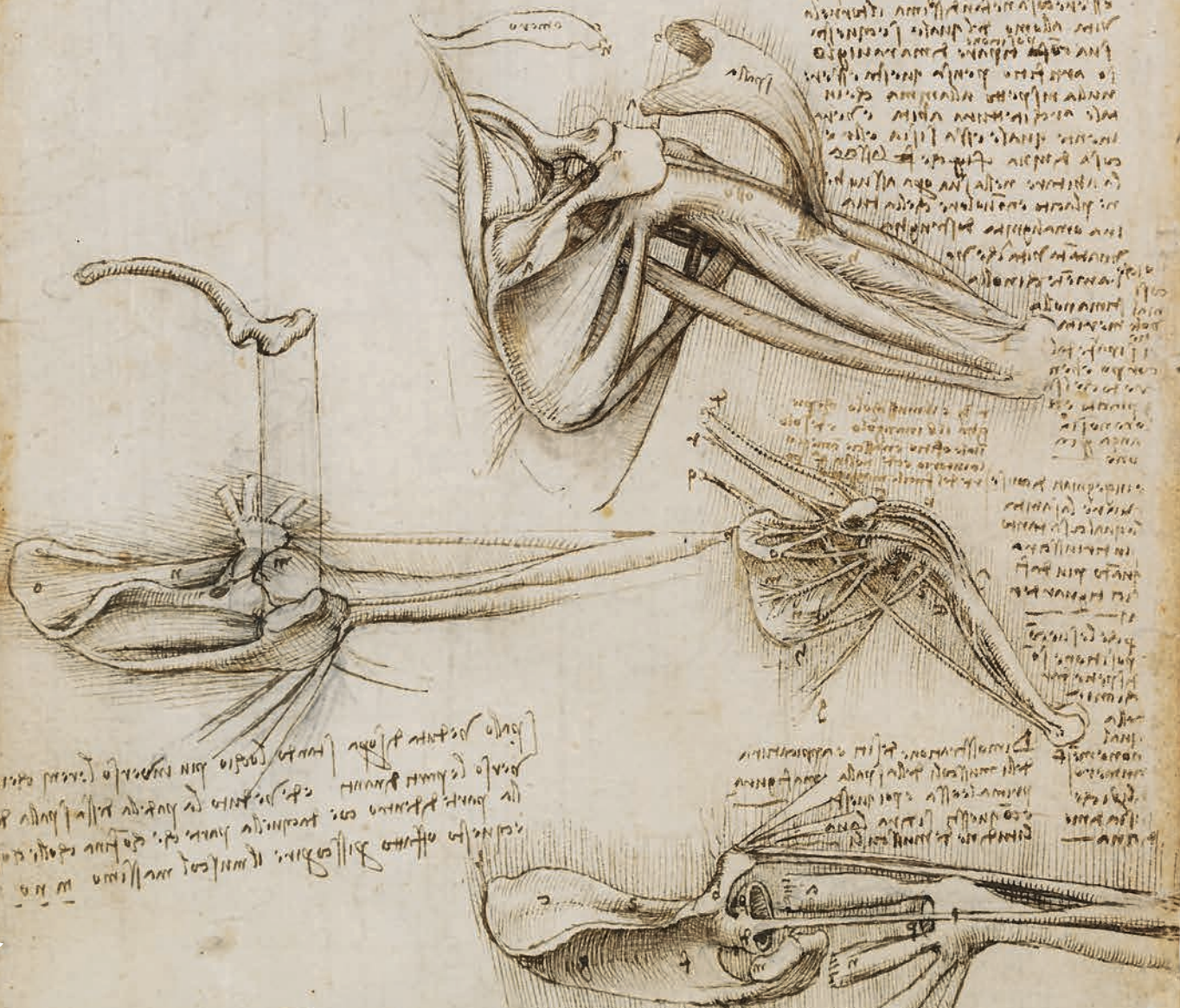


Handwritten text in Hebrew script, located at the top left of the page. It appears to be a preface or introductory text, possibly describing the purpose of the anatomical study or the author's background.

Handwritten text in Hebrew script, located below the first paragraph. It continues the introductory text or provides specific details about the anatomical structures shown.



Handwritten text in Hebrew script, located to the right of the central anatomical drawing. It provides a detailed description of the structures shown in the drawing, likely identifying muscles, bones, and ligaments.



Handwritten text in Hebrew script, located to the left of the lower part of the anatomical drawing. It likely describes the specific muscles or structures shown in that area of the drawing.

Handwritten text in Hebrew script, located to the right of the lower part of the anatomical drawing. It continues the descriptive text, providing further details about the anatomy shown.

Handwritten text in Hebrew script, located at the bottom left of the page. It appears to be a concluding text or a summary of the anatomical study.

Handwritten text in Hebrew script, located at the bottom right of the page. It may be a signature, a date, or additional notes related to the work.

clavicle. But it is odd that, as throughout the manuscript, he shows a narrowing of the clavicle beyond the conoid tubercle, and a strange articulation between the clavicle and the acromion, with the entire curved end of the clavicle as a 'ball' fitting into an extensive shallow 'socket' on the acromion. This is quite incorrect. Leonardo may have inferred this arrangement during the course of a dissection, during which the ligaments of the acromioclavicular joint would have obscured the actual articulation, rather than from the study of prepared bone.

In the drawing at centre left, although ostensibly a view from directly above, Leonardo turns the scapula forward so that the subscapularis muscle (*o n m*) can be seen, passing beneath the coracoid process to contribute to the rotator cuff on the head of the humerus. The tip of the coracoid process appears spatulate (flattened) with one muscle—the short head of biceps—and four tabs radiating from its anterior aspect: the tab to the right is probably coracobrachialis, the other three probably pectoralis minor. The two heads of biceps meet in a long 'v' with the apex towards the elbow.

The drawing at lower right shows the structure from the same angle, now separating the 'ball' of the head of the humerus (*p*) from the 'socket' of the glenoid fossa (*o d*) to clarify the form of the coracoid process (*b*) and acromion (*m*). The depth of the socket at the glenoid, deepened by the cartilaginous labrum and capsule, indicates that this is a dissectional view. The two heads of biceps are seen, the long head originating on the superior aspect of the glenoid fossa at *d*, the short head along with coracobrachialis on the coracoid process (from which tabs representing pectoralis minor are again shown). The four tabs on the head of the humerus represent the muscles of the rotator cuff—subscapularis (*a*), supraspinatus (*n*), and below, infraspinatus and teres minor.

At centre right is one of Leonardo's 'thread diagrams', in which he reduces muscles to cords along their central line of force so as to depict a complex three-dimensional muscular structure in a single drawing—virtually all the muscles discussed above can be identified in this diagram.

The minor sketches at upper right are concerned with the proportions of the foot during the actions of raising the foot (dorsiflexion) and pointing it downwards (plantarflexion). Leonardo identifies the position of the transverse axis (*polo*) of the ankle at *a*, and states that point *o*, the tip of the lateral malleolus of the fibula, moves away from the tip of the toes on dorsiflexion.

Which are the members of man that in their bending grow or diminish; and which are those that grow in one part and diminish in another; and which are those that diminish in one part and grow in another?

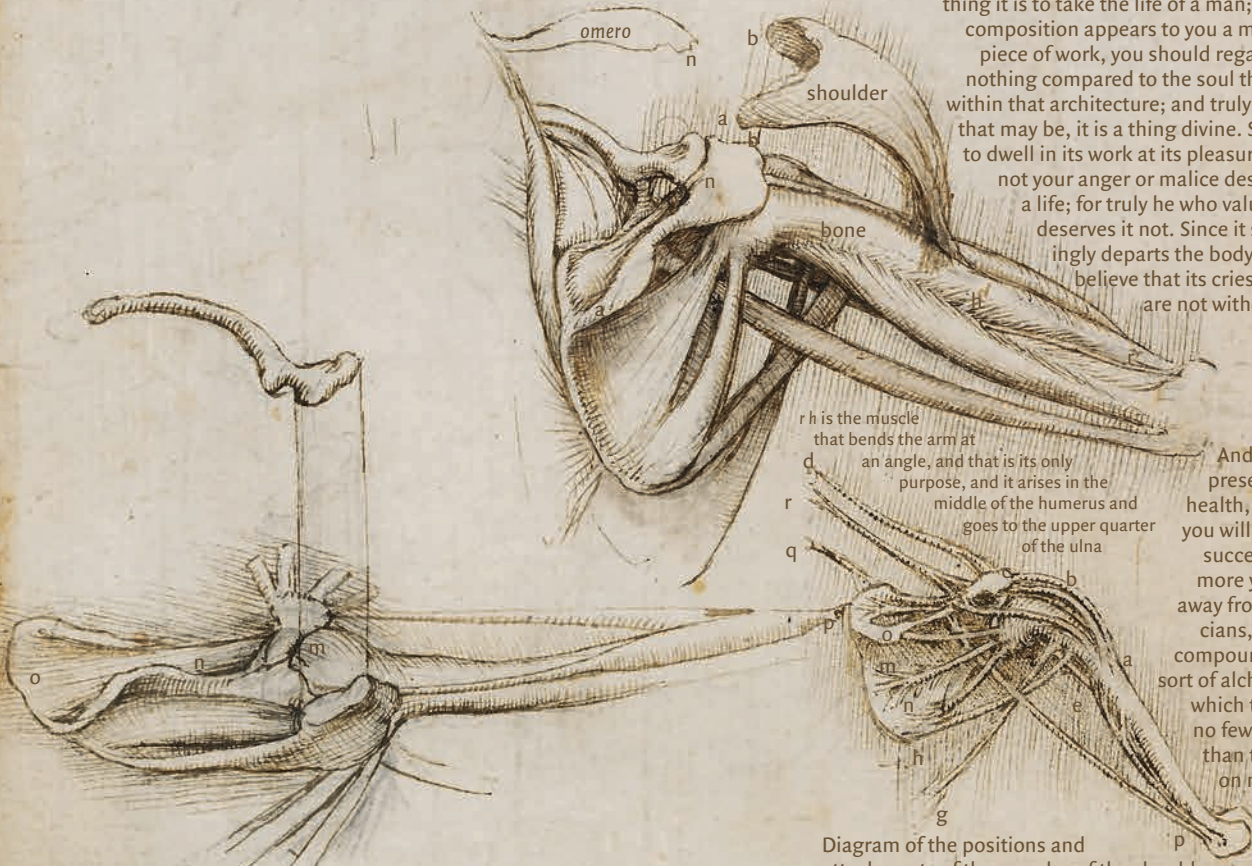
When *m* gets nearer to *f*, the axis of the foot *a* keeps still, and *o* gets further away from *f*

The feelings that use force must be made more evident in their muscles than those that do not use these forces



And you, man, who witnesses in this labour of mine the marvellous works of nature, if you would judge it to be a wicked thing to destroy it, well think what a very wicked thing it is to take the life of a man; if this his composition appears to you a marvellous piece of work, you should regard this as nothing compared to the soul that dwells within that architecture; and truly whatever that may be, it is a thing divine. So leave it to dwell in its work at its pleasure, and let not your anger or malice destroy such a life; for truly he who values it not, deserves it not. Since it so unwillingly departs the body, I indeed believe that its cries and pain are not without cause

And strive to preserve your health, in which you will be more successful the more you keep away from physicians, for their compounds are a sort of alchemy, on which there are no fewer books than there are on medicine



r h is the muscle that bends the arm at an angle, and that is its only purpose, and it arises in the middle of the humerus and goes to the upper quarter of the ulna

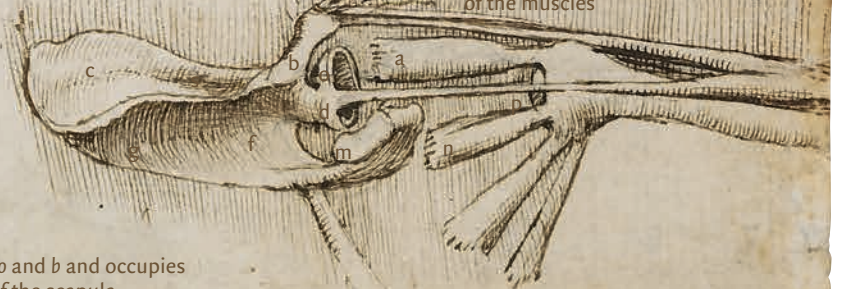
Diagram of the positions and attachments of the muscles of the shoulder; but first draw the bones and then these and with these will be discussed the strength of the muscles

The shoulder seen from above, the eye being more towards the back than towards the front, and showing the inner part the scapula, that is, that part that is in contact with the ribs, and this is done so as to display the largest muscle *m n o*

a, the largest muscle of the shoulder, passes between *o* and *b* and occupies the whole space *s c*, being attached only at the edges of the scapula
The muscle *n* passes between *d* and *m* and occupies the space *f g*, being fixed by its ends to the edges of the space that receives it

The aforementioned muscles are not fixed except at the edges of their receptacles and at the ends of their tendons, and this the master has done so that those muscles are free and readily able to thicken and shorten, and grow thin and elongate, according to the need of the part moved by them

Draw the scapula denuded of its muscles and then clothed, showing naked the head of the humerus, which must be clothed in its turn by those same muscles of the scapula; then show the head of the humerus



THE SUPERFICIAL ANATOMY
OF THE SHOULDER AND NECK
FOL. 2V

This series of surface anatomy drawings, with one dissected view, was in keeping with Leonardo's intention to show the body in action from multiple viewpoints. They run as a sequence from upper right, turning the body slowly in space to end with a frontal view at the bottom of the sheet. One must usually be wary of reading Leonardo's anatomical drawings as simple depictions of what he had in front of him, but here the sensitivity of surface modelling strongly suggests that the drawings were made from the life, with a lean old man as the subject. Nonetheless the realism with which the drawing at lower centre strips the skin from the superficial view to its left emphasises Leonardo's powers of visualisation, and should caution against too literal a reading of any of his anatomical drawings.

There are some erroneous details, which may be due to the absence of a dissection in this case. There is the usual large gap between the heads of attachment of sternocleidomastoid (see fol. 1r), and an extraneous muscle can be seen coursing obliquely to sternocleidomastoid, across the posterior triangle of the neck to travel deep to the anterior border of trapezius. The course of this muscle is similar to that of omohyoid, but that muscle is also present, running under sternocleidomastoid in the drawing at centre right.

Another oddity, throughout the page, is the division of the pectoralis major muscle (running from the chest across to the humerus) into a series of separate fascicles, and the diminution of the clavicular head of that muscle. While it is not unusual to see a difference in the clavicular, sternal and costal portions of pectoralis major, this degree of fasciculation is highly unusual. Dissection of unembalmed tissue may lead to the accidental separation of a muscle into multiple strands, whereas fixation hardens the muscle fibres and accentuates the fasciae that separate the individual muscles. Leonardo was of the opinion that, with enlargement, muscles could fuse, and with atrophy they could separate; and indeed, in the extremely lean individuals that Leonardo liked to draw, muscles can appear fasciculated due to loss of muscle mass. But he divided the muscle primarily for didactic purposes, to emphasise its different portions and wide range of attachment, as a compromise between a 'realistic' depiction and the diagrammatic convention of his 'thread drawings'. Thus Leonardo could show clearly, for example, that the clavicular portion of pectoralis major inserts further down the humerus than the sternal and costal portions. Between the fenestrations in pectoralis major one may glimpse the neurovascular components of the brachial plexus, and pectoralis minor (labelled *m n*) running upwards from the third, fourth and fifth ribs to its attachment on the coracoid process of the scapula.



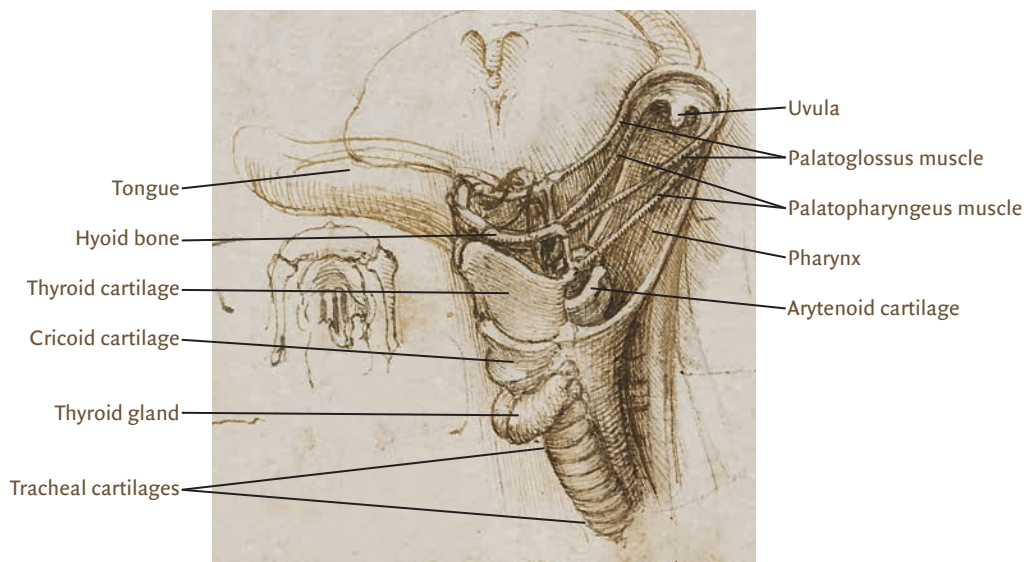
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THE THROAT, AND THE MUSCLES OF THE LEG

FOL. 3R

The inscription at the head of the page states that Leonardo intended to deal with the ramifications of the superficial veins. In fact no drawing on the page deals with that subject. The smaller note above is a glimpse of Leonardo's thoughts about the organisation of his material, expressing his intention to begin his book on anatomy (simply called *l'anatomia*) at the head and end it at the feet. The leg was presumably the first drawing to be made, but again none of the notes describes that drawing, and the remainder of the page is devoted to the throat, with studies of the pharynx, larynx and trachea and their functions in breathing, speaking and swallowing.

The large drawing at upper left displays many of the features seen in the subsequent, less extensive studies (see key diagram). The mouth and throat have many small arches, ridges and recesses, and dissection of any specimen can be confusing without an atlas or guidebook for reference. Leonardo, of course, had none. In addition, some of the structures shown here may have been based upon animal dissection, which would explain the odd form of the palatoglossus and palatopharyngeus muscles (the 'threads' attached to the posterior of the hyoid bone and thyroid cartilage and arching over the top of the uvula), and of the epiglottis and laryngeal vestibule. Leonardo has shown the uvula, the soft organ that dangles in the back of the mouth; the wishbone-shaped hyoid bone; the thyroid gland; and the thyroid, cricoid and tracheal cartilages. But his understanding of the function of these structures was merely speculative: the thyroid gland, for instance, is 'made to fill in where the muscles are missing, and . . . hold the trachea apart from the bone of the clavicle'.



Handwritten text at the top of the page, likely a title or introductory notes, written in a cursive script.

Handwritten text block on the upper left side, describing anatomical details.

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Handwritten text block on the upper right side, describing anatomical details.



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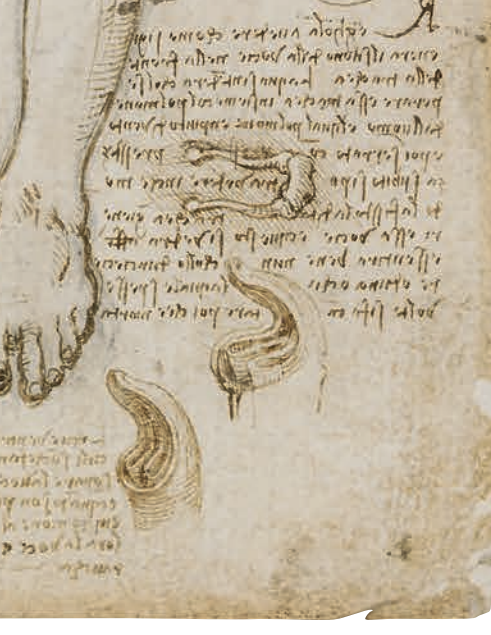
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Handwritten text block at the bottom left side, describing anatomical details.



Handwritten text block in the bottom middle section, describing anatomical details.



The three drawings at centre and centre left show the palatoglossus and palatopharyngeus muscles pulling the hyoid bone backwards in order to press the epiglottis over the opening of the larynx during swallowing, thus preventing food or drink entering the larynx. This is the reason that ‘one cannot swallow and breathe or speak at the same time.’

From here Leonardo moves to the three drawings at centre right. Of these, the upper drawing shows the structure at the same point of swallowing but from the opposite side; at the centre we see a lump of food (a) pushing the epiglottis (b) completely shut with swallowing; below, the cords are relaxed and the structure has returned to normal.

A similarly mechanical depiction of vocalisation is not easy. Leonardo noted correctly that ‘the voice is generated at the head of the trachea’ and that ‘the two ventricles are those that make the voice sound’. The drawing to the left of lower centre is a view down the larynx, showing part of the tongue, the hyoid bone, epiglottis and laryngeal vestibule. The diagram to the right of that is a coronal or frontal section through the larynx, indicating the conus elasticus slanting upwards to end in the vocal cords. The space between the vocal cords (rima glottidis, just above c) was referred to by Leonardo as a flute. He had studied vortices in wind and water, and he believed that turbulence in the expired air passing through the narrowed area of the glottis set up vibrations that produced the voice. This is substantially correct, with fine muscle movements adjusting the length and tension on the vocal cords to vary the air flow.

The diagram at lower centre also depicts the laryngeal ventricles or ‘sacculi’, which Leonardo believed caught particles that were accidentally inhaled, retaining them until coughing caused strong vortices in the ventricles to expel them. The structure of the larynx as represented here was to be revisited by Leonardo a couple of years later, when he analysed the passage of blood through the valves of the heart and inferred the purpose of the equivalent eddies of the blood in the sinuses of Valsalva.

It is a little surprising to find, in the note and slight sketch at top left, that Leonardo posited no role for the uvula in speech, but instead regarded it as ‘the dripstone from which falls the humour that descends from above, and falls by way of the oesophagus to the stomach’. This ancient physiology, in which the systems of the body were controlled by the movement and balance of the ‘humours’, sits uncomfortably alongside the wealth of acute anatomical and mechanical observations seen on the page.

Begin the anatomy at the head and finish it at the soles of the feet

Put in all the exits that the veins make in the flesh, and their ramifications between the flesh and the skin
And thus you will put in all the veins that come out between the flesh and the skin

The uvula is the dripstone from which falls the humour that descends from above, and falls by way of the oesophagus to the stomach; and it has no reason to go by way of the trachea to descend to the spiritual parts

Break the jaw from the side so that you see the uvula in its position, what its purpose is, and how close it is to the opening of the trachea

Which are the muscles that relax or contract in the movement of any limb in any movement?

One cannot swallow and breathe or speak at the same time. Nor can one breathe through the nose and through the mouth at the same time; and this is proved by trying to play a whistle or flute, one with the nose and one with the mouth at the same time

Why the voice becomes weak in the elderly
The voice becomes weak in the elderly because all the passages of the trachea are narrowed, in the same manner as the other entrails

Describe the cause of the voice without sound, as made by those who speak in the ear of someone else

When one swallows or gulps down a mouthful, one cannot breathe

Demonstrate which muscles are those that push the tongue right out of the mouth, and in what way



First draw each piece of the mechanisms that move, and define them separately, and then put them together bit by bit, so that with clear understanding the whole can be put together

These glands are made to fill in where the muscles are missing, and they hold the trachea apart from the bone of the clavicle

Draw this trachea and the oesophagus cut down the middle to show the shape of their cavities and further, show how the bridle of the tongue is situated in the tongue

Note at what point the nerves or cords a b c d arise from the basilar bone, and from which ventricle, and join them all together; and with great diligence demonstrate the mechanism of swallowing, and likewise of high and low voices

Describe what sound is, and what din is, tumult, noise etc

If you draw breath through the nose and want to send it out through the mouth, you will hear the sound made by the partition, that is the membrane in

a shows how a mouthful of food completely closes the little tongue b over the opening by which air enters the lungs



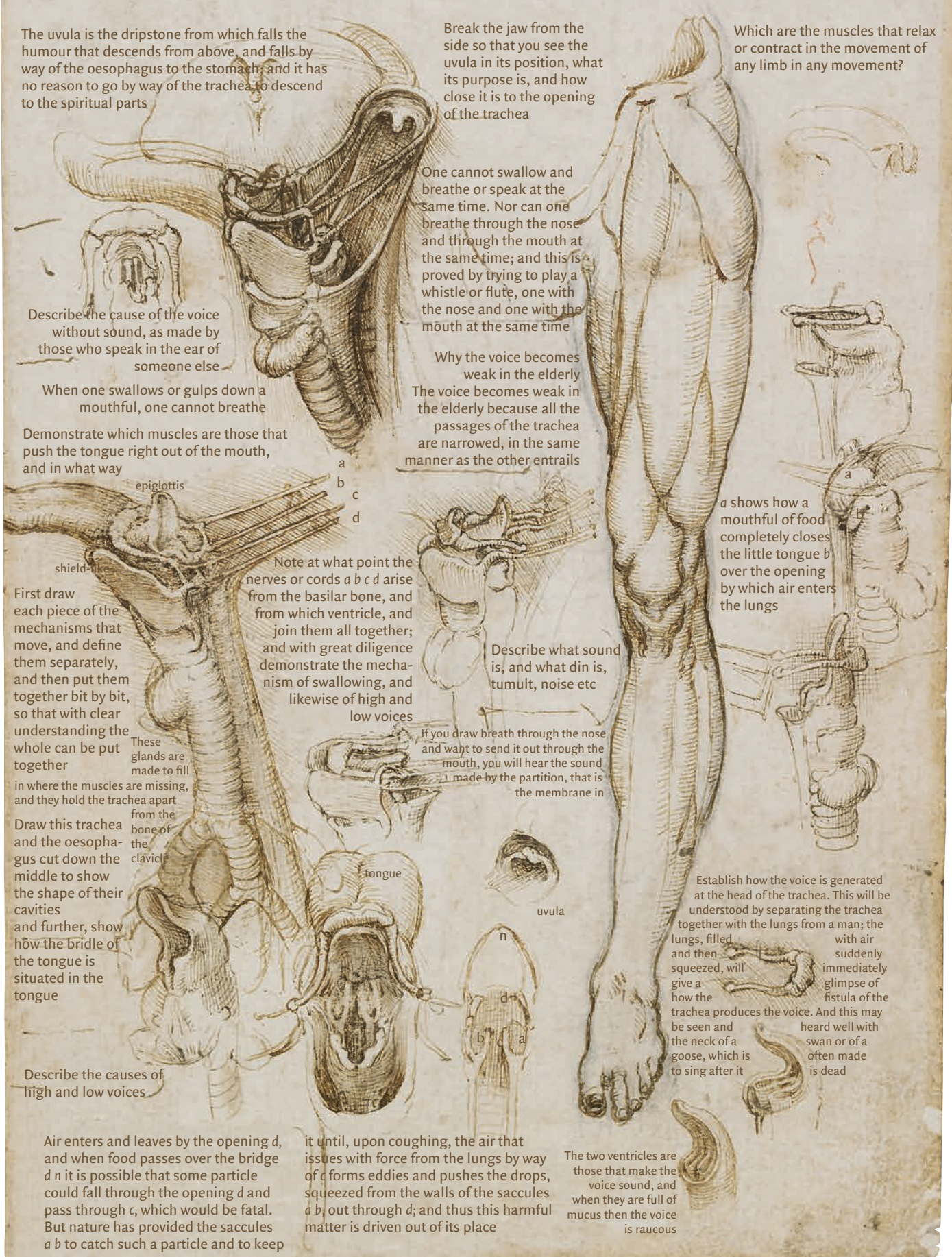
Establish how the voice is generated at the head of the trachea. This will be understood by separating the trachea together with the lungs from a man; the lungs, filled with air and then suddenly squeezed, will give a glimpse of how the trachea produces the voice. And this may be seen and heard well with the neck of a swan or of a goose, which is often made to sing after it is dead

Describe the causes of high and low voices

Air enters and leaves by the opening d, and when food passes over the bridge d n it is possible that some particle could fall through the opening d and pass through c, which would be fatal. But nature has provided the saccules a b to catch such a particle and to keep

it until, upon coughing, the air that issues with force from the lungs by way of c forms eddies and pushes the drops, squeezed from the walls of the saccules a b, out through d; and thus this harmful matter is driven out of its place

The two ventricles are those that make the voice sound, and when they are full of mucus then the voice is raucous



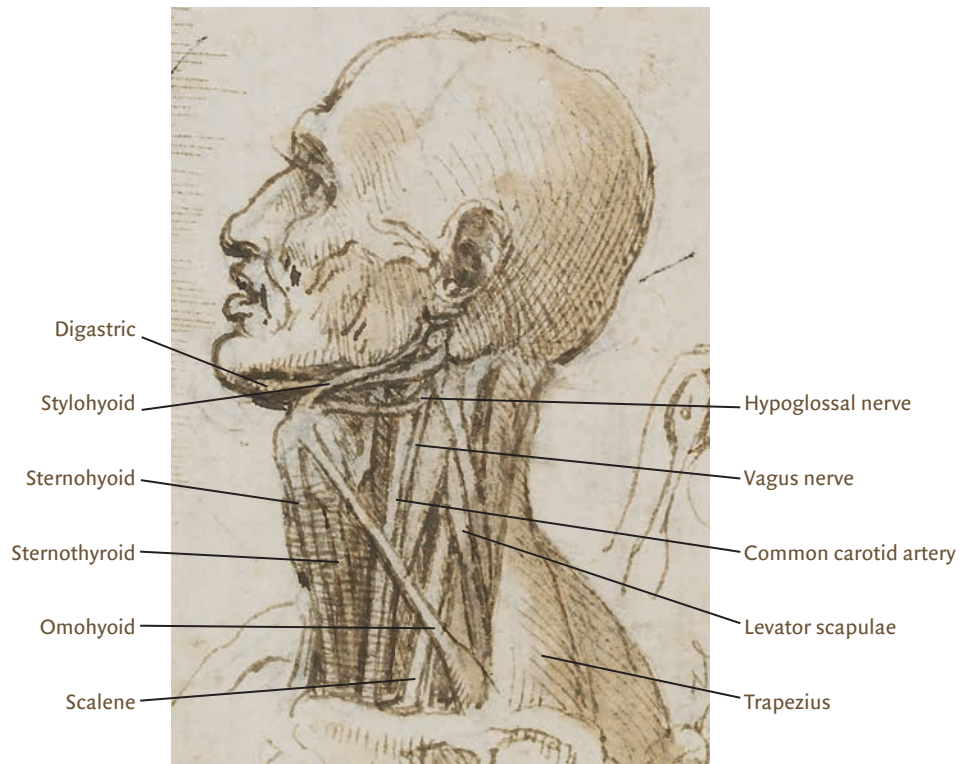
THE BONES OF THE FOOT, AND THE MUSCLES OF THE NECK

FOL. 3V

The views of the bones of the foot should be studied in conjunction with those on fols. 11r, 12r and 14v. They are mostly accurate, but a few inconsistencies can be seen, which may have resulted from Leonardo using fresh material, poorly cleaned dried material with ligamentous structures remaining, or dried material bound together too loosely. The drawing at the centre of the page shows the foot from below (plantar view), and concentrates on the topography of the cuboid bone, with features labelled *a*, *b* and *c*. The prominence *a* is the attachment site of the short plantar ligament, and appears this way because the bone is somewhat out of position, having been rotated medially. The ridge labelled *b* is the cuboid tuberosity, while *c* is the groove for the tendon of peroneus longus.

The drawing at upper left shows a left foot, though the tibia and fibula hovering above are again in the configuration for a right foot (cf. fol. 9r)—Leonardo may have realised his error here, as the lines drawn downwards from the fibula do not end on any tarsal bone. The little toe is shown with two phalanges; three is now usually stated as normal, but in fact two or three phalanges for the little toe occur in roughly equal numbers. The small diagram alongside indicates the action of the abductor and adductor muscles of the toes—those responsible for ‘lateral movement’, to use Leonardo’s term. Analogous muscles to those that move the fingers from side to side are found on the toes, but the ligaments and the shape of the phalanges hinder the distinct actions, and usually the best we can do is spread the toes somewhat.

The four drawings along the bottom of the page concentrate on the muscles of the neck and shoulder, and bear some of the peculiarities found throughout Leonardo’s depictions of this region. The neck muscles, however, are beautifully presented. The two drawings to the left show the same stage



of dissection, with all the muscles intact; in the drawing to the right sternocleidomastoid has been removed to display more clearly the complex of underlying muscles, nerves and vessels, most of which can be identified (see key diagram). The two bellies of the digastric muscle are shown again as *a b* in the diagram of the jaw from below, alongside.

Finally, the sketch at top right epitomises Leonardo's intention to depict the bones of each structure in an 'exploded diagram'. Occasionally he did use this diagrammatic device (e.g. fol. 8v, lower left), but never—so far as we are aware—across the entire skeleton, as here.



Divide or disunite every joint of the bones, one from the other

a b are the two transverse lateral movements of the toes



The pieces of bone of which a man's foot is composed are twenty-seven, taking into account those two that are under the breast of the big toe

Describe the purpose of each gibbosity on the underside of the basilar bone, and likewise every one of its perforations, and in how many parts it is divided



Note the purpose of the lumps a b c, and likewise all the other shapes of the bones



a b are the muscles under the chin

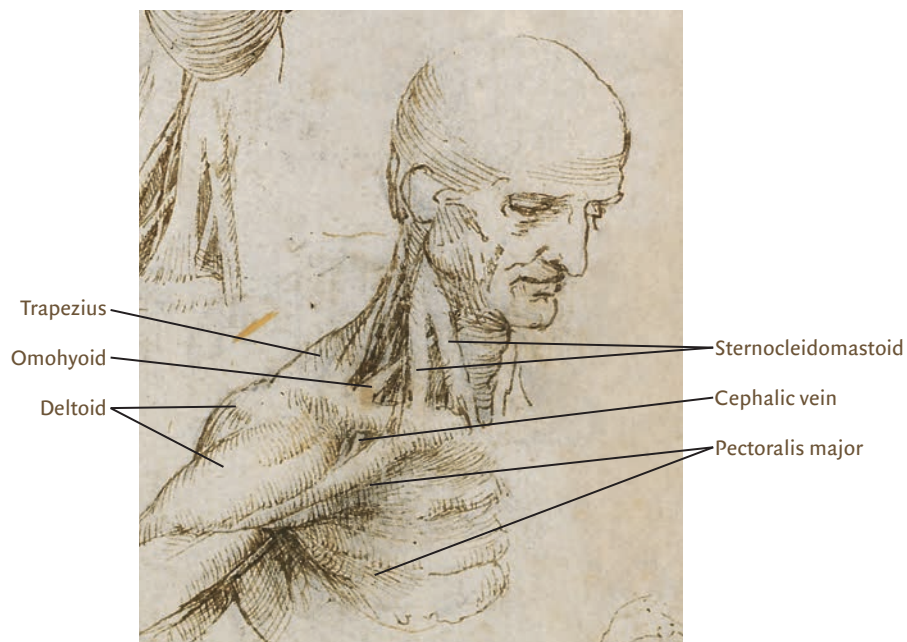
THE SUPERFICIAL ANATOMY OF THE SHOULDER AND NECK

FOL. 4R

The 'individual' depicted here displays the perplexing anatomical features seen on other sheets—a wide gap between the two heads of the sternocleidomastoid muscle (see fol. 1r), and a fascicular appearance to pectoralis major (from the chest to the arm), with a deep furrow between the clavicular and sternocostal portions of that muscle—best seen in the drawing at lower left, which shows a strongly contracted clavicular portion and a virtually flaccid remainder of the muscle. But more disturbing is the depiction of the deltoid muscle (forming the rounded contour of the shoulder), which throughout appears divided almost in half. In the drawing at lower left there is also an unexplained muscle-like feature between the border of trapezius (forming the upper contour of the drawing) and sternocleidomastoid (from the clavicle obliquely up the neck).

The drawing at the centre shows the left shoulder from above with the subject facing to the left; whereas the drawing to the left, which at first glance depicts the same region, shows the right shoulder from above with the subject facing to the right. In this latter drawing, the deltoid is again divided and appears to receive a major contribution from the clavicular head of pectoralis major. The small drawing at top left indicates a prominent upper portion of the trapezius and a more normal deltoid and deltopectoral groove.

The two 'dissection' drawings at lower centre right, which should indicate the structures underlying the superficial views, are simultaneously insightful and confusing (see key diagram). They both indicate the omohyoid muscle (labelled *a* in the smaller drawing below centre), though they seem to show it



Handwritten text in the top left corner, likely describing anatomical details or the artist's notes.

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Handwritten text in the top right corner, likely describing the anatomical features of the head and neck.

Handwritten text in the middle right section, providing further anatomical details or observations.

Handwritten text in the lower middle right section, continuing the anatomical notes.

Handwritten text in the bottom right section, possibly describing the anatomical study of the neck and shoulder area.



Handwritten text in the lower middle section, possibly describing the anatomical study of the hand and forearm.

Handwritten text in the bottom left corner, likely describing anatomical details or the artist's notes.

Handwritten text in the bottom right corner, possibly describing anatomical details or the artist's notes.



attaching to the clavicle rather than to the scapula. A narrow structure seen between the two heads of sternocleidomastoid is unexplained; but the cephalic vein within the deltopectoral groove (called by Leonardo 'the exterior conjunction of the muscle of the shoulder with the tendon of the breast') is well shown in both drawings, and elaborated fully in the sketch and note at bottom right.

The sketch at top right and its accompanying note deal with the mechanism by which muscles may counteract one another to stabilise a joint—this was to be a major theme in Leonardo's analysis of the spine on fols. 16r–v. In this diagram the clavicular head of sternocleidomastoid is counteracted by the clavicular portion of pectoralis major, thus preventing it from dislocating the sternal head of the clavicle (though dislocation of that joint in such a fashion would be most unusual).

The slight diagram at bottom left depicts the clavicle with a 'sinewy little muscle' ('muscoletto nervoso') at its sternal end. This may be a portion of the sternoclavicular ligament, or of the interclavicular ligament that courses across the top of the sternum. Finally, the sketch in the centre of the left margin studies the venous drainage of the posterior scapular area through the suprascapular vein.

In the long note surrounding the drawing at lower right Leonardo discusses his understanding of movement as composed of separable elements. He distinguishes between 'simple' movements, implicitly caused by one muscle or muscle group only; 'mixed' movements (elsewhere called compound or composite movements), caused by two independently operating muscles; and 'decomposite' or doubly compound movements, caused by three independently operating muscles. This is an expression of Leonardo's understandable urge, when confronted by a complex physical scenario (such as turbulence in water), to attempt to resolve it into simpler elements. His work as an anatomist led him to see that the apparently infinite movements of the body were the result of a finite number of muscle actions.

Nature of the veins

The origin of the sea is contrary to the origin of the blood, because the sea receives into itself all the rivers, which are caused only by the aqueous vapours raised into the air; but the sea of blood is the cause of all the veins

On the number of the veins
There is only one vein, which is divided into as many principal branches as there are principal places that it must nourish; and these branches go on branching infinitely

a b is a vein that is to be found under the wide muscle that covers the *omero* of the shoulder

a arises on the clavicle inside the origin of the broad *omero* muscle of the shoulder, which arises on the clavicle

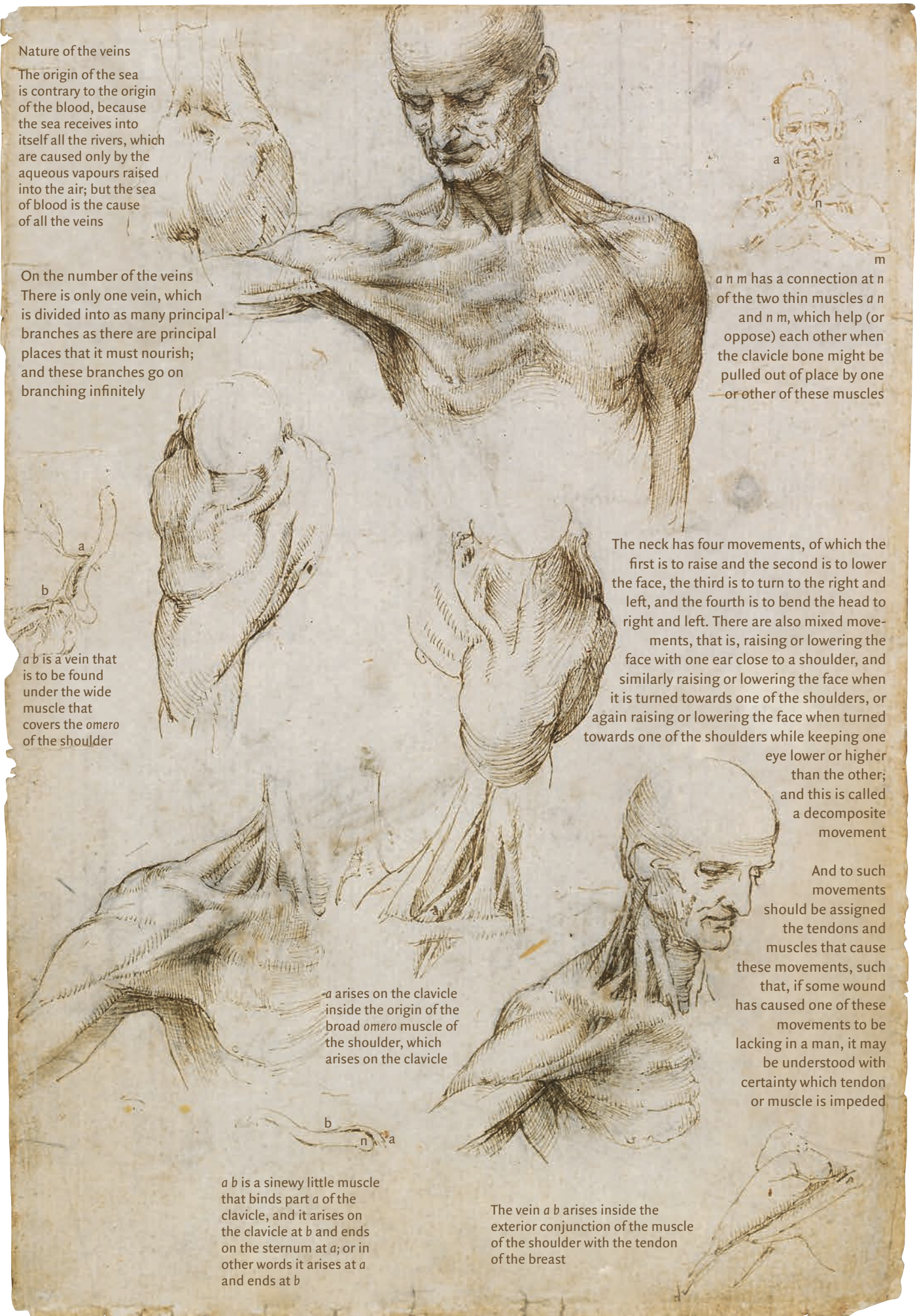
a b is a sinewy little muscle that binds part *a* of the clavicle, and it arises on the clavicle at *b* and ends on the sternum at *a*; or in other words it arises at *a* and ends at *b*

The vein *a b* arises inside the exterior conjunction of the muscle of the shoulder with the tendon of the breast

a n m has a connection at *n* of the two thin muscles *a n* and *n m*, which help (or oppose) each other when the clavicle bone might be pulled out of place by one or other of these muscles

The neck has four movements, of which the first is to raise and the second is to lower the face, the third is to turn to the right and left, and the fourth is to bend the head to right and left. There are also mixed movements, that is, raising or lowering the face with one ear close to a shoulder, and similarly raising or lowering the face when it is turned towards one of the shoulders, or again raising or lowering the face when turned towards one of the shoulders while keeping one eye lower or higher than the other; and this is called a decomposite movement

And to such movements should be assigned the tendons and muscles that cause these movements, such that, if some wound has caused one of these movements to be lacking in a man, it may be understood with certainty which tendon or muscle is impeded



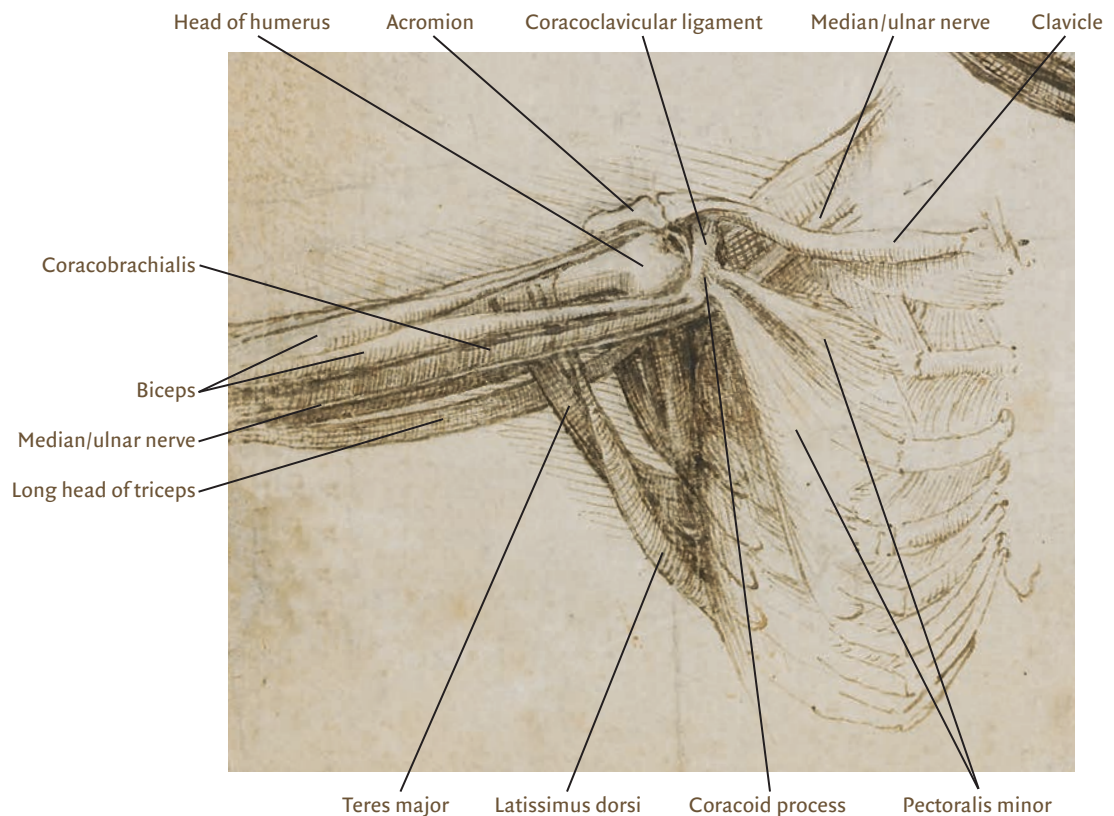
THE MUSCLES OF THE SHOULDER

FOL. 4V

All the drawings here deal with the right shoulder. At upper centre Leonardo once again divides pectoralis major to show the attachment of pectoralis minor. The neck muscles are well shown, and one can see—or infer—sternocleidomastoid, omohyoid, levator scapulae and maybe more before trapezius is reached (cf. key diagram to fol. 3v). Trapezius perplexed Leonardo: it is composed of superior fibres that descend, middle fibres that are horizontal and inferior fibres that ascend, and he therefore sometimes rendered it as several distinct muscles.

In the drawing at top left (cf. key diagram to fol. 2r), trapezius has been lifted off its insertion on the superior angle of the scapula at *a*, and the posterior portion of the deltoid muscle has been fenestrated, to show three of the muscles of the rotator cuff—supraspinatus (labelled *n*), infraspinatus (*o*) and teres minor (*p*). Teres major is at *q* and latissimus dorsi at *r*; rhomboid major is at *s* with rhomboid minor behind, with levator scapulae rising from its point of attachment on the vertebral border of the scapula, to the right of *s*.

At centre left is the deep structure of the right shoulder and scapula from the front, with the ribs lifted away (as indicated by the rough sketch of the ribs in a lighter ink to the right). The contribution of the broad sheet



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of subscapularis (n) to the rotator cuff is elegantly demonstrated; the long head of biceps is present, but its short head and coracobrachialis are indicated only by two of the 'tabs' on the coracoid process (the other two are of pectoralis minor). Leonardo has correctly shown the long head of triceps attaching to the border of the scapula, both here and in the drawing below. A note records the function of teres major and latissimus dorsi in rotating the humerus, but their attachments should be adjacent anterior to posterior, not proximal to distal as indicated.

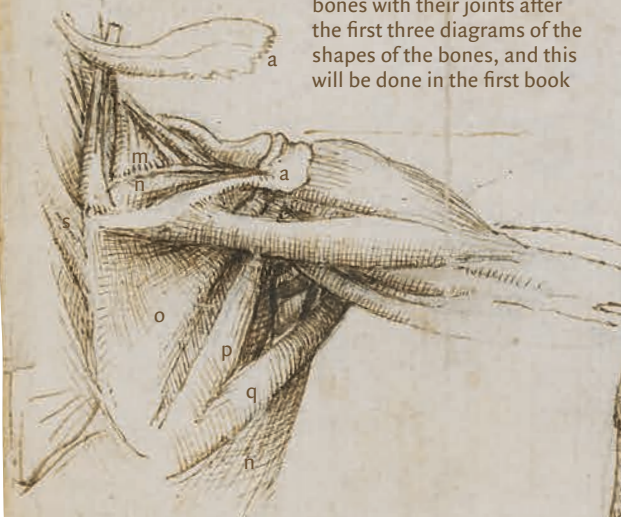
The drawing below places the ribs over the scapula and adds another layer of muscle (see key diagram). A terminal nerve of the brachial plexus, either the median or ulnar nerve, runs adjacent to coracobrachialis and can be followed up into the neck, and the coracoclavicular ligament is clearly depicted. Most of these structures are seen again in the drawing at lower right, with pectoralis major fenestrated as usual.

The drawing at top right is the culminating diagram of Leonardo's exposition of the shoulder, summarising the entire three-dimensional structure in a single depiction. It is perhaps the most complex of Leonardo's 'thread diagrams', with all the major muscles of the shoulder, both anterior and posterior, reduced to threads or cords along their central line of force. The clavicle and ribs are also reduced in thickness to improve the 'transparency' of the diagram, such that even a glimpse of the scapula is provided. But as Leonardo acknowledges in the note tucked under the arm, the density of information in such a diagram hinders its intelligibility, and he reminds himself to draw the diagram larger while maintaining the same thickness of ribs and muscle-threads.

The notes at bottom left discuss aspects of the mechanism of breathing. This subject engaged Leonardo only fitfully, and he never gave a single complete account of the action. Here he suggests that pectoralis minor plays a role in respiration; that is usually regarded as a muscle of the upper limb, but patients with severe emphysema or chronic obstructive pulmonary disease can be seen leaning on a support with their shoulders elevated, to enable pectoralis minor and even the scalene muscles to elevate the ribs and aid in breathing.

True knowledge of all shapes is possessed by knowing their width and length and depth, and therefore if I take note of the same in the shape of man, I will give true knowledge to all of sound intellect

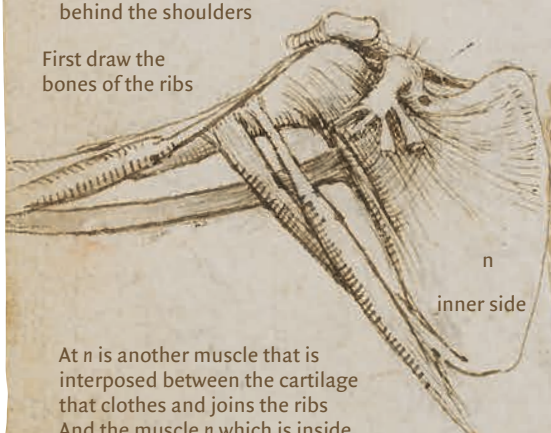
Draw all the movements of the bones with their joints after the first three diagrams of the shapes of the bones, and this will be done in the first book



back

Shoulder from behind, which clothes the ribs behind the shoulders

First draw the bones of the ribs



At n is another muscle that is interposed between the cartilage that clothes and joins the ribs And the muscle n which is inside the scapula, that is, the muscle n which

Depict the ribs from which the scapula n is separated

Make the ribs so thin that in the final diagram, drawn with threads, the scapula can be shown in place

The muscles n m are the cause of circular movement of the humerus

Show here which muscles are the cause of breathing, and what the muscles and tendons do that are attached to the outside of the ribs, which pull up these ribs with their stretching cartilages

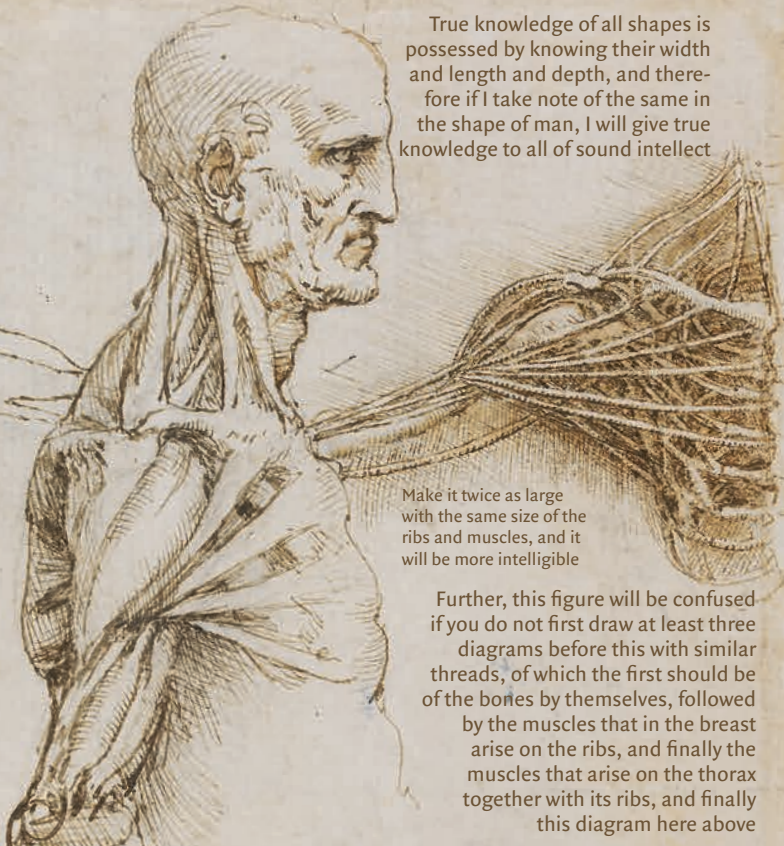
Why was the cartilage a h joined to the rib h c? This was done so that the cartilage could be bent by the voluntary movement of the muscle d f which, pulling the arc a h c, widens it and increases the chord of this arc, that is, the space a c, and through the increase of these spaces throughout the chest



Make it twice as large with the same size of the ribs and muscles, and it will be more intelligible

Further, this figure will be confused if you do not first draw at least three diagrams before this with similar threads, of which the first should be of the bones by themselves, followed by the muscles that in the breast arise on the ribs, and finally the muscles that arise on the thorax together with its ribs, and finally this diagram here above

Before you show the muscles, draw in their place those threads that show the positions of these muscles, the ends of which should terminate at the middle of the attachment of the muscles on their bones, and this will give clearer knowledge when you want to depict all the muscles, one on top of another; and if you draw it otherwise your depiction will be confused



THE BONES OF THE ARM AND LEG

FOL. 5R

Most of the drawings are concerned with pronation and supination (turning the hand) when the arm is flexed (bent) or extended at the elbow, demonstrating how this occurs without rotation of the humerus. There is no verbal explanation of the action—the role of biceps brachii was treated fully in fol. 1v—and the exceptionally beautiful drawings are left to speak for themselves.

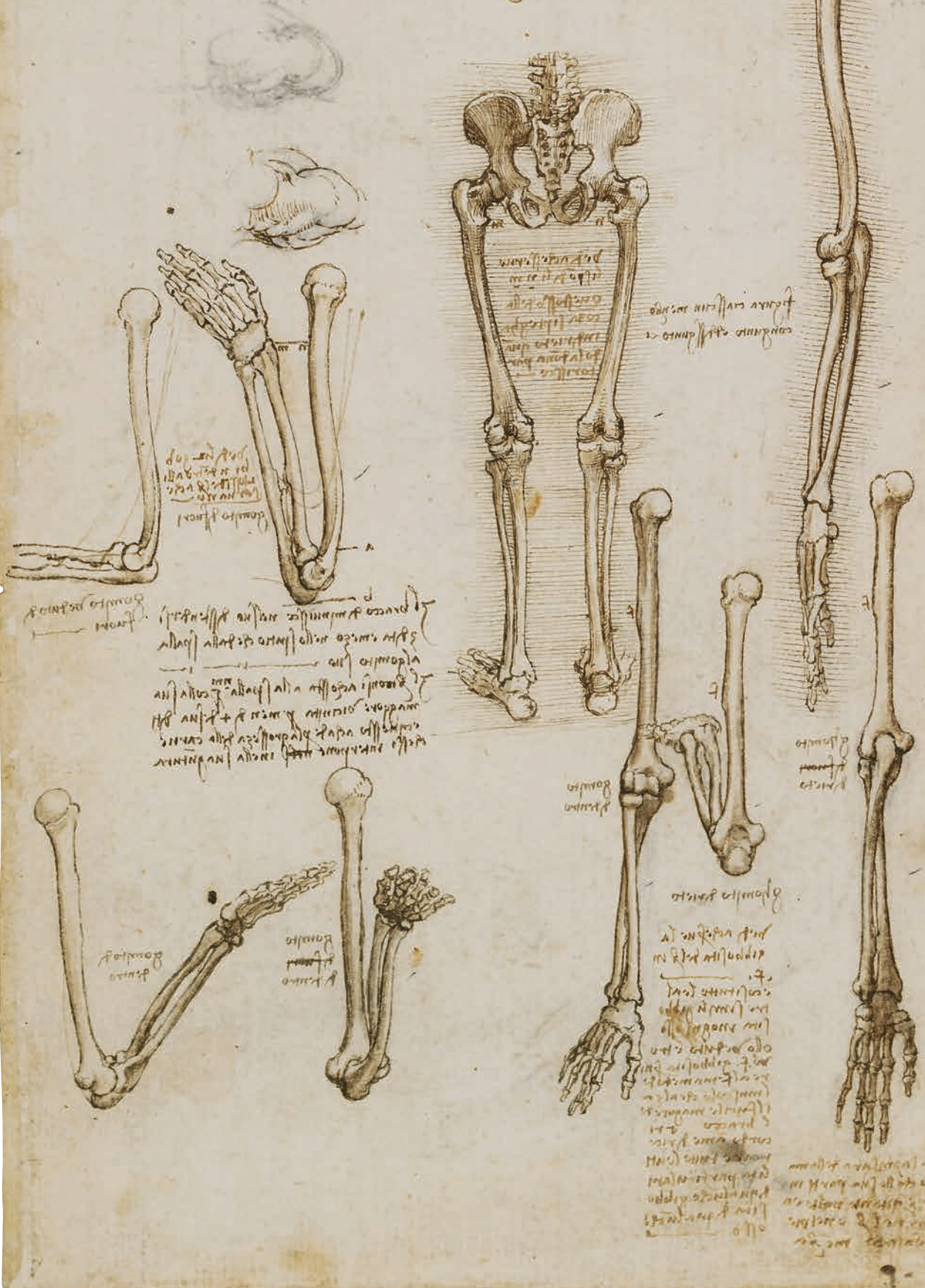
An ancillary theme is the apparent change in the length of the arm during flexion and extension. In particular, Leonardo observed—as shown in the drawings at centre left—that during flexion, the olecranon process of the ulna (the point of the elbow, at the lowest point of the drawing to the left of centre) emerges from the olecranon fossa of the humerus, so increasing the apparent length of the upper arm (though Leonardo expresses this in reverse, stating that the total length of the arm decreases by *a b* when the arm is extended).

In the notes at lower right, Leonardo queries the purpose of the prominence *f*, about half-way down the humerus. He makes a note to ‘see what purpose the gibbosity of the arm at *f* serves’, followed by ‘I have looked at it, and find that the gibbosity *f* serves as the attachment of the muscle that raises the humerus’. This is the deltoid tuberosity, where the deltoid muscle (which passes over the top of the shoulder) is attached to the humerus. Here Leonardo called the bone the *focele maggiore*—this was usually his term for the ulna (as distinct from *focele minore*, the radius; cf. fol. 9r), but the humerus (normally called by him the *aiutorio*) was clearly intended.

There are a couple of misleading or puzzling features in the drawings. As the carpal (wrist) bones are not the focus of study, they are depicted as a single unit rather than as individual bones. In several of the drawings there is a jagged appearance to a portion of the inner margins of the ulna and radius. This may be the result of a healed bad break of both bones, or of ossification or calcification of the interosseous membrane that joined the two bones, due to ageing, diet or hard labour. Leonardo did not realise that these *gobbi* (‘bumps’) were not design features, and with faint pen lines at centre left he posited that they might be the sites of insertion of muscles of the upper arm.

The drawing at the centre of the sheet examines the lower spine, sacrum, pelvic girdle and lower limbs. The number of foramina (holes) in the sacrum is correct, even if the lines where the vertebrae have fused to form the sacrum are not clear. The coccyx appears to be pulled away from its normal location, with the sacral hiatus unnaturally lengthened, and the tip of the coccyx is perhaps

On the left side of the page, there is a block of handwritten text in a cursive script, likely Latin or Italian, which serves as an introductory or descriptive passage for the anatomical drawings.



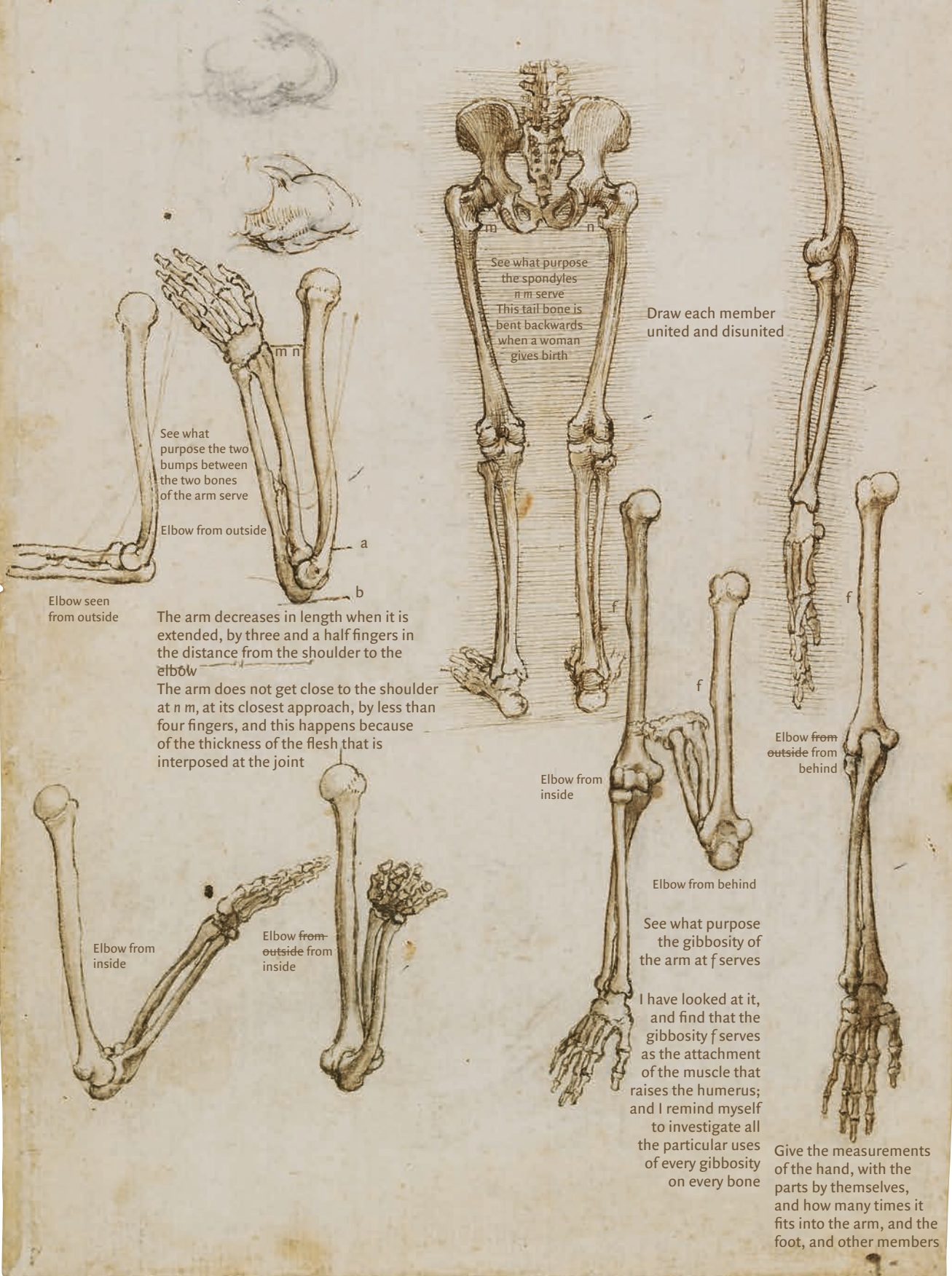
A block of handwritten text located in the middle-left section of the page, providing descriptive information for the anatomical drawings of the hand and forearm.

A block of handwritten text located in the bottom-right section of the page, providing descriptive information for the anatomical drawings of the hand and foot.

too bulbous. But these are minor imperfections, for the pelvic girdle is shown properly articulated and tilted—even Vesalius failed to capture this. The small note between the femurs claims that during childbirth the coccyx moves, and indeed it is pressed backwards by between 25 and 35 mm (1–1½ in.) to allow a significant increase in the size of the birth canal.

We are given a hint of how Leonardo arrived at the spatial sophistication of his drawings in the unfinished study at top left. This, with the pen version below, shows the right shoulder from above (mirroring the studies at the centre and centre left of fol. 4r). The substantial black chalk of the upper sketch indicates that Leonardo prepared most of his anatomical drawings with a similarly extensive black-chalk underdrawing, which was then carefully erased after he had fixed the lines with the pen.

Here is demonstrated how far the hand can turn without moving the shoulder-bone, and similarly the increase in the arm from the shoulder to the elbow in complete bending of the arm is explained



See what purpose the spondyles *m n* serve
This tail bone is bent backwards when a woman gives birth

Draw each member united and disunited

See what purpose the two bumps between the two bones of the arm serve

Elbow from outside

Elbow seen from outside

The arm decreases in length when it is extended, by three and a half fingers in the distance from the shoulder to the elbow

The arm does not get close to the shoulder at *n m*, at its closest approach, by less than four fingers, and this happens because of the thickness of the flesh that is interposed at the joint

Elbow from inside

Elbow from outside from behind

Elbow from behind

Elbow from inside

Elbow from outside from inside

See what purpose the gibbosity of the arm at *f* serves

I have looked at it, and find that the gibbosity *f* serves as the attachment of the muscle that raises the humerus; and I remind myself to investigate all the particular uses of every gibbosity on every bone

Give the measurements of the hand, with the parts by themselves, and how many times it fits into the arm, and the foot, and other members

THE SUPERFICIAL ANATOMY OF THE SHOULDER

FOL. 5V

At first glance these four drawings are deceptively casual, and there is every reason to believe that Leonardo had a toothless old man in front of him as he made them. While the subject was no doubt chosen because his leanness allowed his muscles to be seen with unusual clarity, the muscles are more clearly differentiated than would have been possible from a simple superficial study. In other words Leonardo's knowledge of the muscles obtained through dissection was brought to bear on a study from the model, to produce a hybrid of life study and anatomical study.

Leonardo was aware that in death the muscles are fully relaxed, and that to obtain a true knowledge of their form he had to observe them in the living. Consequently, these drawings were meticulously prepared with an extensive underdrawing, much of it with a stylus leaving only indentations in the surface of the paper that barely register in reproduction. There are also many ink dots and points impressed with the stylus—this is particularly noticeable in the drawing to the right, where the deltoid muscle is sprinkled with such marks around the curve of the shoulder and towards its tendon of insertion on the humerus. Leonardo clearly measured his subject and transferred the measurements to the sheet before constructing the drawing: he devoted the same care to this sheet as he did to the more spectacular 'finished' drawings elsewhere in the manuscript.

In the corner of the sheet is the word *leoni*, not in Leonardo's hand. This word is found again on several of Leonardo's anatomical drawings (including fol. 11v), and its significance is unknown. The sculptor Pompeo Leoni owned the drawings between around 1590 and his death in 1608, but there is no obvious reason why his name would be written on a handful of the sheets.



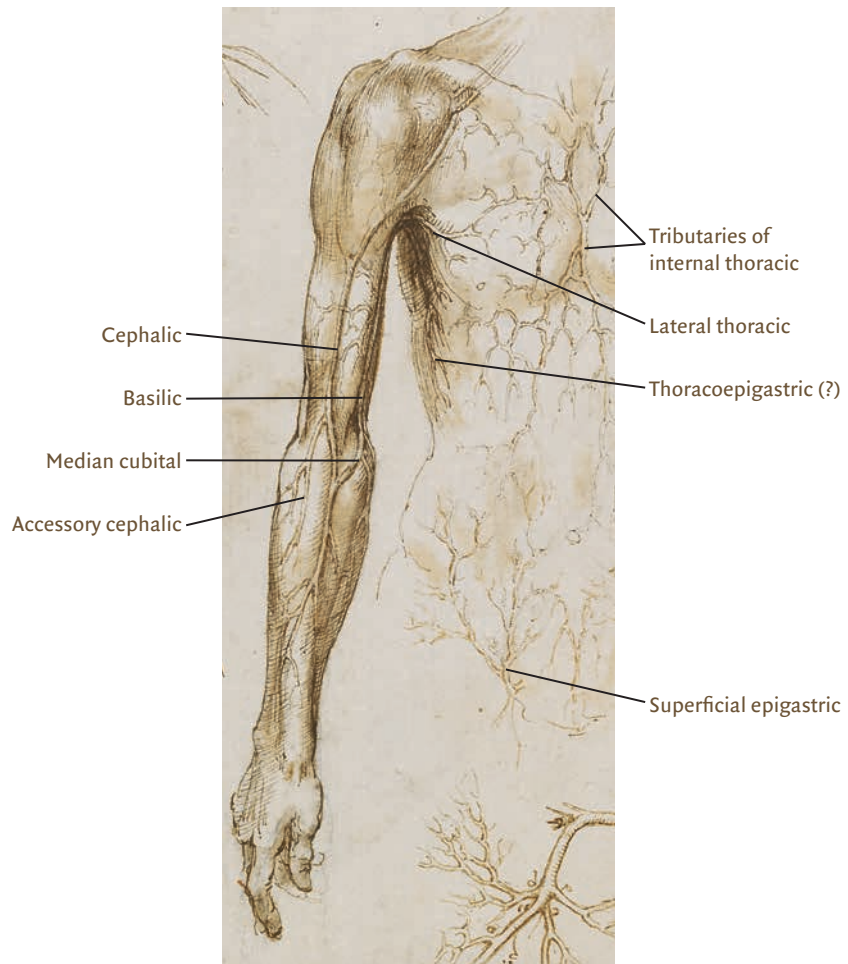
Leon

THE MUSCLES OF THE ARM, AND THE VEINS OF THE ARM AND TRUNK

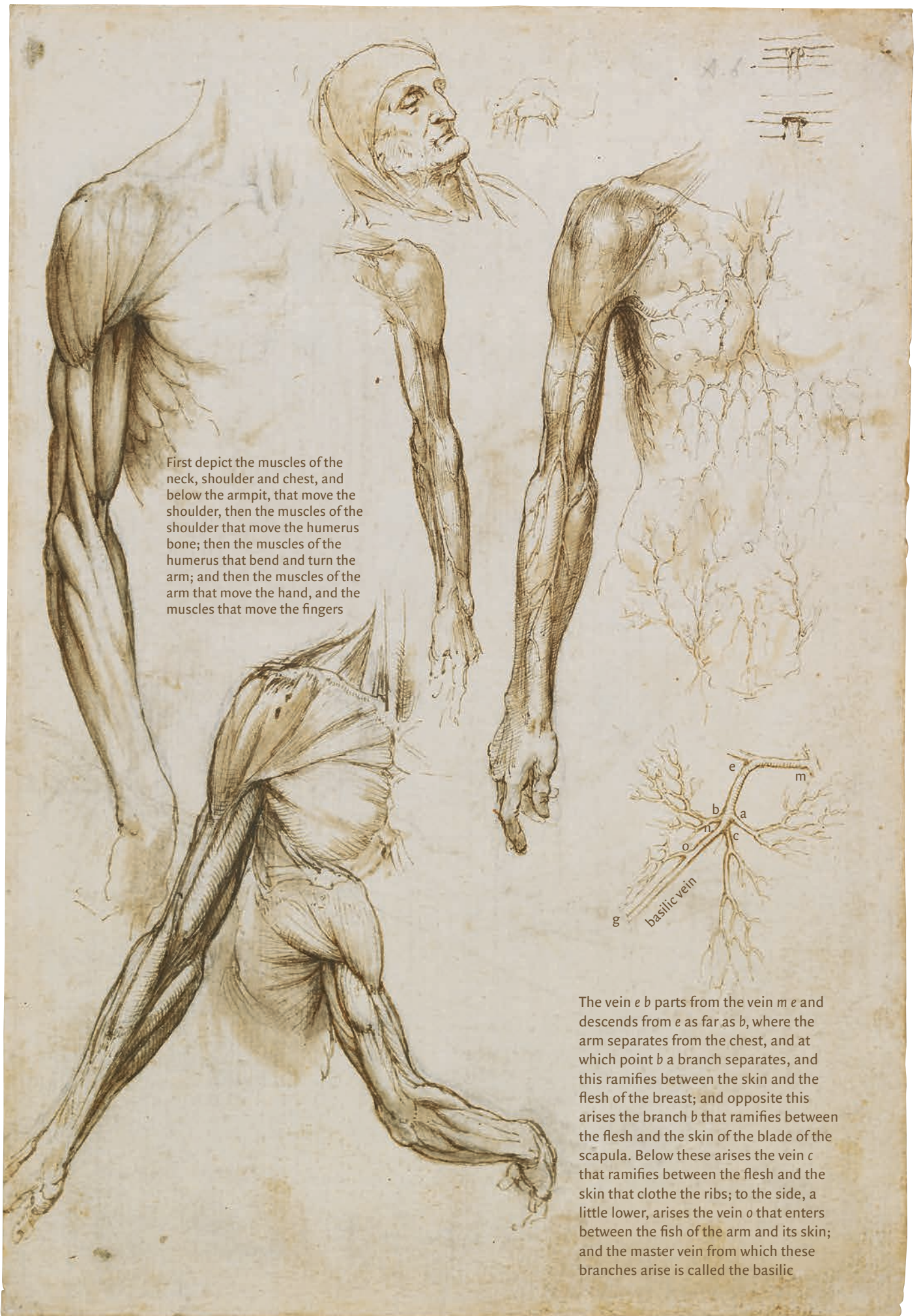
FOL. 6R

The elderly and apparently dead man depicted at the top of the sheet was presumably the subject of dissection studies here and elsewhere in the manuscript. To the right of the head is a brief but detailed sketch of the region of the jaw and neck, with the tongue and hyoid sunken in the flaccidity of recent death. The three consummately elegant studies of the arm down the left side of the page, however, give the old man the musculature of Apollo. As was usual throughout the Renaissance, the corpse is posed as if in action, the muscles imbued with the tension of life. Leonardo has not resorted to diagrammatic devices (such as fenestrating pectoralis major, as is seen repeatedly throughout the manuscript), and all the muscles are identifiable (including biceps brachii, called the ‘fish of the arm’ in the notes—see p. 134). With a few dabs of wash Leonardo has captured the shimmer of the deep fascia, the connective tissue surrounding and interpenetrating the muscles. It is Leonardo at his best.

The two brief diagrams in the top right corner may be intended to demonstrate how a superficial vein can pierce the subcutaneous fascia to enter a deep vein. The upper sketch appears to show fluid flowing from two cut ends of a structure with a lumen, but as Leonardo does not comment, their interpretation is uncertain.



The large drawing at upper right shows the trunk with only the skin removed (see key diagram). The cutaneous veins of the arm—cephalic, basilic and median cubital—are visible, and on the trunk can be seen the lateral thoracic vein, superficial epigastric veins, tributaries of the internal thoracic vein and possibly a thoracoepigastric vein. Below is a more detailed study of what is the basilic vein *g b* as it enters the axillary vein *b e* and then in turn the subclavian vein *e m*. The identities of the other veins in this detail are not certain as there is a large amount of venous drainage in the axillary region, but the cephalic, subscapular, lateral thoracic, thoracoepigastric and thoracodorsal veins are probably all present. Leonardo perceived the venous system as a ‘branching’ system carrying nourishment to the extremes of the body (while the arterial system carried ‘vital spirit’); in truth the blood flows from peripheral to central, and so the systemic veins have tributaries rather than branches.



First depict the muscles of the neck, shoulder and chest, and below the armpit, that move the shoulder, then the muscles of the shoulder that move the humerus bone; then the muscles of the humerus that bend and turn the arm; and then the muscles of the arm that move the hand, and the muscles that move the fingers

The vein *e b* parts from the vein *m e* and descends from *e* as far as *b*, where the arm separates from the chest, and at which point *b* a branch separates, and this ramifies between the skin and the flesh of the breast; and opposite this arises the branch *b* that ramifies between the flesh and the skin of the blade of the scapula. Below these arises the vein *c* that ramifies between the flesh and the skin that clothe the ribs; to the side, a little lower, arises the vein *o* that enters between the fish of the arm and its skin; and the master vein from which these branches arise is called the basilic

THE MUSCLES OF THE SHOULDER AND ARM

FOL. 6V

The two lines at the top of the page concern the buttocks, but the bulk of the sheet is concerned with the muscles and movements of the shoulder and arm. The four largest drawings conclude a sequence that begins on fol. 6v, showing the shoulder and arm in a total of eight views, turned gradually through 180° from a fully anterior to a fully posterior aspect (as usual, Leonardo's page layout should be read from right to left).

Leonardo understood the deltoid muscle (forming the rounded upper contour of the shoulder) as a compound structure that comprises distinct sets of fibres, but he exaggerated the differentiation of these portions, portraying them as four quite separate bundles (a to d). Likewise, the superior portions of the trapezius muscle, running upwards from the spine of the scapula, appear to be separate. Most of the muscles of the arm can be identified (see key diagram, overleaf); towards the wrist at centre right Leonardo has labelled the tendons of the abductor pollicis longus (a) and extensor pollicis brevis muscles (b), both of which act on the thumb, reminding himself to remove the covering muscle (the supinator) to find their origins.

Handwritten text at the top of the page, likely a title or introductory notes, written in a cursive script.



Handwritten text below the small diagram, providing a description or label for the organ shown.

Handwritten text block located between the two main anatomical drawings, likely describing the structures shown.



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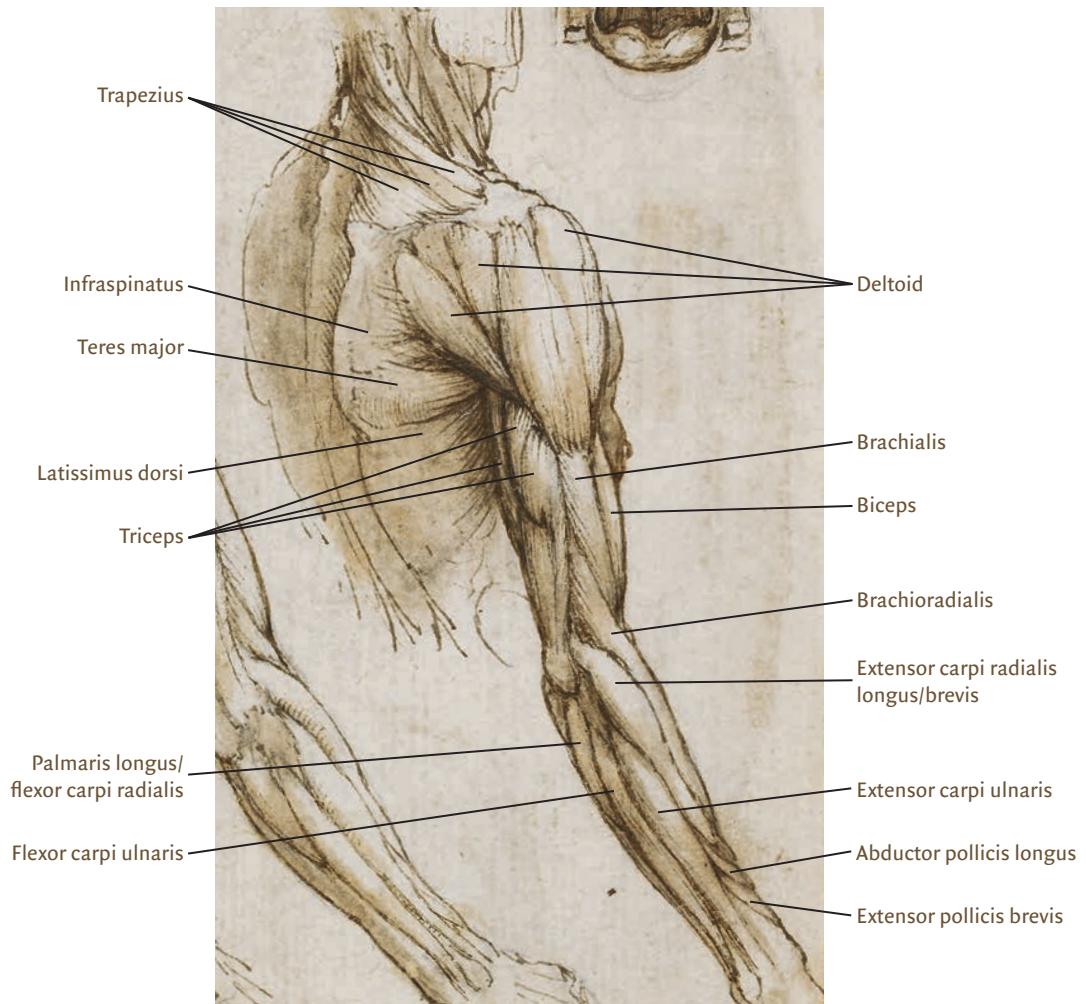
Handwritten text block in the center of the page, between the two main anatomical drawings.

Handwritten text block on the right side of the page, adjacent to the lower part of the anatomical drawings.

Handwritten text block at the bottom left of the page, providing further anatomical information.

Handwritten text block at the bottom center of the page, continuing the anatomical descriptions.

Handwritten text block at the bottom right of the page, providing further anatomical information.



At centre left is a brief sketch of the back of the elbow, showing the olecranon process and humeral epicondyles. Here Leonardo calls the olecranon 'the moveable bone of the elbow', following his studies of the flexion of the arm on fol. 5r. The muscle depicted appears to be brachioradialis. The block of text below contains a rare reference to the artistic usefulness of Leonardo's anatomical studies, noting that the sculptor should understand the function of each muscle so that he could emphasise those appropriate to a particular pose.

At upper right, the drawing of the open mouth, showing the uvula, palatal arches, surface of the tongue and maxillary and mandibular molars, should be studied alongside fol. 3r.

The principal and the greatest and the most powerful muscles in man are his buttocks—these are of marvellous strength, as is demonstrated by the force exerted by a man when lifting weights



n is the uvula, m is the tongue
o p are the last molars

Describe the furthest movements of the edges of the scapula, that is, the movements up and down and to right and left and do the same for each movement of whatever member



The muscle n m turns the arm from behind forwards

a is the moveable bone of the elbow

To be noted
Draw an arm raised and one lowered, one backwards and one forwards, and draw each of these from four aspects, and do the same with the elbow bent

See if the muscle of the shoulder

Lift the muscle b, and thus raised, draw the other muscles successively, right down to the bone, from each of four aspects

This arm from the elbow a as far as b must be drawn in four movements, that is, fully raised and fully lowered, and backwards as far as possible and likewise forwards; and if it occurs to you to draw it in more ways, the purpose of each muscle will be more intelligible. And this will be good for sculptors, who have to exaggerate the muscles that are the cause of the movements of the limbs more than those that are not used in such movements

Depict the arm from the shoulder to the elbow as it makes a circular movement, fixing the shoulder to a wall and moving the hand, with a piece of charcoal, right around that shoulder while keeping the arm straight; and with this rotation all the movements of the muscles that move the shoulder will be made—but draw the shoulder from the spine of the back to the thorax of the chest

Remember to depict the origin of the two tendons a b by exposing the muscles that engage them
And do the same for all the muscles, leaving each one on its own, naked on the bone, so that besides seeing its beginning and end, it is shown in what way it moves the bone to which it is dedicated; and of this, the scientific explanation is to be provided with lines alone

THE MUSCLES OF THE LEG, AND THE INTERCOSTAL MUSCLES

FOL. 7R

The largest drawing is a typical fusion of life study and dissection drawing, in which Leonardo brought his knowledge of the muscles of the leg to bear on a study from life. Most of the muscles are identifiable, if somewhat exaggerated (see key diagram to fol. 15r, page 136): at the front of the thigh, three of the four components of the quadriceps femoris group—rectus femoris (which covers vastus intermedius) at centre, flanked by vastus lateralis and vastus medialis—with the long thin sartorius running obliquely to the inside of the knee. However the identity of the muscles on the inside of the thigh is not altogether certain: on the inner side of sartorius are pectineus and adductor longus, but the muscle on the inner ‘edge’ of the thigh does not look like adductor magnus or gracilis.

To the right Leonardo provided a diagram of a portion of the ribs and intercostal muscles. The note reads:

The *mesopleuri* are those tendons that bind the ribs together. And besides binding them and impeding their dilatation, they impede transverse movements.

The term *mesopleuri* comes from the Greek for ‘between the ribs’; Leonardo described them not as *muscoli* but as *nervi*, a term that encompassed both nerves and tendons (though the latter could also be called *corde*). The intercostals do seem to alternate between muscle, membrane and small tendons, but it is apparent that Leonardo believed that they did not have any muscular action, and functioned simply to hold the ribs firm in relation to one another. As an engineer he would have appreciated the stability engendered by a system of supports crossing over one another in this manner, and the diagram is a schematic depiction of lines of force rather than an actual dissection study.

The drawing below shows the phalanges and metatarsals with the interosseous muscles, the deepest layer of the foot. They are rather roughly drawn, and one cannot clearly distinguish the dorsal from the plantar interosseous muscles. We may surmise by their attachments to the bones that Leonardo understood their function in abduction and adduction of the toes, but the juxtaposition with a diagram of the intercostal muscles implies that he believed they served an analogous purpose, to bind the metatarsals together, as treated in more detail on the other side of the sheet.



Handwritten text in a cursive script, likely Latin or Italian, describing the anatomical features shown in the drawings. The text is written in brown ink and is somewhat difficult to decipher due to the cursive style and the age of the document.



THE MUSCLES OF THE FOOT

FOL. 7V

Dissection of the foot is difficult, with the toughest fascia and aponeuroses (connective tissues) contained within the body. But Leonardo devoted a significant proportion of the Anatomical Manuscript A to the foot—more in fact than to the hand—for he found the mechanics of its compact anatomy fascinating. Considering the complexity of the subject and the difficulty of using fresh material, his work is truly remarkable.

The modern anatomist analyses the plantar surface (sole) of the foot in four or five layers from superficial (surface) to deep (bone), and it is in this manner that this discussion will be organised. The drawing below centre is an incomplete representation of layer 1. The abductor digiti minimi muscle is seen running from the calcaneus (heel-bone) to the little toe, with cut stumps of abductor hallucis and flexor digitorum brevis also visible on the calcaneus. In the drawing below right, these structures are still visible, to which Leonardo has added the four lumbrical muscles (from layer 2) under the ball of the foot, and flexor digiti minimi brevis (level 3) again running to the little toe.

The two upper drawings correspond most closely to the modern layer 3. It is apparent from the roughness of the drawing at upper right, with repeated scratching out and overdrawing, that Leonardo was struggling to make sense of his dissection notes. To the left is the same view with the muscles reduced in size (though not quite to threads) in order to show deeper structures. In both drawings the tendon of peroneus longus can be seen passing beneath the long plantar ligament to the base of the first metatarsal, and in the study to the left a small part of the tendon bifurcates to insert on the medial cuneiform bone. Flexor hallucis brevis (n in the drawing at upper left) is indicated in both drawings, and abductor hallucis is reflected (lifted off) above the drawing at upper right. Attaching to the second toe are two muscles, that closest to the big toe perhaps a lumbrical, the other a portion of flexor digitorum brevis or one of the plantar interosseous muscles from deeper in the foot.

Handwritten text in a cursive script, likely Latin, located in the upper left corner of the page.



Handwritten text in a cursive script, likely Latin, located in the middle left section of the page.




Handwritten text in a cursive script, likely Latin, located in the lower right section of the page.

Handwritten text in a cursive script, likely Latin, located in the bottom right section of the page.

In the drawing at centre right, Leonardo continues his study of the sesamoid bones (see fol. 1r), reflecting flexor hallucis brevis to show the bones both within the tendon and again separately to upper right (m and n). A dual insertion of the tendon of tibialis anterior is also indicated, on both the medial cuneiform bone and the first metatarsal, as is the attachment of the tendon of fibularis longus. A structure adjacent to that tendon appears to recur in the dorsum of the foot, possibly the connection of the deep plantar arch with the deep plantar artery, leading to the dorsalis pedis artery. So ends the sequence of plantar views of the foot.

A lateral view of the foot is given at centre left. The tendon of fibularis brevis is seen inserting at the base of the fifth metatarsal, while abductor digiti minimi has been cut and reflected to show the passage of fibularis longus into the sole. A muscle that may be fibularis tertius, not found in all individuals, is also shown inserting, though not quite at the correct location for that muscle—it should be just anterior to fibularis brevis, as is shown in fols. 17r and 18r. The drawing at lower right demonstrates Leonardo's interest in the function of the deep transverse metatarsal ligaments, which keep the metatarsal bones from separating—analogueous, in his view, to the function of the intercostal muscles.



The muscle n presses
on the two stony bones
under the joint m

Depict clearly these muscles
that bind the bones together,
and then draw the muscles
and tendons of movement,
and define the nature and
power of movement of each
member

a b c d are
tendons without
muscles

On the binding of the
bones of the toes
The tendons arise
at a b; these then
terminate in the
middle of the
next bone at c d,
and likewise for
all the toes of
the feet

THE SUPERFICIAL ANATOMY OF THE SHOULDER
AND ARM
FOL. 8R

These two drawings of an old man are part of the sequence also seen on fols. 1r, 5v, 12v and 14r. Not one shows exactly the same pose—Leonardo appreciated the infinite range of movement of the shoulder (the ‘cone of circumduction’), the potential angles of rotation of the humerus, degrees of supination or pronation, and so on.

Below the old man is a faint black-chalk underdrawing, showing the arm dissected in full extension—similar to that at the bottom of fol. 1v, but viewed from above and slightly from the front. The coracoid process, humerus, biceps, and heads of the ulna and radius are visible, but details at the cubital fossa (inner elbow) are unclear.



THE VERTEBRAL COLUMN

FOL. 8V

This is the first accurate depiction of the spine in history, and five hundred years later no artist or anatomical illustrator has surpassed Leonardo's accomplishment.

The drawing at upper left depicts an ergonomically correct spine with its curvatures and sacral tilt perfectly shown. The only error is that Leonardo has shown twelve vertebral bodies (correctly) but thirteen spines—between thoracic vertebrae 2 and 3, a little below the letter *b*, is a spinous process with no vertebral body attached. So convincing is Leonardo's drawing that even anatomists normally fail to notice this until it is pointed out.

To the right is a correctly articulated frontal view of the spine. The subtlety of Leonardo's shading allows the curvatures to be clearly understood, and variations in the sizes of the vertebral bodies and transverse processes are carefully recorded—vertical lines either side of the spine give the maximum width of the processes. To the right of the image, long oblique lines indicate where the spinal nerves would be.

The viewpoint of the image at lower right is a little unusual, showing the posterior aspect but from an elevated position. Leonardo's reasons for choosing this aspect are not explained in the accompanying notes—perhaps he wished to give a sense of the length of the posterior spinous processes.

The note at centre left is deceptively simple in its accuracy. It enumerates the vertebrae by region in a completely modern manner, though Leonardo did not have the vocabulary that we use. Thus from *a* to *b* he counts seven cervical segments; from *b* to *c*, twelve thoracic segments (he ignored his extra-spine mistake); from *c* to *d*, five lumbar segments; from *d* to *e*, five sacral segments; and from *e* to *f*, two coccygeal segments. Simply stating the correct number of fused sacral vertebrae would have secured Leonardo a place in anatomical history, but this last number requires comment. There is no 'correct' number of separate segments to the coccyx—the 'tail' of the embryo develops and then degenerates, and the degree of degeneration accounts for natural variations in the number of segments between individuals. Modern textbooks state that it is composed of two to three or even three to five rudimentary segments; Leonardo saw two distinct segments in his subject, and we cannot say that he was wrong (though the overall length of the coccygeal portion as illustrated here appears excessive).

The drawing at lower left demonstrates how the first and second cervical vertebrae (atlas and axis) fit onto the third, using the diagrammatic convention of the 'exploded view'. The strong variations in the shape of each of these vertebrae clearly intrigued Leonardo. To the right he presents a detailed view of the cervical vertebrae assembled, with vertical lines again indicating that the transverse processes of the first and last are equal in width.

Leonardo was justifiably proud of his achievement in these drawings, and turned his mind to the problem of reproducing them effectively in the anatomical treatise that he was planning to publish. In the note running along the bottom of the sheet he pleads 'O successors, that avarice does not constrain you to make the prints in . . . '—the last word is cut by the edge of the page, but enough survives to read it as *legno*, 'wood[cut]', the usual method of illustrating printed books of the time. In Rome at that very moment, Raphael was beginning a fruitful relationship with the engraver Marcantonio Raimondi, but even Marcantonio would have been unable to capture fully Leonardo's spatial sophistication. It is only in the modern period, using photographic methods of reproduction, that Leonardo's successors have been able to disseminate his images with some degree of faithfulness.

This is the bone of the back seen from the side, or as one might say, in profile

a b is the bone of the neck seen in profile and divided into seven vertebrae

b c are the twelve vertebrae onto which are attached the origins of the ribs

The greatest width of the vertebrae of the back in profile is the same as the greatest width of the vertebrae from the front

For every type of bone in the back that you depict, draw two similar figures separated and two joined, and likewise draw two in outline, separated and then joined, and thus you will make a true demonstration

- a b 7 vertebrae
- b c 12 vertebrae
- c d 5 vertebrae
- d e 5 vertebrae
- e f 2 vertebrae

which in total makes 31 vertebrae from the beginning of the spinal cord to its end



a b are the seven vertebrae of the neck, through which the nerves issue from the spinal cord and spread through the arms, giving them feeling

b c are the twelve vertebrae on which are fixed the twenty-four ribs of the chest

c d are the five vertebrae through which pass the nerves that give sensation to the legs

d e is the tailpiece, divided into seven parts that are also called vertebrae

This is the bone of the back seen from the inside

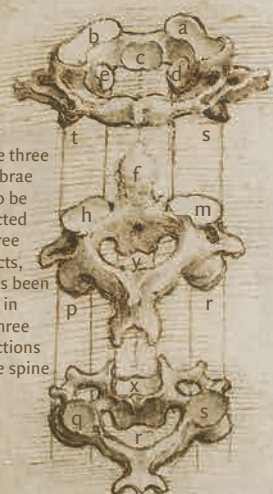
At n is the smallest vertebra, which is among the vertebrae of the ribs, and at b and s are the largest

The vertebra r and the vertebra s are of equal width

o is the smallest vertebra of the neck



Depict the spine first with the bones and then with the nerves of the spinal cord



These three vertebrae are to be depicted in three aspects, as has been done in the three depictions of the spine



Provide a reason why nature has varied the five upper vertebrae of the neck at their points

Depict the spinal cord that passes through the three upper vertebrae of the neck, which you have separated, together with the brain



The fifth bifurcated vertebra is wider than any other vertebra of the neck, and has smaller wings than any of the others

The first bone at the top is joined to the second with two joints, the second is joined to the third with three joints, and all the other vertebrae of the neck, which are seven, do the same

The vertebrae of the neck are seven, of which the first at the top and the second are different from the other five

Draw these bones of the neck in three aspects joined, and in three aspects separated, and then do likewise in two other aspects, that is, seen from below and from above, and thus you will give true knowledge of their shapes, which is impossible for either ancient or modern writers. Nor could they ever give true knowledge without an immense and tedious and

confused length of writing and of time. But through this very brief method of drawing them in different aspects, one can give full and true knowledge of them, and in order to give this benefit to men, I teach the method of reproducing it in order, and I pray to you, O successors,

that avarice does not constrain you to make the prints in [woodcut]

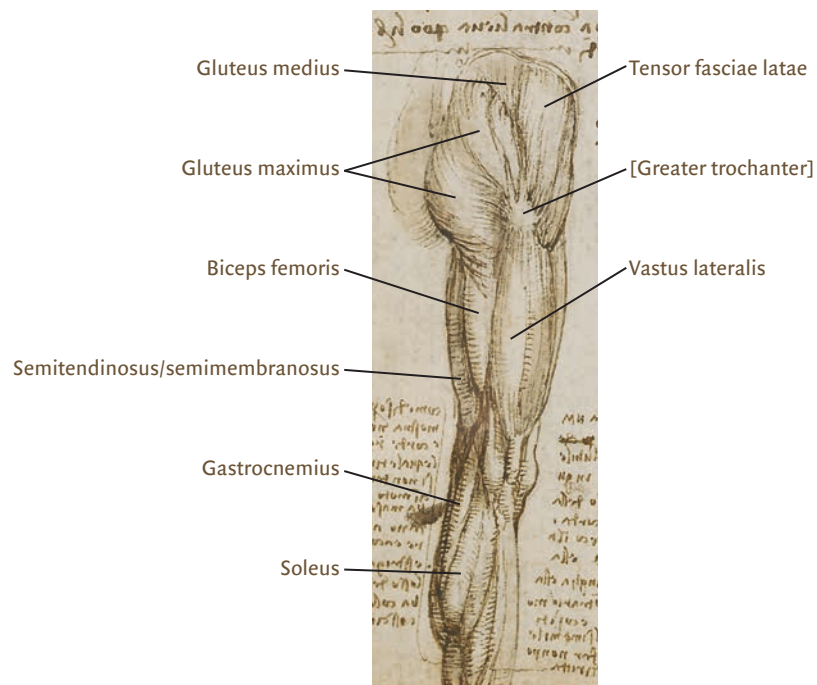
THE BONES AND MUSCLES OF THE LEG

FOL. 9R

The notes on this page reveal that Leonardo was concerned with three of the mechanisms of the leg, though the shapes of the bones themselves are the most prominent topic of the drawings. Leonardo followed his usual practice of drawing the subject from several angles, including two studies of the flexed knee. In all the drawings the talocrural (ankle) joint is well shown, with the mortice formed by the lower heads of the tibia and fibula fitting onto the talus of the ankle (though the tarsal bones of the foot are drawn as a single unit). The slightly enlarged upper head of the fibula and the blunted appearance of the styloid processes at the end of the tibia and fibula may have resulted from using freshly prepared bones, with portions of ligaments and cartilage remaining, rather than dried bones. A small piece of ligament seems to be visible on the head of the femur in the drawings below, at upper right and at upper centre, and the patella drawn in isolation at upper left appears to have some of the patellar ligament remaining on its lower edge.

The drawing at upper right, together with the note running through the centre of the sheet, examines the dynamics of the calcaneal (Achilles) tendon, through which the gastrocnemius and soleus muscles of the calf act on the calcaneus (heel-bone). By a simple proportional calculation, Leonardo stated that the distance from the axis of the ankle to the ball of the foot is twice the distance to the end of the calcaneus, and thus to raise a man of 200 pounds on the ball of one foot requires a pull of 400 pounds—his appreciation of the large forces within the body required to perform a simple action is implicit. This action is studied again, though with the proportions of the ‘lever’ expressed differently, on fol. 11v.

The role of the patella as a sesamoid bone (see fol. 11r) is discussed by Leonardo in the note at lower right, observing that it connects the muscles rectus femoris, vastus lateralis and vastus medialis with the patellar tendon in the lower leg. The note below centre right discusses the lengthening of the surface of the limb in flexion, paralleling Leonardo’s observation on the arm on fol. 5r. Although there is no equivalent of the patella at the elbow, the fact that on fol. 6v he calls the olecranon ‘the moveable bone of the elbow’ suggests that he was trying to find equivalence between the knee and elbow. When kneeling, the ‘outside’ of the leg does lengthen by an amount roughly equal to the length of the patella—but it is quadriceps femoris that elongates, the patella remaining essentially stationary.



The third action to be analysed is more problematic. In the drawings at upper centre and lower centre Leonardo drew threads to indicate antagonistic action of muscles on either side of the leg, and noted that when a flexor contracts, an extensor must relax and be passively stretched. It is not clear which muscles Leonardo intended here—while the lower attachments of semimembranosus (on the inside of the leg) and biceps femoris (on the outside) correspond to those indicated, their origins lie on the pelvis and not at the head of the femur. When the leg is semiflexed, as in the two drawings below, it is true that contraction of one of these muscles will cause some rotation of the tibia at the knee and thus lengthen the other a little, but it is surprising that Leonardo chose to highlight this rather than the much more significant actions of flexion and extension.

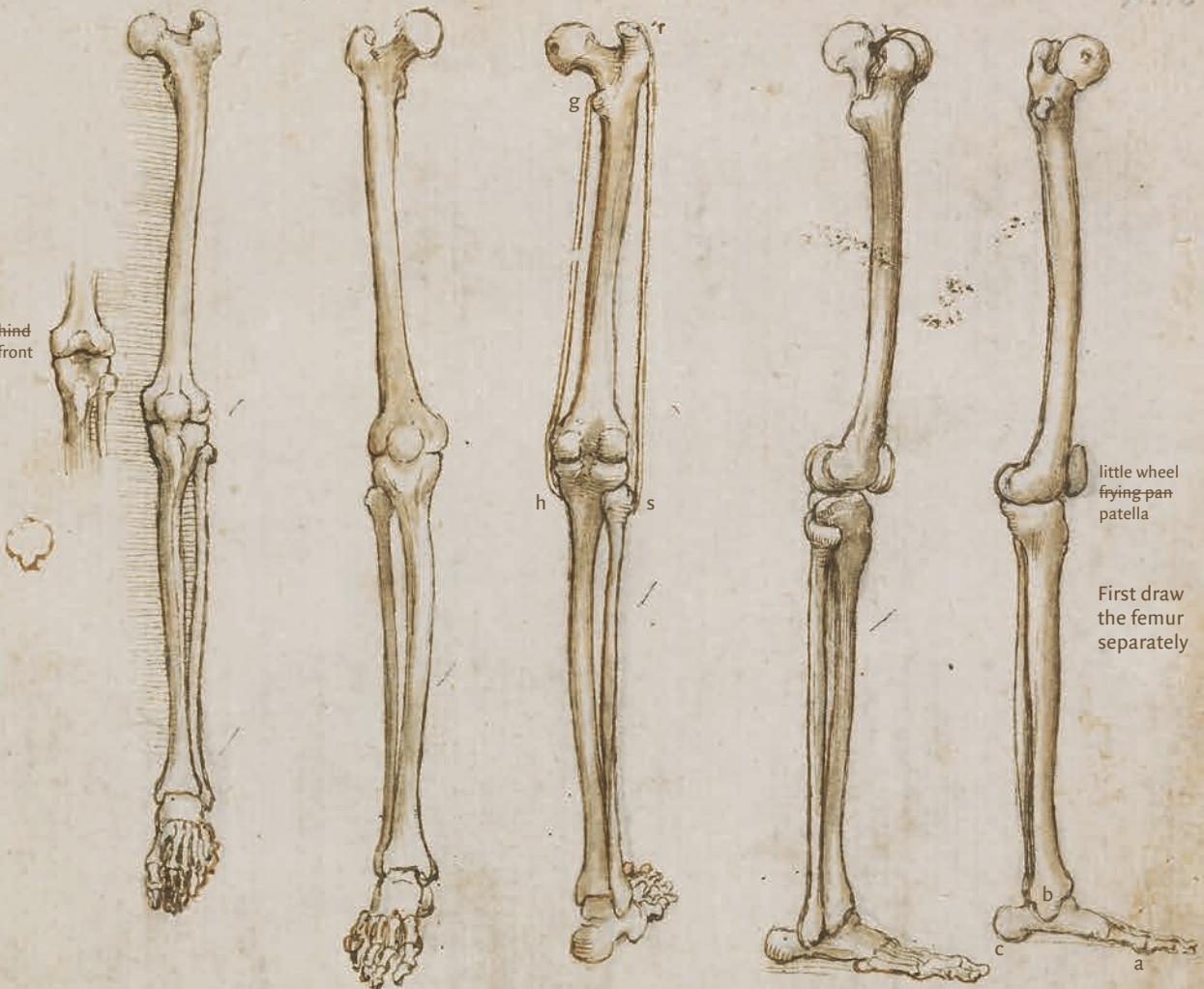
The drawing at lower left clothes these bones in muscle (see key diagram). The location of the greater trochanter is prominent, at the side of the hip from where (in Leonardo's drawing) the fibres of several muscles appear to radiate. Vastus lateralis dominates the side of the thigh; behind, the semitendinosus/semimembranosus pair and biceps femoris can be seen. The posterior compartment of the leg is opened to show gastrocnemius and soleus. At about the plane of the fibula, however, the crural fascia appears to be cut and reflected forwards, impeding further identification of structures.

The small sketch at the top of the sheet shows a steel rod with small ribs or engraved lines along its curved face, used to strike a flint to start a fire. In Italian this had two names: *acciauolo*, as written alongside the sketch here; and *focile*, the word he used elsewhere in the manuscript for the radius and ulna, tibia and fibula, and occasionally the humerus or (as here at upper right) the femur. The allusion is to the long, thin shape of these bones, but Leonardo's reason for making this sketch here is unclear.

fire-stick

A. 10

knee
from behind
from in front



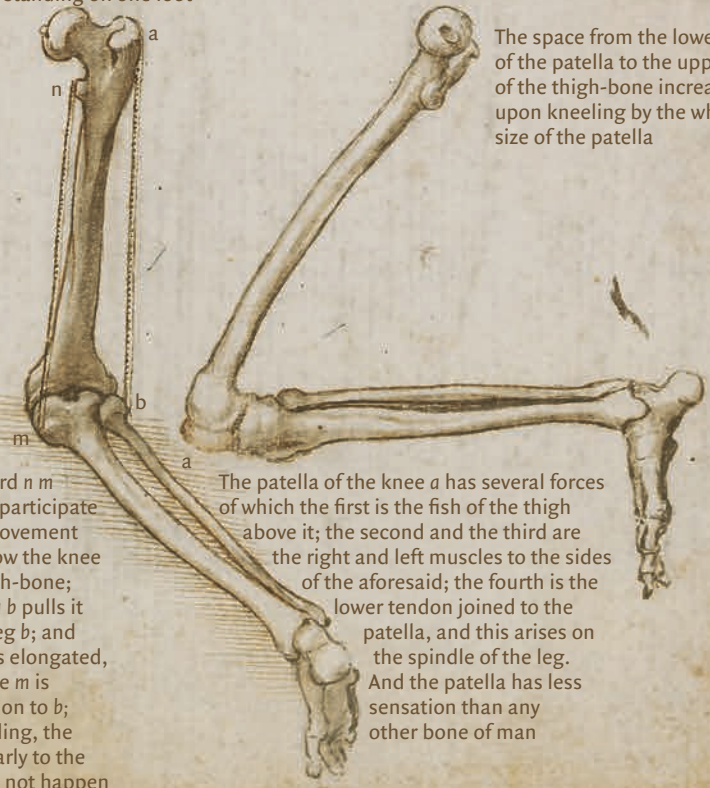
little wheel
frying-pan
patella

First draw
the femur
separately

Note here that the tendon that gets hold of the heel *c* pulls it so far upwards that it raises a man onto the ball of his foot *a*, the weight of the man being at the axis *b*; and because the lever *bc* goes twice into the counterlever *ba*, 400 pounds of force at *c* makes 200 pounds of power at *a*, with the man standing on one foot



Say what the
bump *n* does



The space from the lower edge
of the patella to the upper part
of the thigh-bone increases
upon kneeling by the whole
size of the patella

as is shown
above by the
two cords *rsgh*
which, when
pulling, do
not give any
movement to
the leg but
only serve to
pull, close
and press
together the
bone of the leg
with the bone
of the thigh

The cord *ab* and the cord *nm*
have been arranged to participate
in the circumvoluble movement
that the leg makes below the knee
in contact with the thigh-bone;
that is, when the cord *ab* pulls it
moves the side of the leg *b*; and
the opposite cord *nm* is elongated,
and the side of the bone *m* is
moved in contrary motion to *b*;
and likewise, when pulling, the
cord *nm* behaves similarly to the
cord *ab*. And this could not happen
if the leg were straight

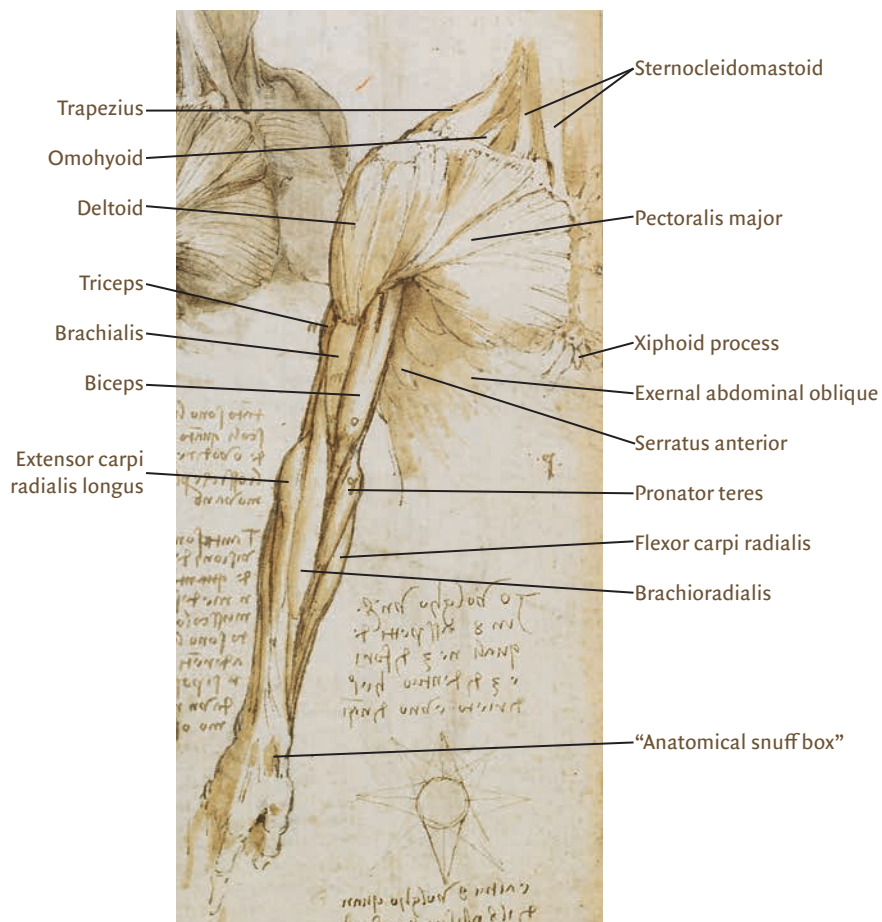
The patella of the knee *a* has several forces
of which the first is the fish of the thigh
above it; the second and the third are
the right and left muscles to the sides
of the aforesaid; the fourth is the
lower tendon joined to the
patella, and this arises on
the spindle of the leg. And the patella has less
sensation than any
other bone of man

THE MUSCLES OF THE SHOULDER, ARM AND NECK

FOL. 9V

This sheet commences a sequence of drawings continued on fol. 6v, turning the shoulder and arm from a fully anterior view to a fully posterior view—the drawing to the right here is labelled 1st. The small star-shaped diagram and accompanying note at lower right explain Leonardo's aim to depict the arm through 360° from eight aspects, but the two pages together provide an even more finely divided set of depictions, giving eight aspects in 180°.

Leonardo labels the muscles triceps (n), brachialis (m), biceps (o) and pronator teres (p; see key diagram). He explains the actions of the scapular muscles upon the humerus, acutely observing that serratus anterior stabilises the scapula against the chest wall in order for the limb to bear weight; and he notes that brachialis can flex the elbow regardless of the degree of supination of the forearm. An outline of the xiphoid process (at the lower end of the sternum) and adjacent ribs is found in the drawing to the right, where Leonardo has also captured the interdigitation of serratus anterior and the external abdominal oblique muscles on the side of the chest. The muscles



Handwritten label for the first anatomical drawing.

Handwritten label for the second anatomical drawing.

Handwritten label for the third anatomical drawing.



Handwritten text block describing the anatomical structures shown in the second drawing.

Handwritten text block describing the anatomical structures shown in the third drawing.

Handwritten text block describing the anatomical structures shown in the fourth drawing.



Large handwritten text block in the center of the page, providing detailed descriptions of the anatomical structures.

Handwritten text block describing the anatomical structures shown in the fifth drawing.

Handwritten text block describing the anatomical structures shown in the sixth drawing.

Handwritten text block describing the anatomical structures shown in the seventh drawing.



Handwritten text block describing the diagram or its application.

Large handwritten text block on the left side of the page, providing detailed descriptions of the anatomical structures.

in the lower arm that operate the thumb are indicated, with their tendons on the back of the hand forming the feature known as the 'anatomical snuff box'. There are, as always, a few idiosyncrasies, but the drawings and notes reveal a profound understanding of the muscles of shoulder and upper arm. Medical illustration has never produced images to surpass those on this sheet.

The three brief drawings at the top of the sheet illustrate the layers of muscles attached to the spinous processes of the neck, but full identification is hindered by the absence of notes and by Leonardo's failure to show the other attachments of the muscles indicated. The study to the right illustrates different layers of muscle on either side of the spinal column, and is thus entitled '1st and 2nd diagrams': on the right is a portion of trapezius, and on the left possibly the rhomboid muscles. The drawing at centre, judging from the direction of the muscle fibres, probably shows one of the splenius group, perhaps splenius capitis. The drawing to the left, again from the fibre direction, could show part of the spinalis group (the fibre direction is also that of multifidis, but the position and size of the fibres indicated in the lower cervical region do not correspond with that muscle). This region was studied in much more detail on fol. 16r.

Which are those veins that are confined to the bones?

4th diagram

3rd diagram

1st and 2nd diagrams



Which are the muscles that are united in men of great strength?

Which are the muscles that are never hidden by fatness or fleshiness?

Which are the muscles that are divided in lean men?



All the muscles arising on the humerus serve to move the two lower bones of the arm

The muscle n is not shown, either relaxed or contracted, if the arm is not extended because, as it is attached to the end of the elbow, it exists for the purpose of extending the arm

The muscle m exists for the purpose of bending the arm, etc

The muscle o is arranged to turn the arm below the elbow, and it rotates it thus whether the arm is extended or bent, and if the hand shows you its hairy side this muscle then assists the strength of the muscle m

All the muscles arising on the chest and on the outside of the scapula serve to move the humerus, that is, the bone between the shoulder and the elbow
But the muscles arising on the anterior part of the scapula partly serve to move the humerus and partly to bind the scapula to the ribs of the chest

There are as many muscles as tendons, or rather, as many as there are bones that are moved by them
There are as many divisions of the tendons and of a muscle itself as there are movements that can be made by a bone

I turn an arm through eight aspects, of which three are outside and three inside and one from behind and one from in front



and I turn it through another eight when the arm has its two lower bones crossed

THE BONES, MUSCLES AND TENDONS OF THE HAND

FOL. 10R

These magnificent drawings and notes are among the high points of Leonardo's career as an anatomist. They demonstrate with complete clarity the mechanical structure of the hand, not stripping it down as in a dissection but building it up in the manner of an engineer. Leonardo begins with the bones at lower left (labelled 1st, and treated in more detail on the other side of the sheet), then adds the deep muscles and tendons of the palm and wrist at lower right (2nd), the first layer of tendons at upper left (3rd) and the second layer of tendons at upper right (4th). Two further drawings, adding the nerves and then the blood vessels, are labelled 5th and 6th on fol. 13v. The smaller drawings study points of detail, and the extensive notes are (almost) all germane to the drawings.

The drawing of the bones is a little confused at the wrist, and more clearly rendered in the images on the other side of this sheet. An erased thread (p q) passes from the metacarpal of the middle finger towards the thumb, probably representing the adductor pollicis muscle; another thread between the radius and the first metacarpal bone of the thumb is possibly the radial or lateral collateral ligament, or a tendon of abductor pollicis longus or extensor brevis.

At lower right the bones are clothed in the deepest muscle and tendon. We see the thenar and hypothenar muscle compartments, controlling the thumb and little finger respectively, and the deep transverse metacarpal ligament spanning the knuckles to keep them from separating. The carpal tunnel is open, and pronator quadratus (a) is shown connecting the radius (c) to the ulna (b; cf. fol. iv).

At upper left Leonardo adds the tendons of flexor digitorum profundus, running from the muscle on the anterior side of the ulna, through the carpal tunnel beneath the transverse carpal ligament (represented here by two threads from p to q), to the palmar side of the distal phalanges (fingertips).

The tendons of flexor digitorum superficialis (or sublimis) are added at upper right, along with the ulnar and median nerves that are reflected to the sides of the wrist. Leonardo has also shown some of the fibrous sheaths and annular ligaments that hold the tendons in place and thus allow the bending of the fingers, as demonstrated in the small but brilliant study of a bent finger at lower right. That drawing also shows, schematically, a tendon of the extensor digitorum muscle running around the outside of the finger. Leonardo comments elsewhere on the page that the tendons on the palm of the hand are thicker than those on its back, and indeed one can grip much more strongly than one can open a closed fist.

Handwritten text at the top of the page, likely a title or introductory notes, written in a cursive script.

Vertical column of handwritten text on the left side, positioned between the two large anatomical drawings.



Vertical column of handwritten text on the right side, positioned between the two large anatomical drawings.



Vertical column of handwritten text on the left side, positioned below the first large anatomical drawing.

Block of handwritten text located in the center of the page, between the two large anatomical drawings.



Block of handwritten text on the right side, positioned below the second large anatomical drawing.



Block of handwritten text on the left side, positioned below the third large anatomical drawing.



Vertical column of handwritten text on the left side, positioned at the bottom of the page.

Large block of handwritten text at the bottom center of the page, below the anatomical drawings.

Vertical column of handwritten text on the right side, positioned at the bottom of the page.

As their names indicate, *flexor digitorum profundus* lies below *superficialis*, but its tendons attach further down the fingers, and consequently the tendons of *profundus* penetrate those of *superficialis*. Leonardo was entranced by the elegance of this arrangement, and he surrounded his diagram of the tendons at upper centre with a note reminding himself to precede his book on anatomy with one on ‘the elements of mechanics’—once again highlighting the purely physical basis of Leonardo’s anatomical work around 1510.

In the bottom right corner, Leonardo queries the mechanism that allows the finger to flex at the first knuckle while keeping the finger straight. The note at centre right answers the question: he observes that the tendons shown at upper right cause ‘movement of the first and second pieces of bone of the fingers’ but not ‘of the third larger bone’, which, he implies, is caused by muscles that do not ‘have any tendons that come into contact with the fingers of the hands’. These are the lumbrical muscles (also present in the feet, as Leonardo notes—see fol. 7v), which attach not to bone but to the tendons of *flexor digitorum profundus*, crossing to the dorsal side at the metacarpal-phalangeal joint (knuckle) to insert on extensor expansions on the dorsal surface (back) of the hand. As such they are difficult to analyse in dissection, but Leonardo appears to have understood their function perfectly.

Most of the material discussed above deals with the flexion and extension of the fingers, but Leonardo was also interested in their abduction and adduction (spreading and closing up). The small drawing at top right shows the spreading of the digits, and a note explains how the shallow ball-and-socket metacarpal-phalangeal joint allows the tendons along each side to move the tip of the finger in a circle (circumduction). The diagrams at the centre of the sheet and below centre right are similarly concerned with the abduction and adduction of the thumb.

In a note to the left of centre, Leonardo noted an interesting sensory illusion but explained it incorrectly (he also examined the phenomenon on fol. 13v). He realised that if you cross the third and fourth fingers and clutch an object between them, it touches sides of the fingers that cannot normally be touched simultaneously by one object, and so one may sense that two objects are being held. Leonardo attributed the illusion to two different nerves (ulnar and median) being involved; not unreasonably, he perceived the nerves as conveying sensation outwards to the members rather than inwards to the brain.

The larger note at the head of the page, and probably the first to be added to the sheet, is an amusing aside on coition, and reminds us that these sheets, however brilliant, are not finished pieces but simply Leonardo’s working studies.

Each finger can individually perform a circular movement with its tip—that is, when holding the hand in the air, supported by the thumb on a level surface, you can describe a circle with each fingertip, because there are four tendons in each of them

The act of coition and the members employed are of such ugliness that were it not for the beauty of the faces and the adornments of the participants and their frenetic state of mind, nature would lose the human species

Show and describe which tendon of each finger is strongest and thickest, and arises from the largest muscle and from the thickest tendon, and is placed on the largest bone of the finger

The tendons of the palm of the hand together with their muscles are much thicker than those of its back

To be noted
Note in what way the muscles arising on the bones of the palm of the hand are joined to the first bones of the fingers, and how they bend them and how the nerves penetrate them

These ten diagrams of the hand would be better turned the other way up; but I am constrained by the first general diagram of man, which requires me to draw him with his hands down, and so as not to deviate from that principle I am persuaded to draw them turned downwards

3rd
Show which muscle is the cause of the tightening of the base p q of the palm of the hand, and likewise of its relaxation

Provide that the book on the elements of mechanics, with its practice, comes before the demonstration of the movement and force of other man and animals; and by of these will be able to prove propositions

Describe how many membranes are interposed between the skin and the bone of the hand

4th
Remember to draw the cause of the widening movement of the fingers a b and b c and by the same rule describe all the widenings of the other fingers and of the other members, and remember that there must be ten diagrams of the hand from the front

I have drawn here the cause of movement of the first and second pieces of bone of the fingers, but not the movement of the third larger bone, which comprises half the length of the fingers; for in truth how this bone is moved could not be shown here without first giving the second diagram of the second hand
But this only makes me doubt whether these muscles have any tendons that come into contact with the fingers of the hands, as is seen here; and the foot has illustrated this case very well

1st
If you cross the fingers c d in such a way that a b touch a single thing between them, in an aggravating way such that the two fingers hurt, I say that the thing will give pain in three places and appear to be two things and this happens because a has sensation from the nerve that passes by the elbow, and b has sensation from the nerve that passes inside the joint of the elbow

a is a strong fleshy muscle that begins on the inside bone of the arm and finishes on the other, outside bone, and is created solely so that the two bones b c do not separate

To make a better diagram of where the muscles of the palm of the hand are attached to the bones, draw them as threads

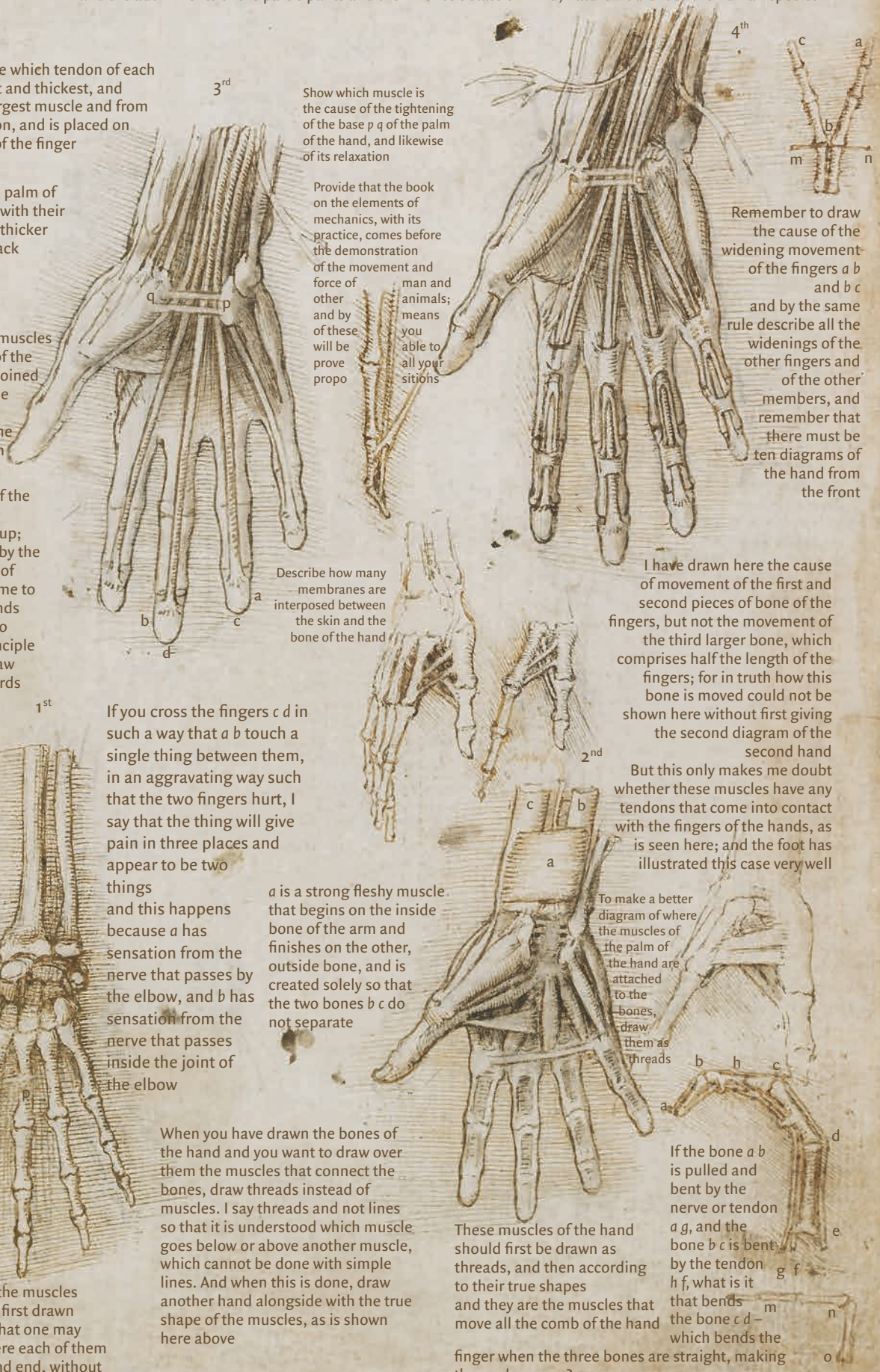
When you have drawn the bones of the hand and you want to draw over them the muscles that connect the bones, draw threads instead of muscles. I say threads and not lines so that it is understood which muscle goes below or above another muscle, which cannot be done with simple lines. And when this is done, draw another hand alongside with the true shape of the muscles, as is shown here above

These muscles of the hand should first be drawn as threads, and then according to their true shapes and they are the muscles that move all the comb of the hand finger when the three bones are straight, making the angle m n o?

Arrange it that the muscles of the hand are first drawn as threads, so that one may quickly see where each of them has its origin and end, without one impeding another

The middle finger has in its custody the thumb by means of the muscle p q

from inside hand seen



THE BONES OF THE HAND

FOL. 10V

This page is the start of Leonardo's exposition of the anatomy of the forearm, wrist and hand, and in the formal note at the top he sets out the sequence of diagrams that he intended to provide. These intentions were mostly carried out, here and on fols. 10r and 13v, though Leonardo did not, so far as we know, make a sequence of drawings of 'the hand clothed with skin . . . for an old man, a young man and a child, and for each will be given the measurements of length, thickness and width for each of its parts'. There is also no clear depiction of the second stage, 'the ligaments and various interconnections of tendons that join them together', though the drawing at lower left of fol. 10r, which seems at first glance essentially to duplicate that at upper right here, may initially have been intended to be such a drawing.

The two largest drawings give palmar (right) and dorsal (left) views of a right hand. While the carpal (wrist) bones are identifiable from their position, the shape of each is not perfectly clear. Below are views from either side, lateral then medial, with the thumb slightly lowered. Leonardo therefore gives four orthogonal views of the same stage of dissection; but his ambitions were endless, and having made these four drawings he recorded at the centre of the sheet his wish to depict each individual bone in four aspects. The magnitude of this task is emphasised by the note at centre left, which enumerates the twenty-seven bones of the hand (assigning them letters and numbers as they did not at that time have standardised names). And while we now consider the thumb as comprising two phalanges and a metacarpal, Leonardo regarded it as three phalanges and no metacarpal.

Handwritten text at the top of the page, likely a title or introductory notes, written in a cursive script.

Vertical column of handwritten text on the left side of the page, providing anatomical descriptions.



Vertical column of handwritten text between the two main hand drawings, providing anatomical descriptions.



Vertical column of handwritten text on the right side of the page, providing anatomical descriptions.



Large block of handwritten text at the bottom of the page, providing anatomical descriptions.



The sketch at bottom right shows the fist clenched with the tendons of palmaris longus and flexor carpi radialis raised. The note alongside is a laborious discussion of the various movements of the wrist: the terminology for movements at the joints was not yet developed, so we must struggle with Leonardo's descriptions of flexion-extension, abduction-adduction and pronation-supination. Picturesquely, he denotes the hairy outside of the arm by the term *silvestra*, literally 'wild', and the smooth inside of the arm by *dimessticha*, 'domesticated'.

The drawings and notes on the (non-specific) finger in the right margin would make more sense at the end of the sequence of hand studies, when all the systems of the hand had been demonstrated. These are lateral views, with the extensor or dorsal side towards the margin of the sheet. Leonardo indicates *a*, the tendon of extensor digitorum, which straightens the finger; *b*, 'the vein that nourishes the finger'; *c*, the nerve; *d*, 'the vein that gives vital spirit to the finger' (i.e. the artery); and *e*, the tendon of flexor digitorum profundus, which bends the finger.

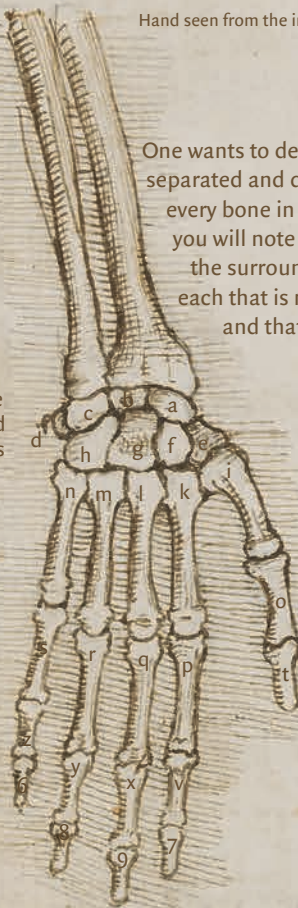
Depiction of the hand

The first diagram of the hand will be of its bones alone. The second, of the ligaments and various interconnections of tendons that join them together. The third will be of the muscles that arise on these bones. The fourth will be of the first tendons that are placed on these muscles, and give movement to the fingertips. The fifth will show the second rank of tendons, which move all the fingers and terminate on the penultimate piece of bone of the fingers. The sixth will show the nerves that give sensation to the fingers of the hand. The seventh will show the veins and arteries that give nourishment and spirit to the fingers. The eighth and last will be the hand clothed with skin, and this will be drawn for an old man, a young man and a child, and for each will be given the measurements of length, thickness and width for each of its parts

First depict these hands with their bones detached one from the other and somewhat separated, such that the number and the shape of these bones will be well understood from both the inside and the outside, and depict the ligaments of the bones

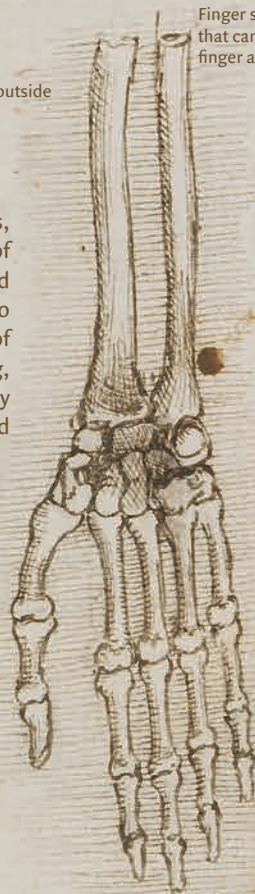
One wants to depict again the bones of these hands, separated and distinct, so that the size and shape of every bone in four aspects is well understood; and you will note the part of each that is connected to the surrounding bones, and likewise the part of each that is not connected to those surrounding, and that must move to effect each and every action of the hand

Hand seen from the outside



27 bones, that is:
 8 in the wrist
 a b c d
 e f g h
 4 in the palm
 k l m n
 15 in the 5 fingers
 i p q r s
 o v x y z
 t 7 9 8 6
 and I give three bones to the thumb as to the other four fingers, because in there are three moveable pieces of bone like the three of each of the other fingers of the hand

Hand that shows the inner side



Finger seen from that side that can be touched by the finger alongside



The first bone of the thumb and the first bone of the index finger are positioned on the basilar bone e, and are direct supporters of each other, in as much as the bone i receives as much support from bone k as bone k receives from bone f

a is the tendon that straightens the bent finger
 e is the tendon that bends the straight finger
 b is the vein that nourishes the finger
 d is the vein that gives vital spirit to the finger
 c is the nerve that gives sensation etc;

upon which, being cut, the finger feels nothing, even when it is put in a fire, and because of this, careful nature arranges to put it between one finger and another, so that it will not be cut



The hand held as a clenched fist has four principal movements, of which the first is towards the smooth part of the arm, and the second is towards the hairy part of the arm; of the other two movements, one is towards the head and the other is towards the feet, or one is



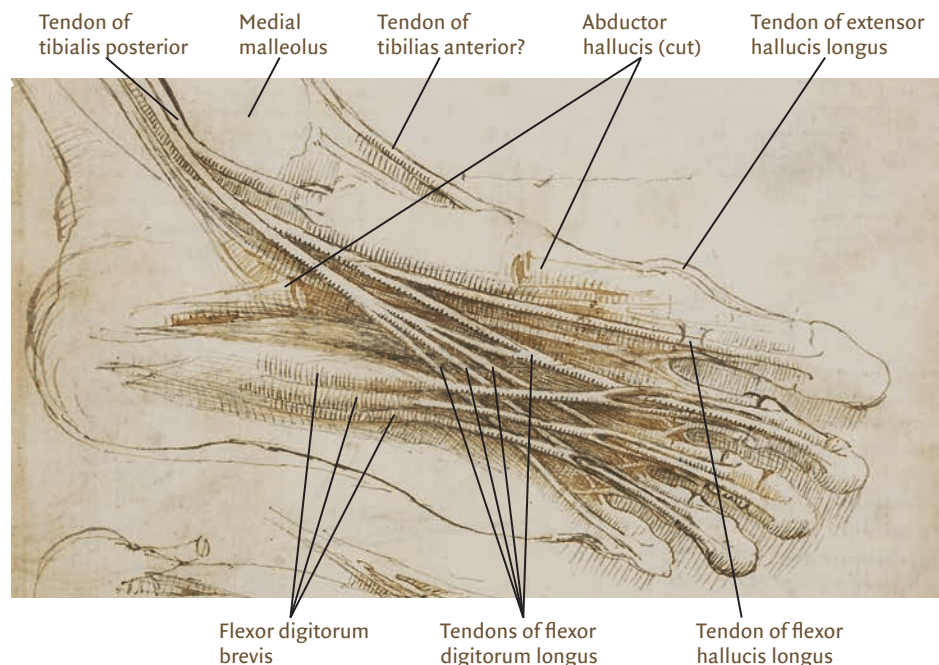
between the smooth and hairy sides towards the large bone of the arm, the other between the smooth and hairy sides towards the small bone of the arm. After these, note the compound movements, which are called compound because they partake of two of the aforesaid movements, and these are infinite, being made through continuous space between the said four principal movements. The rotatory movement of the hand follows, in which none of the aforementioned muscles is used, but the motor muscles of the two bones alone turn the hand around. There follow the muscles and motor tendons of the fingers

THE MUSCLES AND TENDONS OF THE SOLE OF THE FOOT

FOL. 11R

In the principal drawing above, the plantar aponeurosis (the thick connective tissue that supports the arch of the foot) has been removed to reveal the first layer of the sole (see fol. 7v). The oblique angle of view is not entirely consistent—it is mostly an inferior or plantar view, but aspects of the medial (inner) side and even hints of the dorsum (upper surface) are also present. Leonardo labelled the muscles abductor hallucis (a), with its origin on the calcaneus or heel-bone and insertion on the first phalanx of the big toe; and flexor digitorum brevis (b), originating on the calcaneus, then dividing into four tendons, each splitting around the tendons of flexor digitorum longus to insert on the second phalanges of the other toes. Abductor digiti minimi, passing from the calcaneus to the little toe along the outer edge of the foot, is hinted at but not explicitly indicated. Leonardo's dissection technique was precise enough to reveal the fine communications between branches of the medial and lateral plantar nerves, running parallel to and across flexor digitorum brevis.

Below, the nerves have been removed, abductor hallucis cut, and flexor digitorum brevis reduced in size (but not to threads), to show elements of the 'second layer' (see key diagram). The longer tendons passing from the lower leg around the ankle are now fully exposed: that of flexor hallucis longus, passing to the last phalanx of the big toe, and those of flexor digitorum longus, penetrating the tendons of flexor digitorum brevis to attach to the last phalanges of the other toes. This arrangement parallels the penetration of the



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Handwritten text in a cursive script, located below the upper right anatomical drawing.



Handwritten text in a cursive script, located in the middle section of the page, between two large anatomical drawings.



tendons of flexor digitorum sublimis by those of flexor digitorum profundus in the hand, which had so impressed Leonardo in fol. 10r, and thus he was moved to note here that ‘the hand is to the arm as the foot is to the leg’. The tendon along the upper contour of the drawing is probably that of tibialis anterior (anticus), though the view is more plantar than first appears, and the tendon of extensor hallucis longus is not seen until the metatarsal-phalangeal joint.

Leonardo wished to make a series of drawings of the anatomy of the foot equivalent to those of the hand on fols. 10r-v and 13v. The note at the top of the page sets out the series of drawings required, though he does not initially mention the muscles, saying instead ‘leave in place the membrane that clothes [the bones]’. By this it is unlikely that he meant the periosteum, the thin membrane that covers the outer surface of all the bones. Each bone is connected to the adjacent bones at its margins by capsules that contain synovial fluid. These capsules are attached to the periosteum, to the ligaments and to the tendons; with age the ligaments become more accentuated and can spread out to dominate the complicated anatomy of the region. Attempting to remove one element during dissection will tend to remove the others as a continuous entity, and this continuum of capsules, ligaments and tendons is probably the ‘membrane’ that Leonardo refers to.

The two smaller drawings on the page may be sketches made as Leonardo attempted to synthesise his dissection notes. The study at the top of the page shows neurovascular elements streaming into the sole of the foot, but specific identification is not possible. At the bottom of the page, we see both abductor hallucis and flexor digitorum brevis cut and reflected from the sole of the foot to show quadratus plantae (or flexor accessorius). That unusual muscle has multiple origins on the calcaneus (heel-bone) and inserts into the tendons of flexor digitorum longus, and in a confused area at the right of the sketch Leonardo tries to make sense of this tendon-on-tendon insertion.

A. 12
18 June 1788
The anatomy of the foot

Draw a diagram of this foot with the bones alone, then leave in place the membrane that clothes them and draw a simple diagram of the nerves, and then on the same bones draw one of the tendons, and then one of the veins and arteries together. And finally a single diagram that contains arteries, veins, nerves, tendons, muscles and bones

Which are the tendons or cords that widen and press together the toes, one against the other?



The muscles that move the toes at their points, both below the toe and above, all arise on the leg from the knee to the joint of the foot, and those that move the whole toe up and down arise on top of and underneath the foot; and thus the hand is to the arm as the foot is to the leg



THE MUSCLES OF THE LOWER LEG

FOL. 11V

The main drawing depicts the medial aspect (inside) of the left leg, with the muscles of the calf, gastrocnemius and soleus, prominent. The lateral (h) and medial (k) portions of gastrocnemius are shown as distinct muscles. Leonardo recognised that soleus (m) and the two portions of gastrocnemius unite in the calcaneal (Achilles) tendon (s); and he thus asks in a note why there are ‘three’ muscles when one would suffice. Indeed some anatomists now describe soleus and the two portions of gastrocnemius as three portions of a single muscle, triceps surae.

The structures running behind the medial malleolus or ankle (a) include the tendon of flexor digitorum longus (n), the tibial nerve (o), the posterior tibial artery between these two, and the tendon of tibialis posterior between n and a. The tendon of tibialis anterior is prominent at f, with that of extensor hallucis longus passing along the upper contour of the foot to insert on the big toe. Much of the abductor hallucis muscle has been removed from the foot (cf. fol. 11r) in order to show the tendon of tibialis posterior passing along the sole. Cutaneous veins and other structures on the dorsum (upper surface) of the foot are also shown, but it is difficult to distinguish them from one another.

At centre right is a discussion of the statics of standing on the ball of the foot. Leonardo states that the ball of the foot and the heel are effectively equidistant from the axis of the ankle, that the pull exerted by the calf muscle must therefore be equal to the weight supported on the ball of the foot, and thus that the force felt at the joint of the ankle is twice that of the weight supported on that foot. (He makes a similar calculation on fol. 9r, though there he works on the basis that the distance from the ankle to the ball of the foot is twice the distance from the ankle to the heel.) Leonardo appears to show the fibula on the medial side of the tibia, a surprisingly common error in the manuscript. In the brief note alongside the drawing he describes the relaxation of the gastrocnemius muscle, stating that it *disgonfiera*, literally ‘deflates’. This is a reflection of the ancient physiology of the muscles that explained their contraction and relaxation as due to inflation and deflation (see fol. 18r).

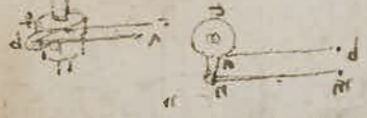
Handwritten text in a cursive script, likely a medical or anatomical treatise, located in the upper left quadrant of the page.

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As on the other side of the sheet (fol. 11r), Leonardo's discussion of the 'membrane that clothes the bones and holds the bones together' at lower right refers not to the periosteum, but to the continuous complex of capsules, ligaments and tendons of the foot. The diagrams and notes below centre left deal in a simple mechanical fashion with the tendons attached to the vertebrae, a subject treated in much more depth on fol. 16r–v.

The note at upper left reminds us once more why Leonardo was never able to complete his study of anatomy. Not content with the majestic depiction of the anatomy of man that we see in these pages, he wished to demonstrate the functioning of the limbs in a variety of actions and from different aspects, both for man and also for 'other animals'. The scope of this functional comparative anatomy—potentially of great use to an artist—was immense, but beyond his studies of the horse, pursued at various points in his career, there is no evidence that Leonardo ever began to compile such drawings systematically.

For the word 'Leoni', written at lower centre, see fol. 5v.

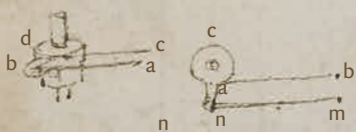
After the demonstration of all the components of the limbs of man and of other animals, the way in which these limbs work so well is to be depicted, that is, getting up from lying down, walking, running and jumping from different aspects, lifting and carrying great weights, throwing things, and swimming; and for each action, depict which limbs and muscles are the cause of the aforesaid operations, especially in the play of the arms

k serves to raise the heel, and this muscle becomes hard in pulling the heel as well as in releasing it

This calf of the leg has several muscles that are joined together along their length; that is, the muscle h, which serves to bend the leg, serves also in part the heel, helping the muscle k with which it is joined

Further, m serves c as it does k; therefore k m c serve the heel, and here one asks why nature did not put one single muscle here, which would be as much use as these three

Why the muscles of the neck are attached to the ends of the spurs of the vertebrae



c is the vertebra, n is the end of its spur. I say that nature has attached these tendons to the ends of the spurs of these vertebrae of the neck because if the tendon is placed at m n it turns that vertebra more easily than if it were placed at b a—because m n is attached to a longer lever than b a, and gives as much more power as it is longer, as is proved in the fifth chapter of the fourth book on the elements of mechanics

Frequently two muscles are joined together even though they have to serve two parts of a limb; and this is done so that if one muscle were impeded by some lesion, the other muscle may in part supply the place of that which is missing

Here is given the reason for the strength and fatigue that the muscles feel

When the muscle d with its adherents deflates, it descends and elongates until the heel descends to the ground at c



When a man raises himself on the points of his feet, the muscles f d feel with their pulling half the weight of the man on each leg; and it is proved thus by the balance a b c, in which the fulcrum is at b and the ends are equidistant from the fulcrum at a and c. Placing the ball of the foot m at a, the axis of the foot v cannot descend because

The tendons that move the foot towards the heel or joint of the foot are n f, therefore f is common to two movements, that is, raising and bending the foot. And here you see the wisdom of nature in providing two causes of movement in each limb, for if one is lacking the other replaces it, in part if not entirely

the tendon f n which is attached to the heel does not want to be extended; and thus the ankle or joint of the foot v bears a weight of 200 pounds, of which 100 is natural weight at m or rather at a, and 100 is accidental weight at n. And both powers are directed upwards because m wants to go to g, and n is pulled up by the calf of the leg

Observe the threads of the muscles that are joined together, as is shown on the smooth side of the calf where m meets with c at s, and see which threads are common and which are separate

Draw a diagram of these feet without the membrane that clothes the bones and holds the bones together, interposing itself between the bones and the muscles and tendons that move them; and in this way you will be able to show under which tendons, nerves, veins or muscles are the joints of the bones

THE BONES OF THE FOOT, AND THE SHOULDER

FOL. 12R

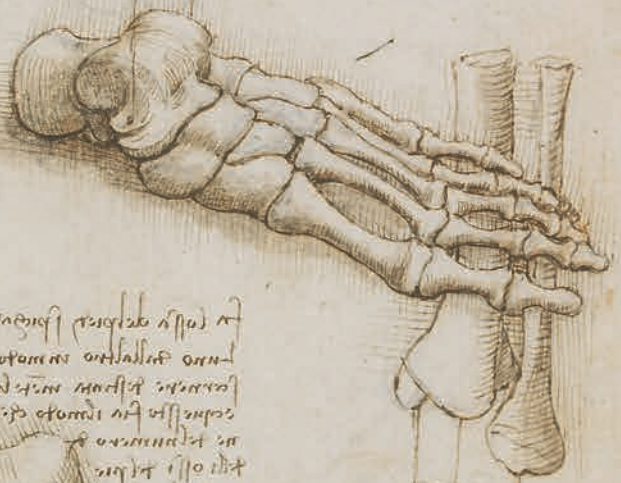
These illustrations of the foot are extraordinary, with every bone evident and accurately articulated (see key diagram to fol. 1r). Leonardo has consistently shown the little toe with two (rather than three) phalanges, a common variation found in almost half of individuals. The only real shortcoming is that these feet are ‘flat’—as Leonardo was working with dry, prepared material he did not capture the normal arch of the foot that may readily be observed in most live subjects.

The drawings at upper left and lower left show the plantar surface (sole) of the foot, and thus include the two sesamoid bones below the first metatarsal of the big toe (see fols. 1r and 7v). In the note at bottom left Leonardo acutely notes that the patella or knee-cap is also a sesamoid bone, serving the same mechanical function for the quadriceps femoris complex in the leg (though he does not draw the patella on this page; see fols. 9r and 13r). However Leonardo also states here that the acromion process of the scapula is a sesamoid bone. This conception of the acromion as a separate bone is a recurrent error in Leonardo’s treatment of the shoulder. It is clearly depicted and labelled as a separate bone in fol. 13r, but on fols. 2r and 4v the acromion is shown as fully united with the scapula, and it may be that this reflects Leonardo’s evolving knowledge of the anatomy of the shoulder as his work proceeded. Indeed the depiction of the shoulder at upper centre here is one of his least satisfactory. He has cut the muscles infraspinatus (*a*) and teres minor (*b*) to show their attachments on the humerus, but these are only approximately correct. The curve of the clavicle is exaggerated, trapezius is coarsely rendered, and the acromioclavicular articulation is poorly represented—supraspinatus travels through a gap between the bulbous scapular spine and the misdrawn acromion. Leonardo has however shown the correct attachment of the long head of triceps, between the two letters *b* on the outer margin of the scapula.

Handwritten text in the upper left corner, likely describing the anatomical structures shown in the adjacent drawing.



Handwritten text in the middle left, providing further anatomical details or descriptions.



Handwritten text in the center, likely describing the bones of the hand and forearm.



Handwritten text in the bottom left corner, providing anatomical descriptions.

Handwritten text in the bottom center, likely describing the anatomical structures.

Handwritten text in the bottom right corner, providing anatomical details.

As is often the case, most of the notes are not directly related to the drawings, but rather set out the plethora of depictions that Leonardo intended to provide. He recommends six orthogonal views of the foot (though it is here shown in a range of oblique views), and also stipulates that the bones should be drawn separated (again in six orthogonal views) and then sectioned both along their length and across their width, with measurements given throughout. This might appear obsessive, but if he had drawn and measured the foot in infancy, youth, adulthood and old age—as recommended for the hand on fol. 10v—he would have been able to demonstrate clear developmental differences.

Draw yet another foot from the same aspect, showing how the ligaments and tendons of the bones bind these bones together

Draw these bones of the foot all equally enlarged, in order that their number and shape can be distinctly understood; and draw this from four aspects so that the true shape of these bones may be better understood in all their aspects

Draw the bones of the foot somewhat separated one from the other, in such a way that they may be clearly distinguished, one from the other, and this is the way that you will give knowledge of the number of the bones and of their shape

The glandular bones are always placed close to the ends of tendons, where they are bound to the bones, and eight of these are found in the composition of the human bones, that is: two in the tendons called omeri in the neck where they are joined to the upper end of the bone called the humerus, and two others at the ends of the muscles arising on the pelvis and terminating at the knee, and four in the feet, that is, two for each big toe, on the underside

The aspects of the foot are six, that is, below, above, inside, outside, behind and in front, and to these are added the six diagrams of the bones separated from each other, and one of the bones sawn lengthways in two ways, that is, sawn from the side, and sawn straight through so as to show the whole thickness of the bones

At the end of every depiction of the foot, give the measurement of the thickness and length of every bone, and its position



THE VEINS AND MUSCLES OF THE ARM

FOL. 12V

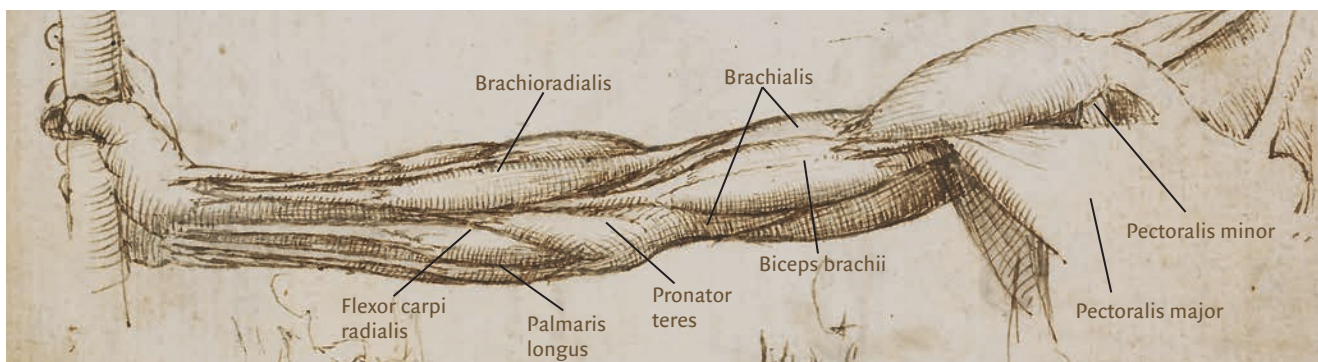
The two upper drawings show the arm and wrist fully extended. Above, the cutaneous veins of the upper limb are accurately rendered: the basilic vein can be followed to its entry deep into the arm near the armpit, and the upper portion of the pectoralis major muscle is reduced to clarify the path of the cephalic vein through the deltopectoral triangle or groove. In the second drawing, this same reduction allows Leonardo to show pectoralis minor through the deltopectoral triangle, inserting at the coracoid process.

Biceps brachii is more accurately illustrated in the second drawing than the first. Its long and short heads are differentiated, showing the broad tendon of origin of the short head, but Leonardo has reduced its size somewhat so that the muscle deep to it, brachialis, is visible on both sides of biceps. The drawing also shows well the muscles and stretched tendons of the lower arm—palmaris longus, flexor carpi radialis, pronator teres and brachioradialis may all be distinguished.

The two drawings below were probably preliminary sketches in which Leonardo was trying to establish the spatial relationships of the muscles, prior to the more finished drawings of the same aspect on fols. 9v, 13v and 14v. The biceps and brachialis muscles are confused, the common extensor muscle origins are exaggerated, and the tendon flow of the common extensors and deeper muscles into the hand is not typical.

The different sizes of the muscles of the shoulder and upper and lower arm led Leonardo, in the note below, to compare the anatomy of a bird and of man:

No movement of the hand or of its fingers is caused by the muscles that lie above the elbow; and it is the same in birds, and thus they are so strong because all the [pectoral] muscles that lower the wings arise in the breast, and they have in themselves greater weight than all the rest of the bird.





Le muscle brachial antérieur se termine par le tendon qui s'attache au
tubercule de la base du 2^e métacarpe. Le muscle brachial postérieur
se termine par le tendon qui s'attache au 5^e métacarpe. Le muscle
brachial antérieur est le plus gros muscle de l'avant-bras. Le muscle
brachial postérieur est le plus gros muscle de l'arrière-bras.

THE SKELETON

FOL. 13R

This page constitutes the most complete representation of a skeleton in the whole of Leonardo's surviving work. The drawings to lower right capture the correct tilt of the pelvic girdle, and include a thread from the anterior surface of the ilium through the patella to the tibia to illustrate the action of the quadriceps. These drawings, however, are not the subject of any of the notes; even the note at lower centre, surrounding (and in the same ink as) a study of the patella, treats the movement of the clavicle.

The three principal drawings and almost all of the notes deal with the joint of the shoulder, the scapula and its relationship to the ribs and the humerus. Whether Leonardo had attempted to visualise a complete skeleton or had actually joined dried bones back together, some errors of detail were perhaps inevitable. In the side view at upper right, the angle of descent of the first two ribs is too acute and the front-to-back dimension of the thorax is somewhat exaggerated; the last two 'floating' ribs (with no anterior cartilaginous attachment) and scapula are far too long. The humerus is well drawn, but the trochlea—the depression in the middle of its lower end, for articulation with the ulna—is on the wrong side of the humerus.

The posterior or rear view at upper left bears many of the same inaccuracies, including the mislocation of the humeral trochlea and the length of the scapula, which should extend from around rib 2 to rib 8. But these comments should not detract from the overall success of the images, with good depictions of vertebral curvature and of the oblique nature of rib placement.

The most peculiar illustration however is that at lower left. It shows separate sternal segments, an unusual rib arrangement, and the acromion (*a*) separated from the remainder of the scapular spine (that this was deliberate is confirmed in the note to the left). In some individuals the acromion can appear separate during ossification (particularly in the young) or as a result of injury, but elsewhere in the manuscript Leonardo plainly showed it as a part of the scapula. The articulations of the clavicle and first rib with the manubrium (*m*) appear accurate, and Leonardo correctly placed the articulation of the second rib at the sternal angle, where the manubrium joins the body of the sternum. While Leonardo correctly indicated twelve pairs of ribs, he shows eight pairs of true ribs (which have a cartilage that joins the sternum independently), two pairs of false ribs (in which the cartilage joins that of the rib above it), and two pairs of floating ribs; now we count seven pairs of true ribs, three pairs of false ribs and two pairs of floating ribs.

Handwritten text at the top of the page, likely a title or introductory notes, written in a cursive script.

Handwritten text block in the upper left corner, providing anatomical descriptions.

Handwritten text block in the upper right corner, providing anatomical descriptions.

Handwritten text block in the middle left area, positioned between the two main torso drawings.

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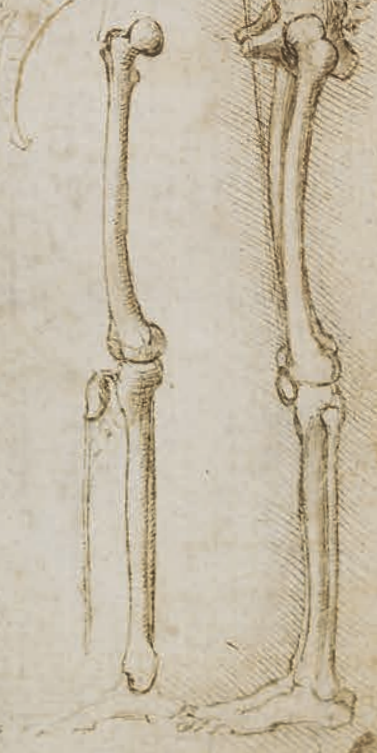
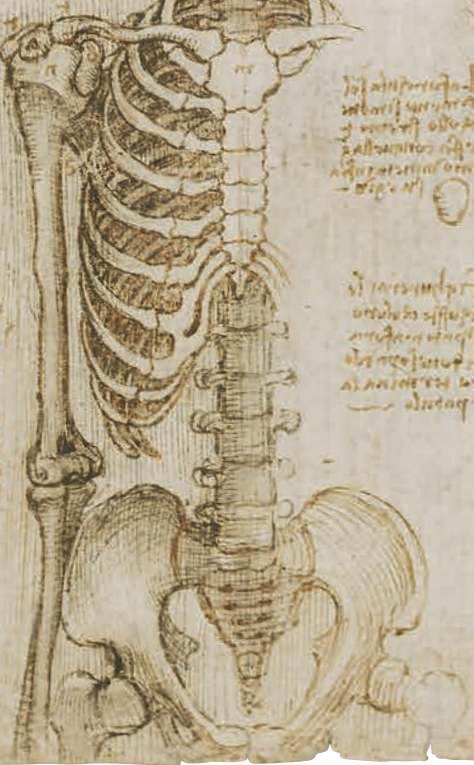


Handwritten text block located to the left of the lower front torso drawing.

Handwritten text block located to the left of the lower back torso drawing.

Handwritten text block located between the two lower torso drawings.

Handwritten text block located between the two lower torso drawings.



The note at the head of the page records Leonardo's intention to determine which parts of the body remain unchanged and which expand the most with different degrees of corpulence—that is, the fat distribution of the body. A concern with different physical types, potentially of great use to the artist, was one of Leonardo's long-term anatomical interests (and was to be one of the dominant themes of Albrecht Dürer's treatise *On human proportion*, published in 1528), but is reflected nowhere else in the manuscript. And there is a solitary echo, in a note to upper centre, of the proportional speculations that had been such an important part of Leonardo's earlier anatomical investigations.

What are the parts of man where the flesh never increases no matter how fat he is, and what are those places where the flesh grows more than in any other place?

A. 14

Draw a diagram of the ribs in which the sternum is shown from within; and likewise a diagram in which the sternum is lifted off, showing the spine of the back from within

Draw the first diagram of the ribs in three depictions without the scapula, and then another three with the scapula

First depict the front of the scapula without the fulcrum of the arm m, and then draw the arm

Head: 1
Jaw: 1
Teeth: 32

Show these two scapulae (thus positioned) from above, from below, from opposite sides, from behind and in front

From the first rib a to the fourth below b is equal to the scapula of the shoulder c d, and likewise to the palm of the hand, and to the foot from its fulcrum to the point of that foot, and all of these things to the length of the face

Before you put in the bone of the arm m, depict the face of the shoulder that receives it, that is, the concavity of the scapula; and do likewise for every joint

5 vertebrae

The scapula takes the bone of the arm on two sides, and on the third side the bone of the clavicle of the chest is taken

First depict the shoulder without the bone a, and then put it in.

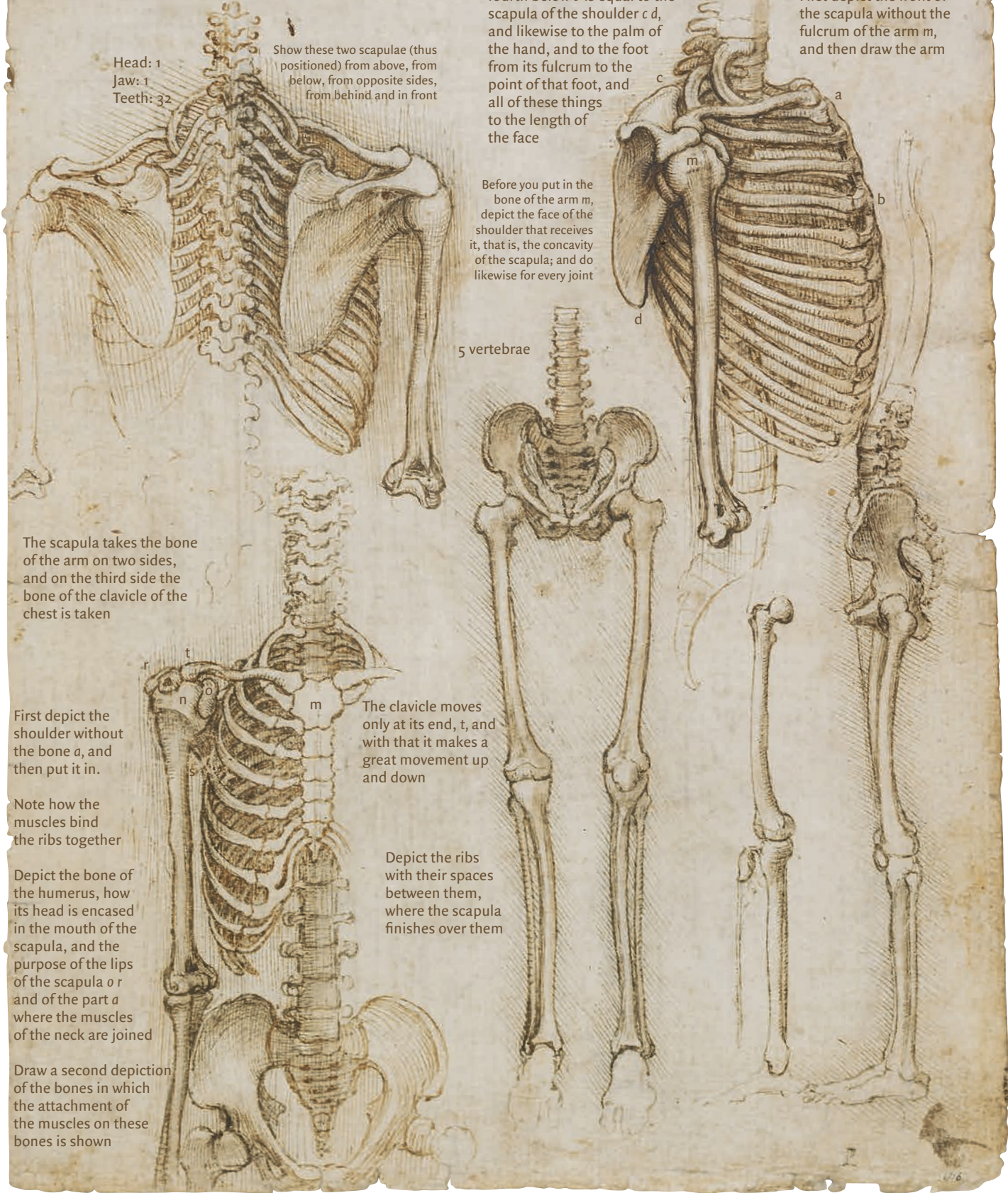
The clavicle moves only at its end, t, and with that it makes a great movement up and down

Note how the muscles bind the ribs together

Depict the bone of the humerus, how its head is encased in the mouth of the scapula, and the purpose of the lips of the scapula o r and of the part a where the muscles of the neck are joined

Depict the ribs with their spaces between them, where the scapula finishes over them

Draw a second depiction of the bones in which the attachment of the muscles on these bones is shown



THE MUSCLES OF THE FACE AND ARM,
AND THE NERVES AND VEINS OF THE HAND
FOL. 13V

Leonardo fits a remarkable amount of information onto this page. There are three main subjects: the palm of the hand, continuing the sequence begun on fol. 10r–v; the muscles of the shoulder and arm, related depictions of which are frequently found elsewhere; and the muscles of the face, a subject treated nowhere else in the manuscript.

These studies of the facial muscles are astonishingly accurate (see key diagram). The drawing to the left depicts the superficial muscles, notoriously difficult to dissect as they may originate and/or insert into the deep surface of the skin; in the drawing at centre some of the superficial muscles have been removed to reveal the deeper structures. Though Leonardo did not distinguish formally between the mimetic muscles of facial expression and the primary muscles of mastication, as today, he did attempt to identify the function of each. The first study shows part of the complex of muscles that raise the upper lip—levator labii superioris (*b n*) and zygomaticus minor (*o t*) and major (*c s*) are clearly distinguished. In a note Leonardo reminds himself to see if this is the same muscle structure that raises the nares (nostrils) of the horse, an action that he had examined in his studies for the *Battle of Anghiari* five years earlier (fig. 9, p. 17).

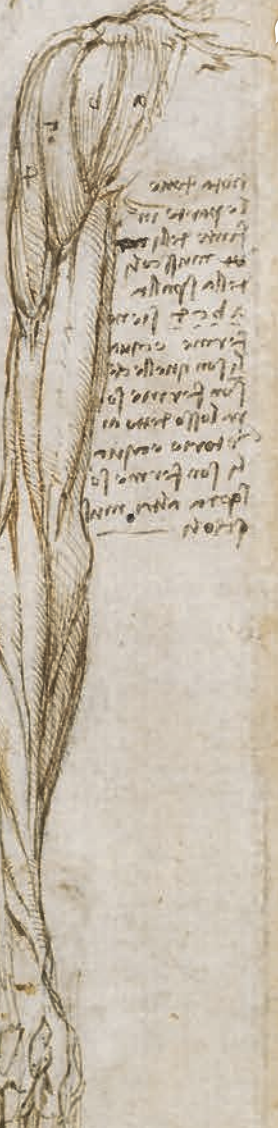
Leonardo called two distinct muscles ‘the muscle of anger’: that along the side of the nose (also labelled *o t*), probably the extravagantly named levator labii superioris alaeque nasi; and *h* at the eyebrow, corrugator supercilii. Above on the forehead is frontalis (*p*), called by Leonardo ‘the muscle of sorrow’. Leonardo regarded temporalis (*g p*) as two distinct muscles, with the anterior portion (*g*) a continuation of the masseter muscle *m n*. With great acuity he identified the two portions of the masseter, noting that when he lifted off the portion *m*, a deeper portion remained on the mandible, labelled at *n* in the deeper dissection at centre. That second drawing also shows the buccinator muscle (*a*) and the zygomatic bone (*f*), below which the levator anguli oris muscle and the duct of the parotid gland may be seen. To the right Leonardo reminds himself to determine whether the nerves that cause movement in the face issue directly from the brain—he has comprehended the difference between spinal nerves and cranial nerves.

The two studies of the hand are as masterful as their associates on fol. 10r. The drawing to the left depicts the entry of the median and ulnar nerves into the hand, with the correct distribution pattern of the nerves for cutaneous sensation. The transverse carpal ligament, which bridges the carpal bones

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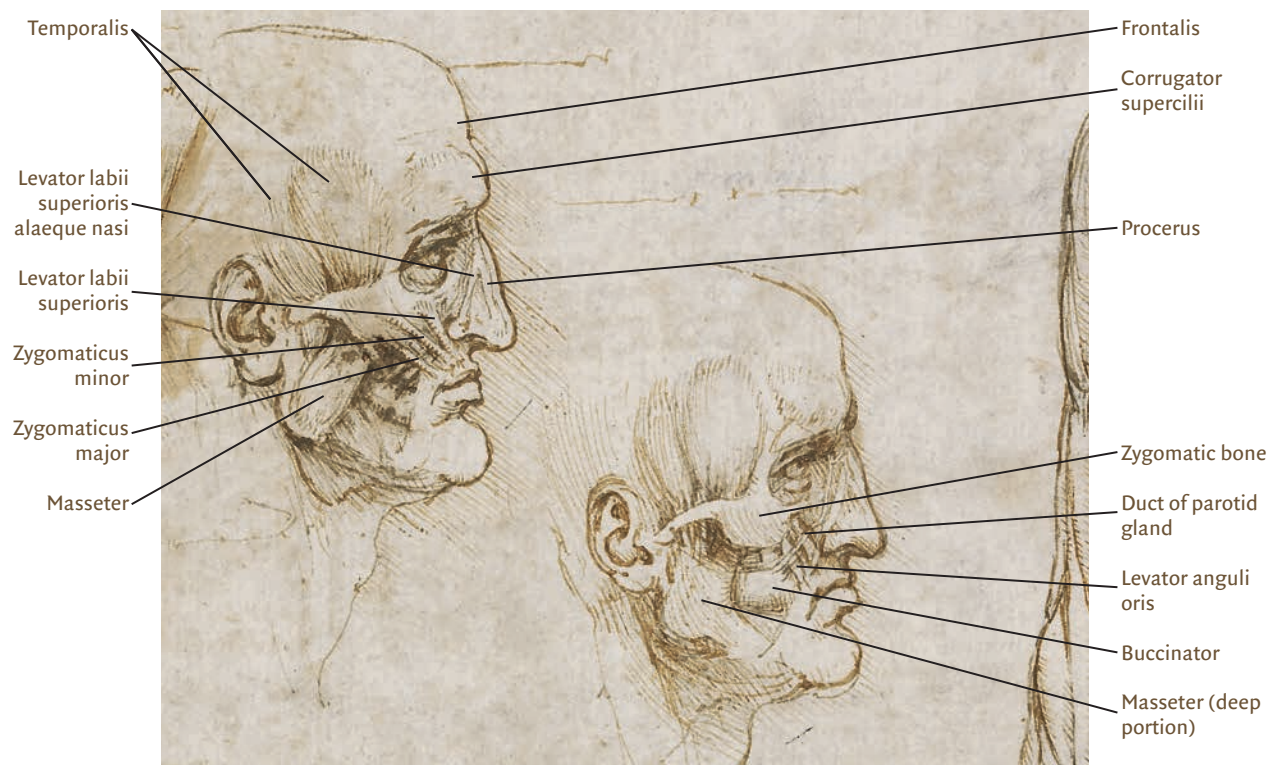


Handwritten text in the upper right quadrant, providing anatomical descriptions and observations related to the adjacent drawings.



Handwritten text at the bottom left, providing further anatomical details and possibly a conclusion to the study.

Handwritten text at the bottom center, likely a continuation of the anatomical notes or a final summary.



and forms the carpal tunnel, is shown (it was represented by two threads on fol. 10r), with the median nerve and long flexors of the fingers passing through the tunnel. The fibrous tendon sheaths are fully indicated; on fol. 10r Leonardo had fenestrated them to show the tendons underneath.

In the drawing of the hand to the right we can see the ulnar artery entering the palm and forming the superficial palmar arch, with the common palmar and proper palmar digital arteries distinct. Running across the palm is the superficial transverse metacarpal ligament (cf. its deep counterpart in the lower right drawing on fol. 10r). The note between the two hand studies discusses the importance of the placement of the vessels and nerves along the sides of the fingers, protecting them from being injured during flexion and extension.

The drawings of the upper limb to left and right essentially repeat those on fol. 9v. The fascicles of the deltoid, labelled *a* to *d* in the drawing to the right, do not correspond with those similarly labelled on fol. 6v; here we see only the anterior (*a* to *c*) and middle (*d*) fibres, and in the drawing to the left the posterior fibres do not appear even to be part of the deltoid. The muscles of the forearm are more distinctly shown than on fol. 9v, with the outcropping muscles of the thumb indicated; there is also a rough portrayal of the extensor expansions or dorsal hoods at the knuckles, not hinted at before.

At the head of the page Leonardo attempts to classify the muscles according to shape (this is done today, but in a different manner), and records his intention to draw for each bone the muscles that attach to that bone. One can recognise in the notes descriptions of an aponeurosis or sheet-like tendon; sheet-like muscles, as in the abdominal obliques; and muscles with intermediate tendons, as in the digastric and omohyoid muscles. The subclavius muscle, running from the clavicle to the first rib, is sketched within the notes at upper left to illustrate one of Leonardo's classifications of muscle form.

There is one sort of muscle that begins as a tendon and finishes as a tendon, and these can be divided into two types, in one of which the tendons expand and become cartilage, and in the other the tendons are rounded like a cord
The second sort of muscle has its tendon only at one end, and these can be further divided into two types, of which the tendons of one expand into the form of fine cartilage, and the other remains quite round

There is another sort of muscle which throughout its length is attached by its underside onto the bone that it covers; and in these, each of its components has a different length, and the shortest is the most powerful, as can be seen in *a b n*, attached to the bone of the arm *p m*, in which the component *a b* is longer than the component *b n*

There is another kind that begins as flesh, born on the bone, and finishes as a tendon, or one might say, begins as a tendon and finishes as flesh



For each bone separately, draw its muscles, that is, the muscles that arise on it

h is the muscle of anger; *p* is the muscle of sorrow; *g* is the muscle for biting; *g n m* is the same muscle; *o t* is the muscle of anger

Depict all the causes of movement made by the skin, flesh and muscles of the face, and if these muscles have their movement from the nerves that come from the brain or not
And do this first for the horse, which has bigger muscles and clearly visible parts

Note where the lowest parts of the shoulder muscles *a b c d* are fixed, and which are those that are fixed onto the humerus, and which are fixed onto other muscles

The muscle *m* is bigger than *p* because it has to endure more work

I lift off the muscle *m* and its site remains, as is seen in the other head at *n*; and I lift off the two muscles *o c* and the bone *f* remains

Note which are those nerves that serve a man's cheek muscles *b o c*, as shown above

a is the muscular flesh that arises in the upper gums and terminates in the lower gums and in the jaw and in the mouth

See if the muscle that raises the nostrils of the horse is the same that in a man lies here at *f*, which issues from the hole in the bone *f*

See if this sense is afflicted in an organ player when his soul is simultaneously giving attention to the sense of hearing

Have you seen here the diligence of nature, in having situated the nerves, arteries and veins on the sides of the fingers and not in the middle, so that in the operation of the fingers they do not in some way become pierced or cut?

Why does a single thing touching the side of the finger at *b* and the side *a* of the second finger seem to be two things, and touching at *n* and *m* seem to be one? It is because *n m* arise from a single nerve, and *a b* arise from two nerves

Here is movement and sensation
Here, through some cut in the hand, sensation in the fingers is sometimes impaired but not movement; and sometimes movement but not sensation; and sometimes sensation and movement

If a single thing touches at *c* and *n*, it seems to be two

The arrangement of the vein *a b c d* is that it goes along the inside of the hand as far as the bifurcation of the fingers, that is to *a o*, and then is divided at *o* and makes three branches, of which the branch *o b* passes on the outside of the hand, and the two branches *o c* and *o d* go along the inner side of the fingers



THE MUSCLES OF THE SHOULDER AND ARM

FOL. 14R

As on several other pages in the manuscript, Leonardo here applies his knowledge gleaned from dissection to a series of superficial studies of a live model.

The circular diagram at bottom right conveys Leonardo's understanding of the infinite gradations of movement—in this case, rotation or circumduction of the wrist—in terms of varying combinations of principal, orthogonal movements. Next to the diagram he writes:

Circular movement of the hand, showing first the four principal movements, *ad* and *da*, and *bc* and *cb*; and beyond these four principal movements, mention can be made of the non-principal movements, which are infinite.

Towards the lower right is the brief note: 'Wrist, seven bones; the eighth is the base of the thumb'. This may be clarified with reference to fol. 10v, where Leonardo correctly stated '8 [bones] in the wrist'. It may be that here Leonardo considered the metacarpal of the thumb as a third phalanx, to make it consistent with the other fingers, and thus in turn regarded the trapezium bone (at the base of the thumb) as the equivalent of the metacarpals of the other fingers—leaving only seven bones in the wrist. Leonardo regarded the hand and foot as parallel structures, and indeed the foot has only seven bones in the tarsal segment. The pisiform bone in the wrist is actually a sesamoid bone, but Leonardo (who was generally fascinated with the sesamoid bones—see fols. 1r and 12r) did not describe it as such, so that cannot in itself explain his unusual enumeration here.

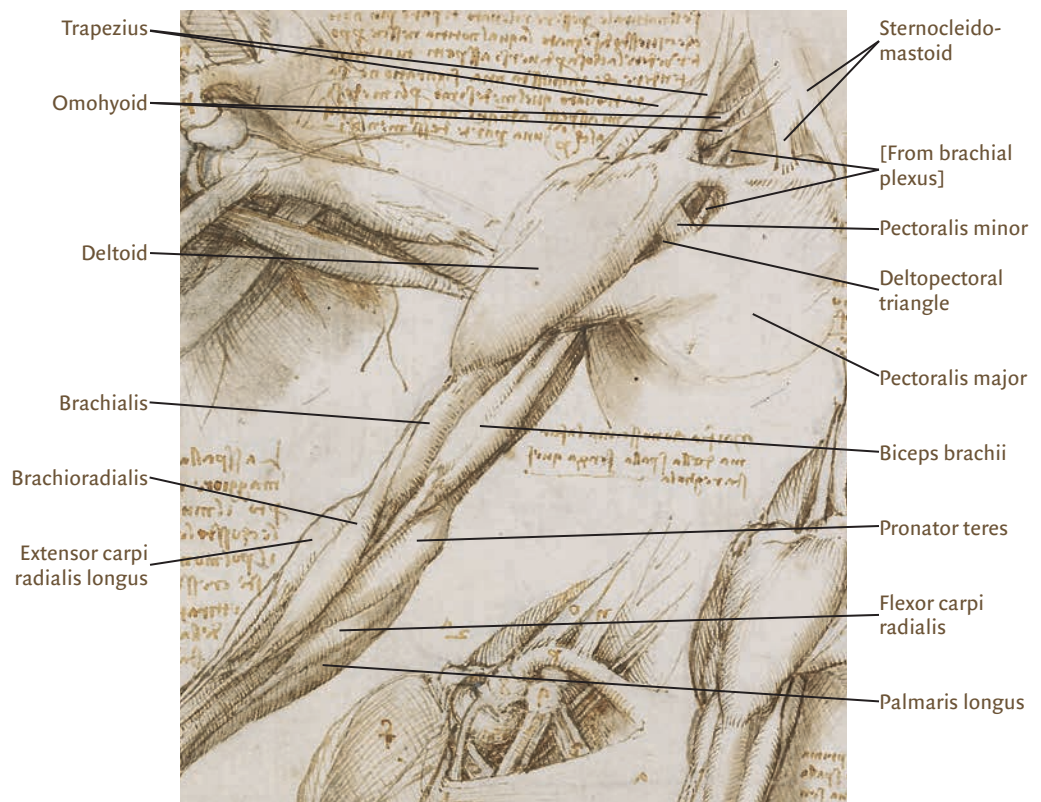
THE MUSCLES OF THE SHOULDER AND ARM, AND THE BONES OF THE FOOT

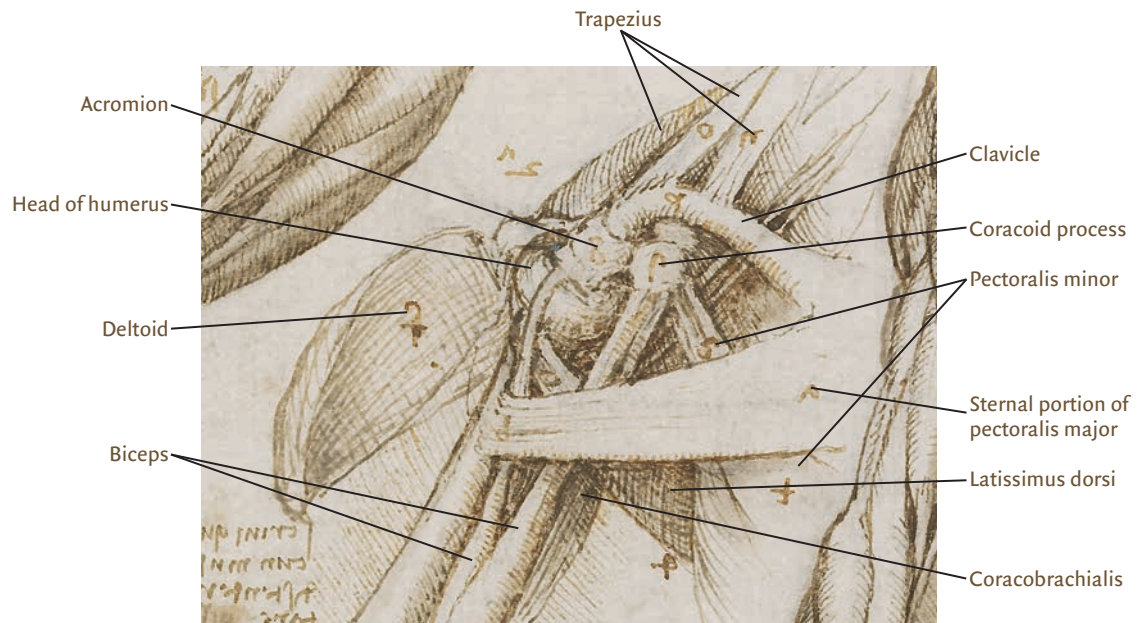
FOL. 14V

This is one of the densest and most majestic of Leonardo's anatomical sheets. Many of the drawings and notes consider the muscles and bones of the shoulder: the drawings at upper centre, centre and lower left are labelled 1st, 2nd and 3rd, and were conceived by Leonardo as showing stages in the gradual dissection of the structure.

The first of these, at upper centre (see key diagram, below), should be considered together with the drawing at centre right, which shows the same stage of dissection from a slightly different aspect. While other drawings demonstrate that Leonardo was aware of the difference between the two heads of biceps brachii, their origins and insertions, and their separation from the underlying brachialis, these issues seem to have plagued him and are not well depicted here. The muscles and tendons of the forearm, however, especially those that act upon the thumb, are exquisitely drawn.

In the drawing at the centre of the page (see key diagram, overleaf), the deltoid (f) is lifted away and the upper and lower portions of pectoralis major removed (the sternal portion a b remains) to reveal more of the shoulder joint, showing clearly the attachment of pectoralis minor, coracobrachialis and the short head of biceps to the coracoid process. The structures shown here are represented in the thread diagram in the right margin, with an accompanying





note that claims to explain the mechanism by which the cavity of the chest expands. It traces a chain of connections from the first vertebra of the neck, through trapezius (depicted as separate muscles or distinct fascicles, *a n* in the thread drawing, *o* and *n* in the main drawings), the clavicle, the coracoid process (called the ‘beak of the scapula’) and pectoralis minor to the ribs. There must have been great satisfaction for Leonardo in explaining how this structure worked as a unit, but in reality none of these structures effects the expansion of the chest. The action of pectoralis minor is the reverse of that posited by Leonardo, as it arises on the ribs and is attached to the coracoid process to depress the point of the shoulder. Of the muscles Leonardo describes, only serratus posterior superior (‘the muscles that arise on the last vertebra of the spine of the back’) can be considered as respiratory.

At lower left, pectoralis major has been reflected to the side of the humerus, and what is probably serratus anterior is seen on the medial wall of the axillary fossa (though Leonardo has labelled it ‘scapula’). Components of the brachial plexus, glimpsed in the previous drawings, can now clearly be seen streaming into the region from the neck, with structures perhaps including the axillary nerve and posterior humeral circumflex vessels. The note below explains the action of latissimus dorsi (*g r*) as clearly as any current text.

This third drawing is very similar in its content to that at lower left of fol. 4v, and when Leonardo reminds himself here ‘in the fourth diagram, lift off the fish of the arm [i.e. the biceps] and describe what remains’, he is essentially describing the drawing at centre left of fol. 4v. The drawing at upper left of this sheet, on the other hand, is en suite with that at upper centre of fol. 12r, and shares many of its shortcomings—the curvature of the clavicle is exaggerated, and the acromion is shown as a separate bone.

The drawing of the bones of the foot and ankle at lower right belongs to the long series of studies on other pages, especially fols. 1r, 3v and 12r.

If the actual object, by being in relief, appears to you more informative than this drawing, which succeeds in giving information by being able to show the object from different aspects, you must understand that in these, my depictions, will be found the same information from the same aspects, as no part of the limbs will be hidden from you

And you who want to demonstrate with words the form of man with all the aspects of his limbs, put aside such an idea, because the more minutely you describe it, the more you will confound the mind of the reader, and the further you will remove him from understanding of the thing described—therefore it is necessary both to depict and to describe

The shoulder, deprived of its largest muscle *f*, has revealed the muscle *s t* that raises the ribs of the chest when the lungs inside these ribs expand; and that muscle is pulled by the bone *q*, the beak of the scapula where it is fixed, and that beak together with the scapula is pulled by the cartilage *g* at the head of the clavicle *p*; and that clavicle is moved by the two muscles of the neck, *n o*

The form of the shoulder will never be understood without this rule—

Describe how much each muscle can be lengthened or shortened, or thinned and thickened, and which are more or less strong

In the fourth diagram, lift off the fish of the arm and describe what remains

The muscle *a b* and the muscle *d c* serve to press the arm towards the ribs, with the result that impetus in the hands is taken from the arms, and thus they are such large muscles

Describe each muscle, which finger it serves and which part, and thus depict it alone without any impediment from another muscle placed over it; and thus it will be possible to identify injured parts

First depict this shoulder with its bones alone, and then opposite depict it with these muscles

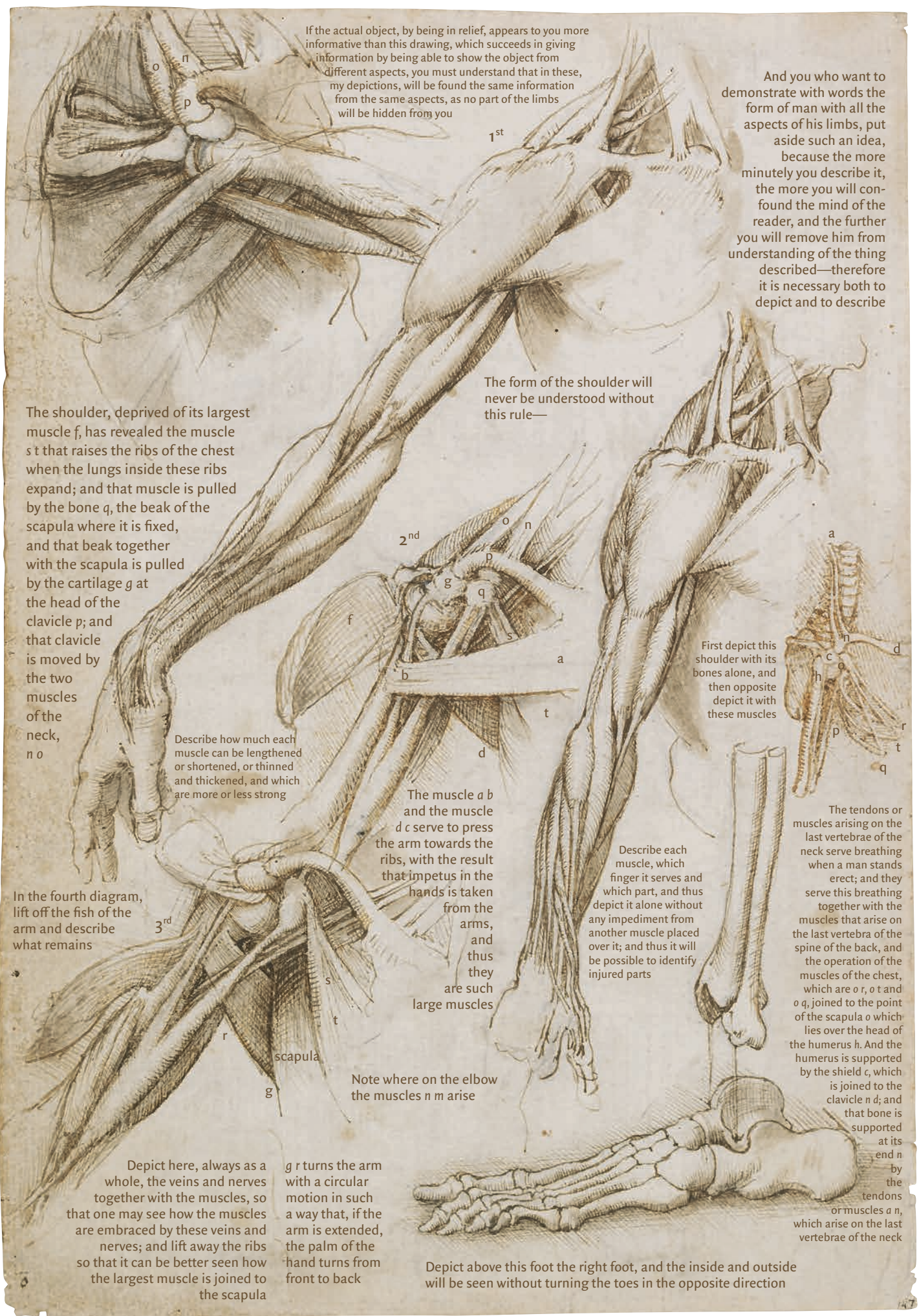
The tendons or muscles arising on the last vertebrae of the neck serve breathing when a man stands erect; and they serve this breathing together with the muscles that arise on the last vertebra of the spine of the back, and the operation of the muscles of the chest, which are *o r*, *o t* and *o q*, joined to the point of the scapula *o* which lies over the head of the humerus *h*. And the humerus is supported by the shield *c*, which is joined to the clavicle *n d*; and that bone is supported at its end *n* by the tendons or muscles *a n*, which arise on the last vertebrae of the neck

Note where on the elbow the muscles *n m* arise

Depict here, always as a whole, the veins and nerves together with the muscles, so that one may see how the muscles are embraced by these veins and nerves; and lift away the ribs so that it can be better seen how the largest muscle is joined to the scapula

g r turns the arm with a circular motion in such a way that, if the arm is extended, the palm of the hand turns from front to back

Depict above this foot the right foot, and the inside and outside will be seen without turning the toes in the opposite direction

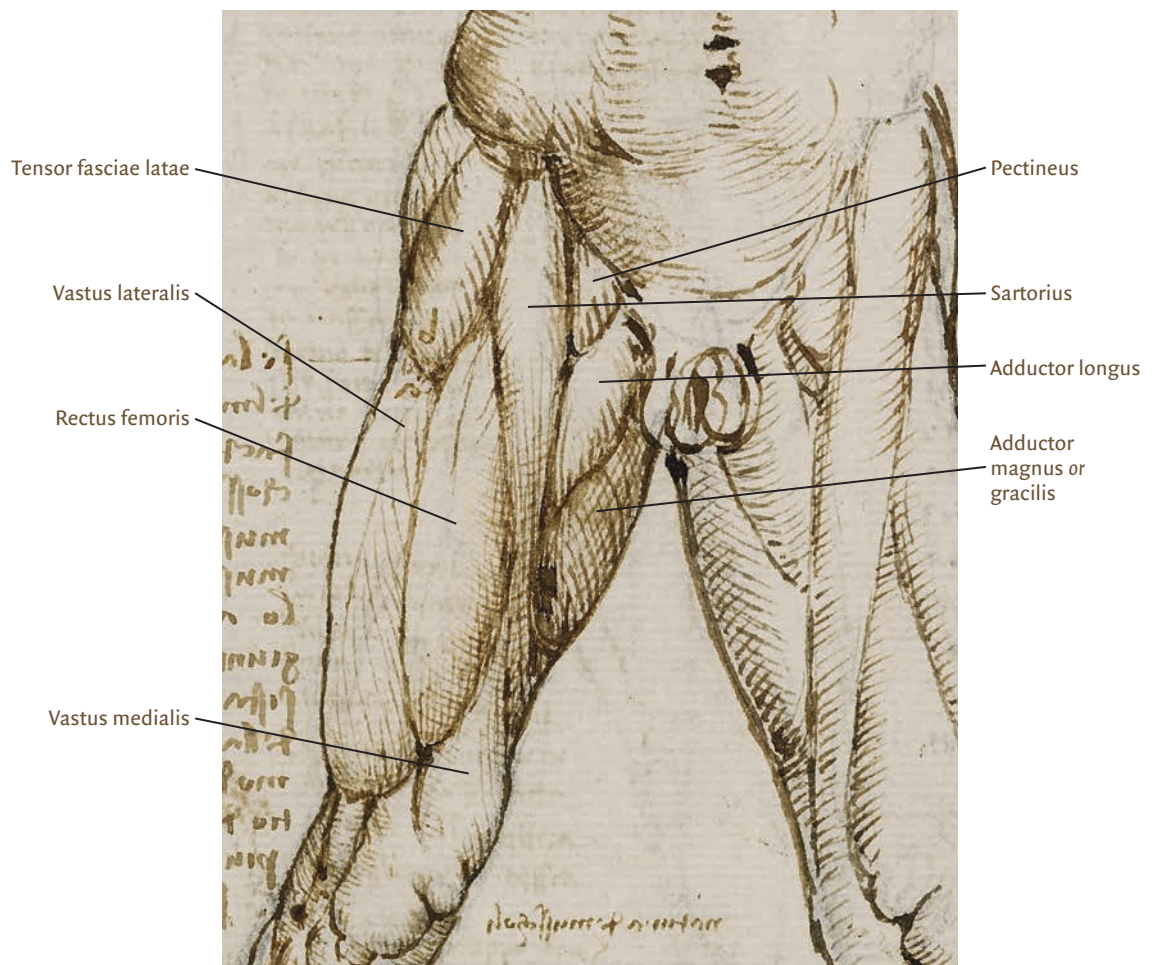


THE MUSCLES OF THE LEG

FOL. 15R

The principal drawing is a hybrid of life study and dissection drawing, the figure posed with many of the external features apparent, but the muscles shown with a degree of differentiation that suggests a flayed figure (see key diagram). Leonardo labelled the muscles *vastus lateralis* (a) and *tensor fasciae latae* (b), and in the rather opaque note alongside he attempts to analyse their interrelationship. This is a complex region, as the fascia lata, the deep connective tissue of the thigh, is attached to many different structures, including both *vastus lateralis* and *tensor fasciae latae*. Leonardo had perceived that the two muscles were connected in some way, but he was unable to make full sense of his findings. His mistaken conclusion was apparently that the two muscles were attached to the femur and also, independently, to each other, such that if one were damaged the other would still be able to contribute to movement of the femur.

The depiction of the long, thin *sartorius* muscle, passing obliquely across the front of the thigh, led Leonardo to comment on the shape of muscles in the note at centre right. He distinguished between two shapes (initially three, corrected to two)—the usual bulbous *muscolo*, whose name derives from its supposed resemblance to the shape of a mouse (Latin *musculus*, ‘little mouse’), and the longer, thinner *lacerto* (Latin *lacertus*, ‘lizard’). In fact Leonardo very rarely used the term *lacerto* in his notes, almost all muscles being called *muscolo*. The third shape that Leonardo considered was probably the *pesce*, with a double or bifurcated ‘fish-tail’ origin; he occasionally calls *biceps brachii* the ‘fish of the arm’, and on fol. 9r *rectus femoris* (and not *biceps femoris*) is the ‘fish of the thigh’.



At the top of the page is a faint drawing of the anterior aspect of the shoulder (with pectoralis major removed), very similar to that at lower left of fol. 4v but with more detail at the neck. Why Leonardo chose not to fix the outlines with ink is puzzling, and much of the fine detail has been lost by rubbing of the charcoal over the centuries. As the accompanying note explains, the muscles are 'lean and thin' so that the spaces make 'a window' on what lies beyond—the origin of Leonardo's 'thread diagrams'.

110
A.7.

Draw a diagram with lean and thin muscles, such that the space that arises between one and the other makes a window, to demonstrate what is found behind them as in this depiction of a shoulder made here in charcoal

Whether the conjunction of the muscle *b* is made with the bone of the thigh and truly with the muscle *a*, or whether the muscle *b* and the muscle *a*, after they are joined together, are joined and fixed upon this bone of the thigh? This third way is more useful for the movement of the thigh, and more safe, because if the muscle *a* were cut or injured in some other way, the muscle *b* would move the thigh, which it could not do if it were disunited from the bone between *b* and *a*

The muscles are of 3 2 shapes with 3 2 different names, of which the shortest is called *muscolo*, the middle and the longest is called *lacerto*

The nature of muscles

The tendons of muscles are of lesser or greater length in proportion as the man is fatter or of leaner flesh. And the flesh in a lean man always draws back towards its origin from the fleshy part. And in the acquisition of obesity, it spreads towards the origin of its tendon

How muscles are bound to the joints of bones

The end of every muscle becomes a tendon that binds the joint of the bone to which that muscle is conjoined

On the number of tendons and muscles

There are as many tendons (which successively, one above the other, clothe each other and together clothe and bind the joints of the bones to which they are conjoined) as there are muscles that converge on the same joint



THE MUSCLES OF THE TRUNK AND LEG

FOL. 15V

The page is dominated by a boldly modelled study of the superficial muscles from the neck to the ankle—Leonardo has shown more of the structures to front and rear than should be visible in a simple side view. Trapezius has been removed from the neck and shoulder, and thus the spine of the scapula is unusually prominent. Latissimus dorsi occupies the region under the arm; to its right is serratus anterior, interdigitating on the lower ribs with the external abdominal oblique muscle, the lower portion of which (*m*) descends to its insertion on the iliac crest (called by Leonardo the *anca*, a term that in modern Italian can mean, according to context and user, anywhere down the flank). Leonardo was of the opinion that the slight flare of the abdominal wall just above the iliac crest was due to the gastrointestinal tract inside the abdomen.

Below the iliac crest (cf. key diagram on p. 92) are the muscles tensor fasciae latae (*a*) and gluteus medius (*b*, rather exaggerated) and maximus (*c d*) converging on the greater trochanter (*n*), with the head of sartorius (*r*) just visible. Vastus lateralis (*e*) is mistakenly stated to be attached along its whole length to the femur. Leonardo puzzlingly distinguished an anterior portion of that muscle (*h*) and stated that it is attached to the skin; as it appears to be continuous with tensor fasciae latae this may in fact be a portion of the fascia lata, the tissue that connects many of the structures of the thigh. The muscles of the lower leg are less clearly differentiated.

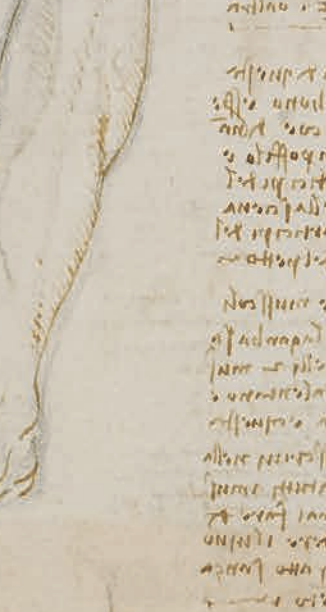
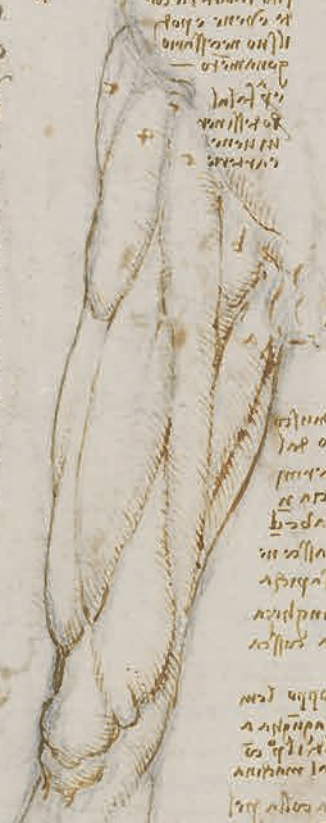
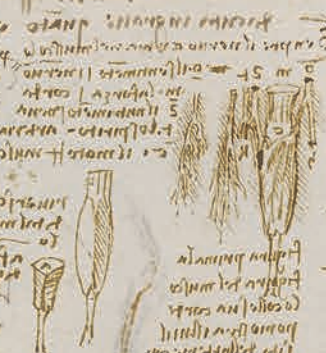
To the left, the front view of the leg is more lightly modelled and shows some of the same muscles differently lettered (cf. key diagram on p. 136): sartorius is *c*, tensor fasciae latae is *d*, and gluteus medius is *e*. Also depicted on the inside of the thigh are pectineus (*b*) and adductor longus (*a*); gracilis may be seen on the inner edge of the thigh, unlabelled, and there may be a portion of iliopsoas in the small triangle between sartorius and pectineus.

The small diagrams and notes at upper centre constitute a wonderfully clear-sighted analysis of the structure and function of the muscles. Leonardo depicts a broad, thin tendon of attachment (*a b*), a muscle body (*b c*), a narrower tendon of insertion (*c d*), and connections to the nerves, arteries and veins. All of these components are identified with specific functions—not just the mechanical function of the muscle and tendon, but also the sensation due to the nerve, and the archaic concepts of ‘nourishment’ provided by the venous system and ‘spirit’ by the arterial. In two small diagrams he sketches a muscle cut through the middle to show that its section is not circular. Leonardo states

Handwritten text at the top left of the page, likely serving as an introduction or title for the anatomical study.

Main body of handwritten text on the left side, providing detailed descriptions of the anatomical structures shown in the drawings.

Lower section of handwritten text on the left side, continuing the anatomical descriptions.



Handwritten text on the right side, positioned between the top and middle drawings, likely describing the structures shown in the middle drawing.

Handwritten text on the right side, positioned between the middle and bottom drawings, likely describing the structures shown in the bottom drawing.

Handwritten text on the right side, positioned below the bottom drawing, likely providing further details or a conclusion.



Small handwritten text at the bottom right corner of the page, possibly a signature or a reference note.

that the nerve always enters a muscle at its thickest part; in fact the neuro-vascular elements tend to enter muscle somewhat closer to its origin than the middle, on its deep surface.

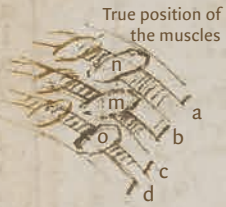
The two diagrams at upper left represent intercostal or subcostal muscles (more likely the latter, as Leonardo counted only seven). The annotation ‘true position of the muscles’ by the left-hand diagram indicates Leonardo’s knowledge of the oblique positioning of these muscles with respect to the ribs—the diagram alongside, labelled ‘these muscles are poorly positioned’, shows the schematic muscles passing perpendicularly from rib to rib.

The notes and diagram below outline a reciprocal system by which the act of breathing aids propulsion of the intestinal contents. According to this system, when the subcostals shorten, the ribs (*a b* and *c b*) are pulled together, the chest is compressed and thus the lungs are squeezed (exhalation). When the subcostal muscles relax, the ribs dilate, the lungs inflate (inhalation), and the diaphragm (*a d c*), attached to the bottom of the ribs, stretches and flattens. This flattening of the diaphragm compresses the intestinal contents, thus propelling the contents of the colon. While much of this is incorrect, Leonardo did realise that the lungs are passive and inflate due to expansion of the chest.

At the top of the page Leonardo leapt from considering the lungs of man to the ‘voice’ of a fly. In a succinct experiment he impeded the wings with a dab of honey or a judicious cut, causing them to beat more slowly and lowering the pitch. Leonardo thus determined that this noise was due to the vibration of the wings.

You will see that flies have their voice in their wings by cutting them a little, or by daubing them with a little honey in such a way that they are not entirely impeded from flying; and you will see that the sound made by the movement of their wings is made raucous; and as their wings are more impeded, so the voice changes more from high to low

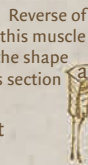
The nerve always enters a muscle at its thickest point and directs its branching towards the tendon that arises on that muscle



These muscles are poorly positioned



o is the sensation or nerve
m is the force or tendon
s is the nourishment or vein
t is the spirit or artery
c is the movement or muscle



The muscles n m o that bind the ribs a b c that are attached to the sternum are seven

These muscles have voluntary and involuntary movement, in that they are those that open and close the lungs; they open when they leave off their role, that is, of shortening themselves, for at that time the ribs that were initially pulled and forced together by the shortening of these muscles, are then left free and return to their natural separation, and then the chest enlarges; and because there cannot be a vacuum in nature, the lungs, which touch the ribs inside, necessarily follow their dilatation, thus opening the lungs in the manner of a bellows drawing in air to fill its created space



The shortening and extension that the aforesaid muscles perform are the cause of giving continuous movement to the faeces of the intestine. Proof: a b c d is the space where the lungs are in the chest; b a and b c are the ribs of the chest, which open and close the space a c, as said above. In opening this space a c, the diaphragm, the great membrane that is interposed between the intestines and the lungs, becomes straightened by the dilatation of the ribs, and thus straightened it diminishes the space a d c, thus squeezing the aforesaid intestines. And thus, diminishing and increasing the said space, the intestines themselves also increase and then diminish when they are compressed, and this movement lasts throughout life

First depict the shape of the muscle with its tendons, then show with lines the position of the arteries, tendons and veins, and then its essential actions; and first draw the tree of the nerves, veins and arteries



Describe each muscle by itself, its shape and the places where it terminates, and its substance; and ensure that this is not lacking, and do it as I have depicted it here below

a b is a thin and broad tendon, and at its upper end it terminates on the bone of the flank
b c is a fleshy muscle, round on the outside and obtusely angular inside, like this, and its threads converge at the end and beginning of this muscle
c d is a round tendon that arises at the lower end of the muscle and terminates at the binding that swathes the knee

There are four muscles that descend from the iliac crest m to the hip joint n, which are a b c and d. The muscle e arises at the hip joint n and is attached along its whole length to the bone of the thigh

If it seems too much, take some away; if it seems too little, add to it; if it seems sufficient, praise the first composer of such a machine

h is joined to the skin more than e or any other part

There must be five aspects of this figure; that is, from in front, behind, in profile, and one partly in profile and from the back, and one partly in profile and from the chest

When the two muscles a r pull the leg, it is raised forwards, and the two muscles b c are relaxed and d is elongated; and describe this rule for the operation of all the muscles, and you will be able to make out, without study from the life, almost every action without fail

The axis n is always found in well-proportioned men opposite the forking of the thighs

The projection of the flank m is skin and thin muscle, but it is made prominent by the colon on the left and by the caecum on the right

There are as many membranes that clothe the joints of the bones, one above the other, as there are muscles that converge on the end of each bone



THE MUSCLES OF THE UPPER SPINE

FOL. 16R

Leonardo's primary concern here was the movement and stabilisation of the upper spine, expanding on his first sketch of the system on fol. 9v, with incidental comments on the mechanics of respiration. As usual, the page should be read from upper right to lower left—the first five drawings are labelled 1st to 5th, showing the order of dissection from superficial to deep.

In the first drawing the trapezius muscle is shown, with its origins running down the upper vertebrae (its upper point on the occipital bone is not seen) and its insertion on the spine of the scapula. However Leonardo's drawing seems to show the lower portions attached to, or even disappearing under, the medial (inner) margin of the scapula, below the level of its spine; further, it is not clear in the drawing that trapezius is a single muscle. This conception of the muscle as a fused bundle of more or less distinct elements is also seen in Leonardo's treatment of the deltoid (over the curve of the shoulder), which remains intact in all five main drawings.

Next, trapezius is removed to reveal supraspinatus (*a*), and levator scapulae (*b*) running upwards from the top of the scapula. What is probably serratus posterior superior is shown as three muscles running diagonally downwards from the spine; these are more distinctly (if inaccurately) shown as *n m o* in the third drawing, in which rhomboid major and the posterior layer of the thoracolumbar fascia have been removed. It is puzzling that Leonardo emphasised serratus posterior superior, for that muscle is often so poorly developed that it can be missed by the novice dissector. Possibly its insertion on the ribs led Leonardo to believe that it was important for breathing—and indeed it was the focus of his attention on the other side of the sheet (fol. 16v), in which he explained how oblique muscles could both assist breathing and stabilise the spine.

In the third drawing the erector spinae muscles can be seen coursing upwards, and some ribs with their external intercostal muscles. The inferior belly of the omohyoid muscle and components of the brachial plexus are indicated above the scapula. In the fourth figure Leonardo removes serratus posterior superior, and the view of the erector spinae muscles is now unimpeded. A splenius muscle, probably splenius capitis, can also be seen coursing upwards; in the fifth drawing this has been removed, and the spinalis muscles, coursing downwards, are revealed, with what may be semispinalis capitis running more vertically. This is a complex, layered region and extremely difficult to dissect

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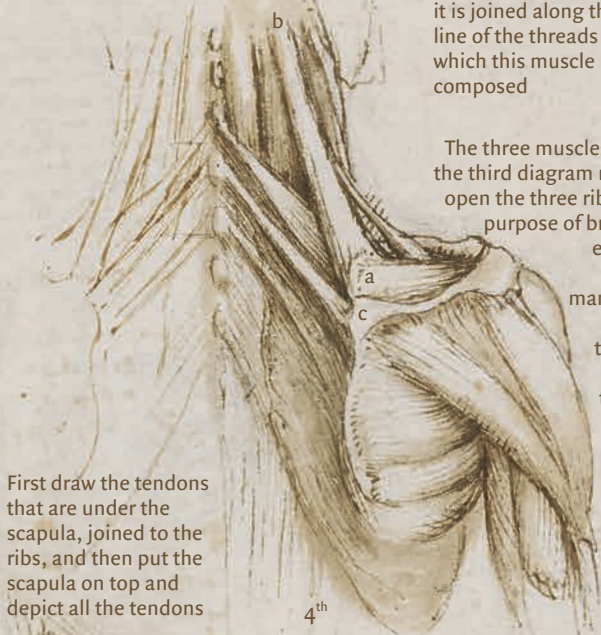
with fresh material; while Leonardo's details are not perfect, the fact that he was able to arrive at a clear grasp of the area is highly impressive.

At lower right is a 'thread diagram' that attempts to combine the muscle systems shown in the previous five drawings into a single schematic depiction. The limitations of this mode of representation are made clear in its treatment of trapezius, which is shown as at least twelve threads inserting on different parts of the scapula—not even Leonardo believed that trapezius was made up of this many distinct fascicles. In the right margin is an even more schematic representation of the same system, using simple lines rather than three-dimensional threads. And below centre is a schematic depiction of the spine of a vertebra pulled in different directions by the tendons of ten muscles: Leonardo saw that for almost every muscle acting on a vertebra, another acts in the opposite direction, and the system therefore effects movement while simultaneously stabilising the spinal column.

A high proportion of the notes are directly relevant to the drawings, outlining the supposed action of a muscle or group of muscles. At top right Leonardo reminds himself once more of the structure of his intended treatise, beginning with the mature male as the 'perfect' body, then treating the variants—the old man, the infant, and the reproductive organs of the woman (the rest of a woman's body being treated as essentially the same as a man's).

2nd

Every muscle moves the member to which it is joined along the line of the threads of which this muscle is composed

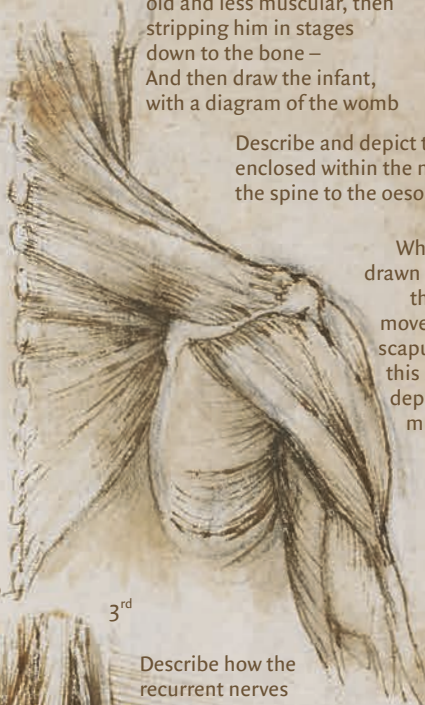


First draw the tendons that are under the scapula, joined to the ribs, and then put the scapula on top and depict all the tendons

5th

1st

Begin your book on anatomy with a perfect man, and then draw him old and less muscular, then stripping him in stages down to the bone - And then draw the infant, with a diagram of the womb



Describe and depict the muscles enclosed within the neck from the spine to the oesophagus

When you have drawn the muscles that serve the movement of the scapula, lift away this scapula and depict the three muscles n m o, which serve only the purpose of breathing

The three muscles n m o in the third diagram raise and open the three ribs for the purpose of breathing, especially when a man is bent, and the three ribs pull with them the other four below

4th

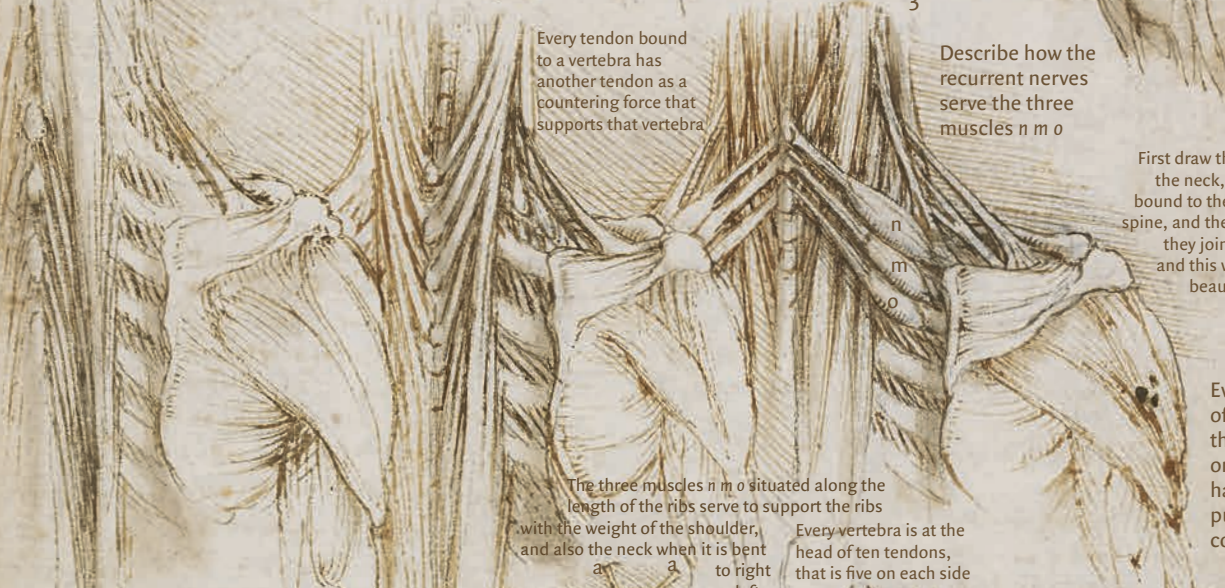
11th rib

3rd

Every tendon bound to a vertebra has another tendon as a countering force that supports that vertebra

Describe how the recurrent nerves serve the three muscles n m o

First draw the tendons of the neck, how they are bound to the ribs and the spine, and then finally how they join the scapula, and this will be a most beautiful diagram

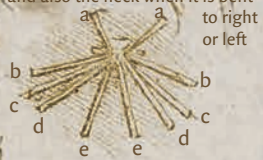


The three muscles n m o situated along the length of the ribs serve to support the ribs with the weight of the shoulder, and also the neck when it is bent to right or left

Every vertebra is at the head of ten tendons, that is five on each side

Every muscle of the neck that pulls in one direction has one that pulls in the contrary

Note whether the muscles that bind the ribs together, being placed in their interstices, whether their lengths are directed towards the neck or not



Every vertebra is bound to 10 tendons that is 5 here — and 5 there —

Draw a similar one from the inside of the bone of the neck and shoulder



In all the places where a man exerts himself with greater effort, there nature has made the muscles and the tendons of greater size and width

n m o are three muscles that pull the tendons fixed to the vertebrae of the neck, and as the vertebrae cannot come towards the muscle, it raises the muscle together with the rib to which it is attached, towards that vertebra; and this is the cause of turning the chest around when sitting

The third diagram The muscles that terminate on the vertebrae are continuous with the muscles of the fourth diagram, and this helps the lateral movements of the head; and they are attached to the ends of the vertebrae to allow the head to turn this way and that

Draw for each tendon the bones where they arise and finish

The vertebrae of the spine in the fifth diagram have muscles that pull them in a contrary direction to that made by the muscles in the fourth diagram; and this is done because those vertebrae would come apart in bending the head if the muscles below did not make a contrary force

ab cd ef gh are muscles that

THE MUSCLES OF THE UPPER SPINE

FOL. 16V

The emphasis of this page is more functional than anatomical. It is primarily concerned with the mechanics of breathing, and the stabilisation and movement of the spine and head. Leonardo realised that the ribs rise and fall during inspiration and expiration, but here he investigated a possible ‘double function’ of the muscles attached to both spine and ribs—that, anchored to the spine, they pull the ribs up in breathing, and conversely, anchored to the ribs, they hold the spine erect. Leonardo states candidly that he had long wondered about this arrangement, and here he appealed to the analogy of the standing rigging of a ship, which he felt mutually supported both the mast and the hull of the ship. He notes that the angle at which the muscles lie affects how well they perform these respective functions: a muscle placed more ‘obliquely’ (by which Leonardo means ‘at a greater angle from the vertical’) supports the spine more effectively but has less of an upwards pull on the rib; one placed less ‘obliquely’ (closer to vertical) pulls the rib up more strongly, but has less stabilising force. At lower left he claims that the muscles of the shoulder and clavicle play no part in supporting the head, as one can move the shoulders when bent over without affecting the position of the head.

The three small rounded muscles shown on either side of the diagram at upper right are probably intended to represent serratus posterior superior, labelled as *n m o* in the drawing at centre right on the other side of the sheet (fol. 16r). We now know that this muscle, though classified as a muscle of respiration, is minimal in function; but Leonardo would not readily have accepted that a muscle might exist without a clear function necessary for the operation of the body.

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Main block of handwritten text on the left side of the page.

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Handwritten text block on the right side, adjacent to the anatomical drawing.

Handwritten text block located below the main text on the left.

Second main block of handwritten text on the left side of the page.

Handwritten text block on the right side, below the anatomical drawing.

Handwritten text block located below the second main text block on the left.

Third main block of handwritten text on the left side of the page.



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In general, Leonardo's understanding of the complex muscles of the back was not as well developed as, for instance, his grasp of the mechanics of the shoulder, where the action of each muscle is more distinct. Even though the layered system of the back is persuasively depicted on fol. 16r, it is clear that there was a gap between Leonardo's knowledge of the anatomy of the region and his understanding of the function of these muscles; and the paragraph immediately to the right of the diagram here is just one of his repeated attempts to explain the mechanism of breathing.

On the demonstration of how the spine of the neck is positioned

In this demonstration of the neck there will be drawn as many depictions of muscles and tendons as there are functions in the actions of the neck; and this first, which is here noted, shows how the ribs with their forces hold straight the spine of the neck; and by means of the tendons that ascend to the spine, these tendons have a double function, that is, they support the spine by means of the ribs, and they support the ribs by means of the spine. And this duplication of powers situated at the opposite ends of such a tendon works with this tendon in the same way that a string works on the ends of a bow. But this convergence of muscles on the spine holds it straight, just as the ropes of a ship support its mast; and the same ropes bound to the mast also support in part the sides of the ship to which they are attached

On the method of depicting the causes of the movements of any member

First draw the motor muscles of the humerus; then draw on the humerus the motor muscles of the arm, for straightening and bending it; then show separately the muscles arising on the humerus that serve only to rotate the arm when the hand is turned upside-down. Then depict on the arm only the muscles that move the hand up and down, and this way and that, without moving the fingers; then depict the muscles that move only the fingers, those gripping or extending or separating or closing up. But first depict the whole body, as is done in cosmography, and then divide it into the aforesaid parts; and do the same for the thigh, lower leg and feet

On the stabilising muscles of the ribs, depicted above

I have long, and not without reason, doubted whether the muscles under the scapulae that are fixed on the third, fourth and fifth ribs, on both right and left sides, are made to help hold straight the spine of the neck, to which they are joined by their tendons; or rather whether these muscles, in shortening, pull themselves together with their ribs towards the nape of the neck by means of the aforesaid tendons joined to the spine. And reason leads me to believe that these muscles are supports of the spine such that it is not bent by having to support the heavy head of man when he bends and rises, as the muscles of the shoulders or clavicle do not help in this—since a man will relax these muscles arising on the shoulders and clavicle when he raises his shoulders to his ears, and takes away the force of his muscles. And by such relaxation and contraction the movement of the neck is not restricted, and the resistance of the spine in supporting the head is not diminished. And I am further persuaded in this opinion by the very powerful shape that the ribs have where these muscles are situated, which is very well suited to resist every weight or force that would pull in the contrary direction the tendon *a b*—which, pulling the rib *b r*, stabilises it more firmly at the point *r*; and if this tendon had to raise the rib in the service of expansion for breathing, nature would have placed this tendon not obliquely at *a b*, but more obliquely at *a c*. And read the propositions placed at the foot of the margin that are relevant etc

Man is to be treated according to the instrumental method, and not

Of the muscles, it happens almost universally that they do not move the member on which they are fixed, but they move the member where the tendon arising from the muscle is connected, except those that raise and move the ribcage in the service of breathing



All these muscles are lifters of the ribs, and lifting of the ribs is dilatation of the chest, and dilatation of the chest is inflation of the lungs, and inflation of the lungs is drawing-in of the air, which through the mouth penetrates the increased capacity of the lungs

And these same muscles hold straight the spine of the neck when the power of the lower muscles arising from the pelvis prevails; these muscles, terminating on the ribs, when these exert force, they act to resist and support the roots of the muscles that hold the neck straight



Those ropes more easily prohibit the fall of the mast, to the end of which they are joined, which converge on their junction with the mast at a greater angle

and that rope has less potential for ruining the mast that is joined to that mast between more unequal angles

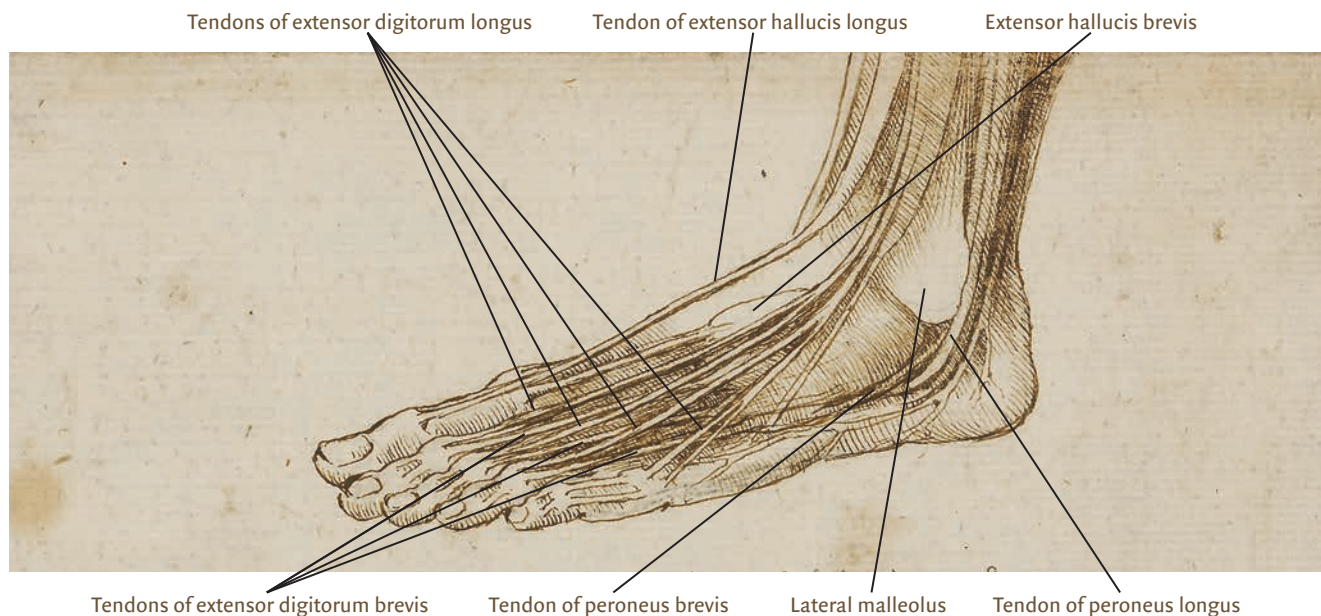
THE TENDONS OF THE LOWER LEG AND FOOT

FOL. 17R

This page and the next (fol. 18r) stand apart from the rest of the material in the Anatomical Manuscript A. The sheets of paper are twice the size of the other pages, and each is dominated by a single drawing. There is nothing written or drawn on the reverse of either sheet; the block of text at the right of fol. 18r jumps over the central fold, indicating that it had already been folded when Leonardo compiled it. Many of the blocks of notes are written in a uniform shade of ink with the same pen, and on fol. 17r in particular they have a neatness and regularity not found elsewhere.

The content, too, is subtly different. Here, there is no attempt to describe the drawing directly; the notes and drawing are related but independent and self-sufficient, and many of the notes read as summaries of previously determined material rather than as exploratory passages. Leonardo states as a principle, based on all the studies that have gone before, that the muscles within each component of the limbs (e.g. shoulder, upper arm, lower arm, hand, fingers) do not move that component, but rather the next component along. Taken with the last line of the penultimate paragraph, which states that ‘this winter of 1510 I believe I shall finish all this anatomy’ (which should probably be understood to mean, as elsewhere, ‘this treatise on anatomy’), it is hard to avoid the conclusion that this is one of the last sheets compiled during this campaign of dissection.

The principal drawing concentrates on the interaction of the tendons of extensor digitorum brevis and extensor digitorum longus on the upper side of the toes (see key diagram). The tendons of extensor digitorum longus pass



from the lower leg to the metatarsal-phalangeal joints of the four lesser toes—as usual Leonardo has omitted the ligaments at the ankle. In the case of the three middle toes, those tendons are joined at that point, on the lateral side, by the tendons of *extensor digitorum brevis* (the bodies of that muscle, arising on the calcaneus, are not shown here—they can however be seen on fol. 18r). The longus and brevis tendons merge to form a broad aponeurosis that then divides into three slips on each toe, the central slip inserting into the second phalanx, the two lateral slips going on to insert into the third phalanx. Leonardo has shown this arrangement perfectly.

The only muscle clearly shown in the foot itself is *extensor hallucis brevis*, with its tendon inserting on the first phalanx of the big toe, whereas the tendon of *extensor hallucis longus*, running down from the leg, inserts on the second phalanx. Again, this is correctly depicted. Behind the lateral malleolus (ankle), the tendons of *peroneus longus* and *brevis* are seen coursing into the lower part of the foot, though their insertions are not shown. The vessel below may be a continuation of the small saphenous vein, possibly accompanied by the lateral dorsal cutaneous nerve, a branch of the sural nerve; but this vessel and nerve are close to the surface, not deep with the tendons as implied here. Leonardo has not shown the origins of the muscles of the lower leg that give rise to these tendons, but many of these muscles have complex origins, arising on an extended area of bone and fascia.

When you depict the hand, depict with it the arm as far as the elbow, and with this the tendons and muscles that come to move the arm below the elbow — and do the same in the diagram of the foot

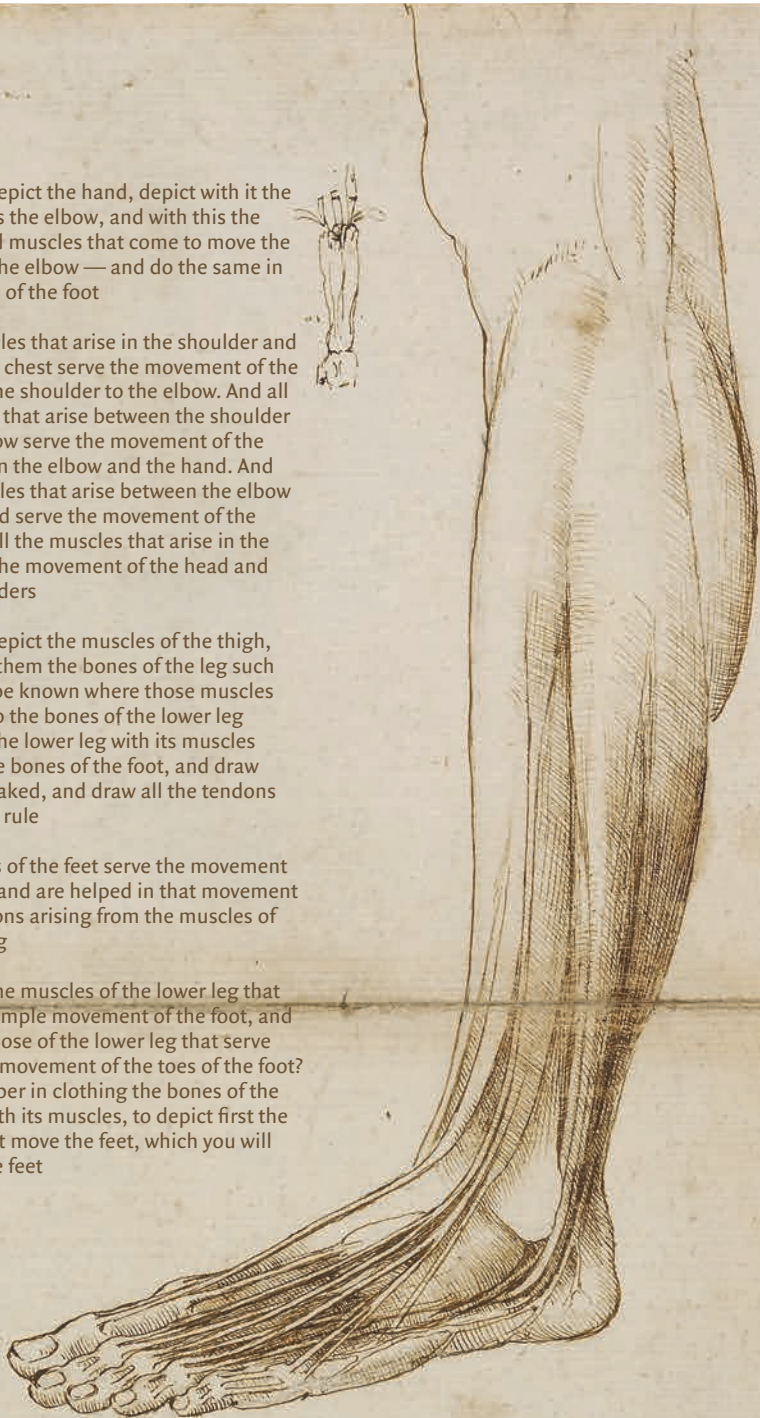


All the muscles that arise in the shoulder and scapula and chest serve the movement of the arm, from the shoulder to the elbow. And all the muscles that arise between the shoulder and the elbow serve the movement of the arm between the elbow and the hand. And all the muscles that arise between the elbow and the hand serve the movement of the hand. And all the muscles that arise in the neck serve the movement of the head and of the shoulders

When you depict the muscles of the thigh, depict with them the bones of the leg such that it may be known where those muscles are joined to the bones of the lower leg. Then draw the lower leg with its muscles joined to the bones of the foot, and draw the bones naked, and draw all the tendons by the same rule

The muscles of the feet serve the movement of the toes, and are helped in that movement by the tendons arising from the muscles of the lower leg

Which are the muscles of the lower leg that serve only simple movement of the foot, and which are those of the lower leg that serve only simple movement of the toes of the foot? And remember in clothing the bones of the lower leg with its muscles, to depict first the muscles that move the feet, which you will join to those feet



Depict here the foot of a bear, a monkey and other animals, inasmuch as they differ from the foot of a man, and also put in the foot of some bird

There are as many muscles of the leg, from the knee to the joint of the foot, as there are tendons joined to the upper part of the toes, and likewise below; to which are to be added those that move the feet up and down and from side to side; and there are five that raise the toes. And there are as many muscles of the foot, below and above, as there are toes, doubled. But as I have not yet finished this discourse, I shall leave it for the present; and this winter of 1510 I believe I shall finish all this anatomy

The tendons that lower the toes arise from the muscles born on the sole of the foot; but the tendons that raise the same toes do not arise on the outer part of the thigh, as has been written by some, but rather they arise on the upper part, called the dorsum, of the foot. And if you wish to confirm this, clasp your thigh with your hands, a little above the knee, and move your toes upwards, and you will feel the flesh of your thigh does not have any movement in its tendons or muscles. Indeed this is very true

THE MUSCLES AND TENDONS OF THE LOWER LEG AND FOOT

FOL. 18R

Many of the structures shown here are the same as those on fol. 17r (see the key diagram to that sheet). The interactions of the extensor digitorum longus and brevis tendons are again well displayed—the inset diagram at lower right depicts the arrangement of the three middle toes, not the big toe as its size might suggest. These tendons run from the muscle bodies of extensor digitorum longus (s and r), extensor hallucis longus (t), extensor digitorum brevis (a, b and c) and extensor hallucis brevis (d)—though the brevis muscles appear in the drawing to have their origins on the lateral malleolus (h) rather than on the calcaneus. Tibialis anterior is at m and peroneus longus at f; peroneus tertius, not found in all individuals, is accurately shown at n—that muscle is often mistakenly located in the lateral muscular compartment of the leg, but Leonardo has correctly placed it in the anterior crural compartment.

As attentive as Leonardo was to detail, and especially to those features with direct mechanical implications, it is interesting that neither here nor in any other image of the human leg did he depict the structures known as retinacula, the dense fibrous bands that extend around the ankle, in particular, to keep the tendons in place during flexion and extension.

In the notes—running to some 1,200 words—Leonardo revisits themes treated throughout the manuscript, with reminders or exhortations to draw the bones separately, from all sides, and then joined; then adding the muscles, drawing them as threads to convey their multilayered structure, and so on. He also considers what ‘enlarges a muscle so quickly’, that is, what causes it to contract. Ancient Greek physiology held that muscles contracted (and the penis erected—see Leonardo’s anecdote at centre right) by being inflated with pneuma, systemic air that circulated within the body and was involved in the functioning of the organs. Leonardo doubted that this ‘air’ could possibly inflate a muscle so quickly and deflate so quickly, and that the volume of air that would need to be compressed to harden a large muscle would be more than could be moved through the nerve fibres.

Handwritten text at the top left of the page, likely a title or introductory note.

ANATOMIA

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Handwritten text in the upper middle, possibly a label for a specific part of the anatomy.

Handwritten text in the middle left, continuing the anatomical description.

Handwritten text in the middle left, further detailing the anatomical structures.

Handwritten text in the lower middle left, likely a label or note.

Large block of handwritten text in the lower left quadrant, providing a detailed account of the anatomy.

Handwritten text in the lower left, possibly a list or specific notes.

Handwritten text in the lower middle left, continuing the notes.

ANATOMIA

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Large block of handwritten text in the bottom middle left, continuing the anatomical notes.

Handwritten text in the upper right quadrant, likely a label or note.

Large block of handwritten text in the middle right, providing a detailed account of the anatomy.

Large block of handwritten text in the lower middle right, continuing the anatomical notes.

Large block of handwritten text in the bottom middle right, providing a detailed account of the anatomy.

Handwritten text in the bottom middle, possibly a label or note.

Handwritten text in the bottom right, likely a label or note.



In two notes Leonardo also cites Avicenna and Mondino, the principal authorities for the study of anatomy before the revival of interest in the works of Galen in the sixteenth century. This is the only mention of either in the manuscript, and, as in the discussion of the pneuma, Leonardo cites them only to disagree with them, implicitly or explicitly. Moving towards the conclusion of his work on the muscles and bones—which was as far as possible conducted without reference to tradition—Leonardo now felt able to state his conclusions even when he disagreed with his great predecessors. In his work around 1510, Leonardo matured as an anatomist, as accomplished as any in the history of the field.

Remember that to make certain of the origin of any muscle, you should pull the tendon issuing from that muscle in such a way that you see the muscle move and its origins on the ligaments of the bones

To be noted

You will never cause anything but confusion in your diagrams of the muscles and their positions, origins and ends, if you do not first draw a diagram with thin muscles, in the manner of fine threads; and thus you will be able to depict one on top of the other as nature has positioned them, and thus you will be able to name them according to the member that they serve, that is, the mover of the point of the big toe, of its middle bone, of its first bone, etc; and given that you have such knowledge, you will depict alongside the true shape and number and position of each muscle. But remember to draw the threads that represent the muscles in the same positions as the central lines of each muscle, and thus these threads will demonstrate the shape of the lower leg, and their spacing is quickly known

Avicenna: there are sixty muscles that move the toes

The muscles that move only the foot upwards in front are *m n*, arising on the leg from the knee downwards, and those that bend it outwards are the muscles *f n*; therefore *n* is common to the two said movements

I have stripped the skin from one who, through an illness, had become so diminished that his muscles had been consumed, and what remained was like a thin membrane, such that the tendons, instead of being converted into muscle, were converted into a broad skin. And when the bones were clothed with skin, they gained little more than their natural size

The muscles *n m* extend only to move the whole foot upwards

First depict the bones separated and a little dislocated so that the shape of each piece of bone may be better distinguished. Then join them together in such a way that they do not differ from the first diagram except in that part that deals with their contact. This done, draw the third diagram, of those muscles that bind the bones together; then draw the fourth diagram of the nerves that carry feeling; and then follows the fifth, of the nerves that move or give sensation to the first joints of the toes; and for the sixth, draw the muscles on top of the foot where the sensory nerves are distributed; and the seventh is that of the veins that nourish the muscles of the feet. The eighth is that of the tendons that move the ends of the toes; the ninth, of the veins and arteries that are placed between the flesh and the skin; the tenth and last is the foot finished with all its feelings; you would be able to draw an eleventh in the manner of a transparent foot where all the aforesaid things could be seen

But first draw the diagram of the sensory nerves of the leg and their ramifications in four aspects, so that one may easily see whence these nerves derive; and then draw a diagram of a young, tender foot with few muscles

It is necessary that in defining the foot, it is joined to the leg as far as the knee, because in the leg arise the muscles that move the points of the toes, that is, the furthest bones

In the first diagram are the bones separated a little one from the other, so that their true shape is known; in the second are shown these bones sawn through, to see which are hollow and which are solid; in the third diagram are these bones joined together; in the fourth are the ligaments of these bones, one with the other; in the fifth are the muscles that strengthen these bones; sixth, the muscles with their tendons; seventh, the muscles of the leg with the tendons that go to the toes; eighth, the nerves of feeling; ninth, the arteries and veins; tenth, the skin of the muscles; eleventh, the foot in all its beauty—and each of the four aspects should have these eleven diagrams

All the tendons on the front of the leg serve the points of the toes, as is shown in the big toe

To be noted

When you have drawn your diagram of the bones in different aspects, then draw the membranes (or whatever) that are interposed between the bones and the muscles; and in addition to this, when you have depicted the first muscles and described and shown their action, draw the second diagram upon these first muscles, and the third diagram on the second diagram, and so on

First draw here the bones alone, and then clothe them successively by degrees in the same way that nature clothes them

First

First place the two lower bones of the leg from the knee to the foot; then depict the first muscles that arise on the said bones; and carry on thus, drawing one on the other in as many different diagrams as there are degrees of their superposition. And draw it thus until completion for the same side, and do likewise for four sides, together with the whole foot, because the foot is moved by means of the tendons issuing from the muscles of the lower leg; but the sole is moved by the muscles that arise on the sole. And the membranes of the joints of the bones arise from the muscles of the thigh and lower leg

What is it that enlarges a muscle so quickly? They say it is air. And where does it retreat to when the muscle diminishes with such speed? Into the nerves of feeling which are hollow. Then there would have to be a great wind to enlarge and elongate the penis and make it as dense as wood, such that so great a quantity of air was reduced to such a density. Indeed there would not be enough in the nerves, and even if the whole body were full of air there would not be sufficient. And if you say that it is the air in the nerves, what air would it be that courses through the muscles and reduces to such hardness and power at the time of the carnal act?

For once I saw a mule that could barely move from the fatigue of a long journey under a great load, and seeing a mare, immediately its penis and all its muscles swelled up, in such a way that its forces were multiplied and it reached such a speed that it caught up with the fleeing

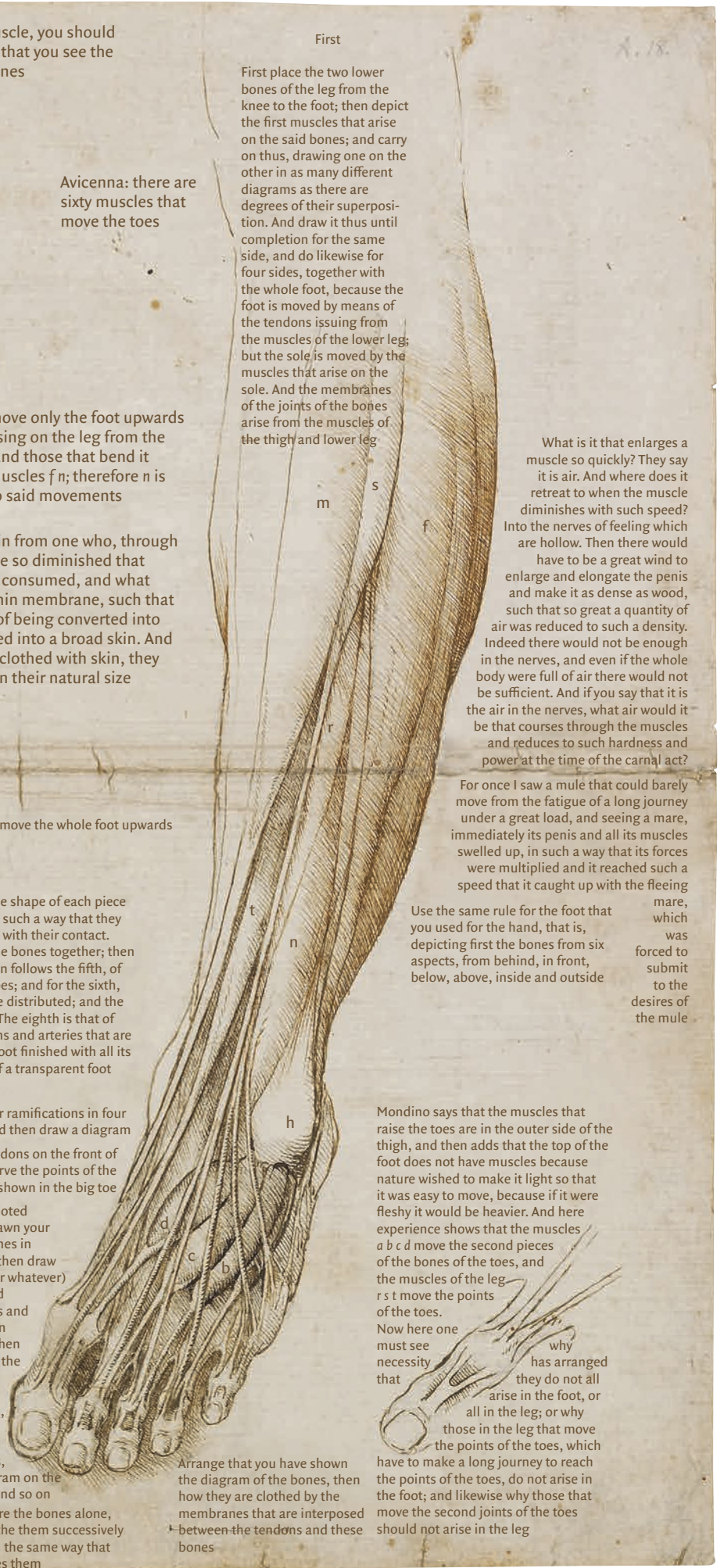
Use the same rule for the foot that you used for the hand, that is, depicting first the bones from six aspects, from behind, in front, below, above, inside and outside

mare, which was forced to submit to the desires of the mule

Mondino says that the muscles that raise the toes are in the outer side of the thigh, and then adds that the top of the foot does not have muscles because nature wished to make it light so that it was easy to move, because if it were fleshy it would be heavier. And here experience shows that the muscles *a b c d* move the second pieces of the bones of the toes, and the muscles of the leg *r s t* move the points of the toes.

Now here one must see why that has arranged they do not all arise in the foot, or all in the leg; or why those in the leg that move the points of the toes, which have to make a long journey to reach the points of the toes, do not arise in the foot; and likewise why those that move the second joints of the toes should not arise in the leg

Arrange that you have shown the diagram of the bones, then how they are clothed by the membranes that are interposed between the tendons and these bones



LIST OF WORKS, MEDIA AND REFERENCES, AND COMPARATIVE FIGURES

Listed below are the media and dimensions of the sheets of the Anatomical Manuscript A, with the foliation following G. Piumati, *I manoscritti di Leonardo da Vinci della Reale Biblioteca di Windsor. Dell'anatomia*, Fogli A, Paris 1898, together with Royal Library inventory numbers (RL) and references to the standard catalogues, abbreviated thus:

O'M&S: C. D. O'Malley and J. B. Saunders, *Leonardo da Vinci on the Human Body*, New York 1952

K&P: K. Keele and C. Pedretti, *Leonardo da Vinci. Corpus of the Anatomical Studies in the Collection of Her Majesty The Queen at Windsor Castle*, 2 vols and facsimiles, London 1979–80

fol. 1r

The bones of the foot, and the superficial anatomy of the shoulder
Pen and ink with wash, over traces of black chalk
293 × 201 mm (11⁹/₁₆ × 7¹⁵/₁₆ in.)
RL 19000r; O'M&S 13; K&P 135r

fol. 1v

The bones and muscles of the arm
Pen and ink with wash, over traces of black chalk
293 × 201 mm (11⁹/₁₆ × 7¹⁵/₁₆ in.)
RL 19000v; O'M&S 8; K&P 135v

fol. 2r

The bones and muscles of the shoulder
Pen and ink with wash, over traces of black chalk
289 × 198 mm (11³/₈ × 7¹³/₁₆ in.)
RL 19001r; O'M&S 50; K&P 136r

fol. 2v

The superficial anatomy of the shoulder and neck
Pen and ink with wash, over traces of black chalk
298 × 198 mm (11³/₈ × 7¹³/₁₆ in.)
RL 19001v; O'M&S 44; K&P 136v

fol. 3r

The throat, and the muscles of the leg
Pen and ink with wash, over traces of black chalk; red chalk sketch at top right
290 × 196 mm (11⁷/₁₆ × 7¹¹/₁₆ in.)
RL 19002r; O'M&S 169; K&P 134r

fol. 3v

The bones of the foot, and the muscles of the neck
Pen and ink with wash, over traces of black chalk
290 × 196 mm (11⁷/₁₆ × 7¹¹/₁₆ in.)
RL 19002v; O'M&S 36; K&P 134v

fol. 4r

The superficial anatomy of the shoulder and neck
Pen and ink with wash, over traces of black chalk
292 × 198 mm (11¹/₂ × 7¹³/₁₆ in.)
RL 19003r; O'M&S 43; K&P 137r

fol. 4v

The muscles of the shoulder
Pen and ink with wash, over traces of black chalk
292 × 198 mm (11¹/₂ × 7¹³/₁₆ in.)
RL 19003v; O'M&S 48; K&P 137v

fol. 5r

The bones of the arm and leg
Pen and ink with wash, over traces of black chalk; black chalk sketch at top left
286 × 193 mm (11¹/₄ × 7⁷/₈ in.)
RL 19004r; O'M&S 9; K&P 138r

fol. 5v

The superficial anatomy of the shoulder
Pen and ink, over stylus and compass points
286 × 193 mm (11¹/₄ × 7⁵/₈ in.)
RL 19004v; O'M&S 40; K&P 138v

fol. 6r

The muscles of the arm, and the veins of the arm and trunk
Pen and ink with wash, over traces of black chalk
289 × 199 mm (11³/₈ × 7¹³/₁₆ in.)
RL 19005r; O'M&S 45; K&P 141r

fol. 6v

The muscles of the shoulder and arm
Pen and ink with wash, over traces of black chalk
289 × 199 mm (11³/₈ × 7¹³/₁₆ in.)
RL 19005v; O'M&S 47; K&P 141v

fol. 7r

The muscles of the leg, and the intercostal muscles
Pen and ink, over traces of black chalk
286 × 198 mm (11¹/₄ × 7¹³/₁₆ in.)
RL 19006r; O'M&S 63; K&P 146r

fol. 7v

The muscles of the foot
Pen and ink, over some stylus
286 × 198 mm (11¹/₄ × 7¹³/₁₆ in.)
RL 19006v; O'M&S 80; K&P 146v

fol. 8r

The superficial anatomy of the shoulder and arm
Pen and ink, and black chalk
286 × 200 mm (11¹/₄ × 7⁷/₈ in.)
RL 19007r; O'M&S 41; K&P 139r

fol. 8v

The vertebral column
Pen and ink with wash, over traces of black chalk
286 × 200 mm (11¹/₄ × 7⁷/₈ in.)
RL 19007v; O'M&S 2; K&P 139v

fol. 9r
The bones and muscles of the leg
Pen and ink with wash, over traces of black chalk
288 × 202 mm (11¹⁵/₁₆ × 7¹⁵/₁₆ in.)
RL 19008r; O'M&S 11; K&P 140r

fol. 9v
The muscles of the shoulder, arm and neck
Pen and ink with wash, over traces of black chalk
288 × 202 mm (11⁵/₁₆ × 7¹⁵/₁₆ in.)
RL 19008v; O'M&S 46; K&P 140v

fol. 10r
The bones, muscles and tendons of the hand
Pen and ink with wash, over traces of black chalk
288 × 202 mm (11⁵/₁₆ × 7¹⁵/₁₆ in.)
RL 19009r; O'M&S 57; K&P 143r

fol. 10v
The bones of the hand
Pen and ink with wash, over traces of black chalk
288 × 202 mm (11⁵/₁₆ × 7¹⁵/₁₆ in.)
RL 19009v; O'M&S 10; K&P 143v

fol. 11r
The muscles and tendons of the sole of the foot
Pen and ink, over some stylus
295 × 200 mm (11⁵/₈ × 7⁷/₈ in.)
RL 19010r; O'M&S 79; K&P 147r

fol. 11v
The muscles of the lower leg
Pen and ink, over traces of black chalk
295 × 200 mm (11⁵/₈ × 7⁷/₈ in.)
RL 19010v; O'M&S 76; K&P 147v

fol. 12r
The bones of the foot, and the shoulder
Pen and ink with wash, over traces of black chalk
287 × 198 mm (11⁵/₁₆ × 7¹³/₁₆ in.)
RL 19011r; O'M&S 12; K&P 145r

fol. 12v
The veins and muscles of the arm
Pen and ink, over traces of black chalk
287 × 198 mm (11⁵/₁₆ × 7¹³/₁₆ in.)
RL 19011v; O'M&S 53; K&P 145v

fol. 13r
The skeleton
Pen and ink with wash, over traces of black chalk
288 × 200 mm (11⁵/₁₆ × 7⁷/₈ in.)
RL 19012r; O'M&S 1; K&P 142r

fol. 13v
The muscles of the face and arm, and the nerves and veins of the hand
Pen and ink with wash, over traces of black chalk
288 × 200 mm (11⁵/₁₆ × 7⁷/₈ in.)
RL 19012v; O'M&S 56; K&P 142v

fol. 14r
The muscles of the shoulder and arm
Pen and ink
289 × 201 mm (11³/₈ × 7¹⁵/₁₆ in.)
RL 19013r; O'M&S 42; K&P 144r

fol. 14v
The muscles of the shoulder and arm, and the bones of the foot
Pen and ink with wash, over traces of black chalk
289 × 201 mm (11³/₈ × 7¹⁵/₁₆ in.)
RL 19013v; O'M&S 49; K&P 144v

fol. 15r
The muscles of the leg
Pen and ink with a little wash, over traces of black chalk
286 × 207 mm (11¹/₄ × 8¹/₈ in.)
RL 19014r; O'M&S 61; K&P 148r

fol. 15v
The muscles of the trunk and leg
Pen and ink with wash, over traces of black chalk
286 × 207 mm (11¹/₄ × 8¹/₈ in.)
RL 19014v; O'M&S 20; K&P 148v

fol. 16r
The muscles of the upper spine
Pen and ink with wash, over traces of black chalk
289 × 205 mm (11³/₈ × 8¹/₁₆ in.)
RL 19015r; O'M&S 16; K&P 149r

fol. 16v
The muscles of the upper spine
Pen and ink, over traces of black chalk
289 × 205 mm (11³/₈ × 8¹/₁₆ in.)
RL 19015v; O'M&S 17; K&P 149v

fol. 17r
The tendons of the lower leg and foot
Pen and ink, over traces of black chalk
390 × 265 mm (15³/₈ × 10⁷/₁₆ in.)
RL 19016r; O'M&S 75; K&P 150r

fol. 18r
The muscles and tendons of the lower leg and foot
Pen and ink, over traces of black chalk
389 × 282 mm (15⁵/₁₆ × 11¹/₈ in.)
RL 19017r; O'M&S 74; K&P 151r

COMPARATIVE FIGURES

All the works are in the Royal Library, Windsor Castle, and all except fig. 13 are by Leonardo da Vinci

Fig. 1. Hemisection of a man and woman in the act of coition, c.1490–95. Pen and ink, 273 × 202 mm (10³/₄ × 7¹⁵/₁₆ in.). RL 19097v

Fig. 2. The anatomy of a bear's foot, c.1488–90. Pen and ink with white heightening, over metalpoint, on blue-grey prepared paper, 162 × 137 mm (6³/₈ × 5³/₈ in.). RL 19372r

Fig. 3. Miscellaneous anatomical studies, c.1488–90. Pen and ink and metalpoint on blue-grey prepared paper, 298 × 225 mm (11³/₄ × 8¹³/₁₆ in.). RL 12613r

Fig. 4. The muscles of the upper leg, c.1488–90. Pen and ink and metalpoint on blue-grey prepared paper, 101 × 141 mm (4 × 5⁹/₁₆ in.; area shown). RL 12626r (detail)

Fig. 5. A skull sectioned, 1489. Pen and ink over traces of black chalk, 124 × 137 mm (4⁷/₈ × 5³/₈ in.; area shown). RL 19058v (detail)

Fig. 6. The proportions of the leg, c.1490. Pen and ink, 201 × 142 mm (7¹⁵/₁₆ × 5⁹/₁₆ in.; area shown). RL 19136v (detail)

Fig. 7. The viscera of a horse(?), c.1490–95. Pen and ink, 273 × 202 mm (10³/₄ × 7¹⁵/₁₆ in.). RL 19097r

Fig. 8. A nude man from behind, c.1504–6. Red chalk, 270 × 160 mm (10⁵/₈ × 6⁷/₁₆ in.). RL 12596

Fig. 9. Studies of horses, a lion and a man, c.1503–4. Pen and ink with wash, 196 × 308 mm (7¹¹/₁₆ × 12¹/₈ in.). RL 12326

Fig. 10. The uterus of a gravid cow, c.1508. Pen and ink over traces of black chalk, 192 × 142 mm (7⁹/₁₆ × 5⁹/₁₆ in.). RL 19055r

Fig. 11. The lungs and other viscera, c.1508. Pen and ink with touches of wash, over traces of black chalk, 194 × 142 mm (7⁷/₈ × 5⁹/₁₆ in.). RL 19054v

Fig. 12. Studies of an ox's heart, c.1511–13. Pen and ink on blue paper, 288 × 413 mm (11⁵/₁₆ × 16¹/₄ in.). RL 19073–4v

Fig. 13. The *Leoni* binding, Milanese, c.1590–1600. Goatskin, gold tooled, 470 × 330 × 65 mm (18¹/₂ × 13 × 2⁹/₁₆ in.). RL 33320

FURTHER READING

The literature on Leonardo is vast, and it is impossible here to give more than a guide to the books of most use to those wishing to read further about his anatomical studies and their context. There have been many articles published in specialist journals bringing Leonardo's anatomical observations to the attention of a medical audience; the most significant of these should be found in the bibliographies of the following works.

- E. Belt, *Leonardo the Anatomist*, New York 1955
- M. Cazort et al., *The Ingenious Machine of Nature. Four Centuries of Art and Anatomy*, exh. cat., National Gallery of Canada, Ottawa 1996
- K. Clark and C. Pedretti, *The Drawings of Leonardo da Vinci in the Collection of Her Majesty The Queen at Windsor Castle*, 3 vols, London 1968–9
- M. Clayton, *Leonardo da Vinci. The Divine and the Grotesque*, London 2002
- M. Clayton and R. Philo, *Leonardo da Vinci. The Anatomy of Man*, Houston 1992
- S. Esche, *Leonardo da Vinci. Das anatomische Werk*, Basel 1954
- K. Keele, *Leonardo da Vinci on the Movement of the Heart and Blood*, London 1952
- K. Keele, *Leonardo da Vinci's Elements of the Science of Man*, New York 1983
- K. Keele and C. Pedretti, *Leonardo da Vinci. Corpus of the Anatomical Studies in the Collection of Her Majesty The Queen at Windsor Castle*, 2 vols and facsimiles, London 1979–80
- M. Kemp, *Leonardo da Vinci. The Marvellous Works of Nature and Man*, London 1981
- M. Kemp, *Leonardo da Vinci. Experience, Experiment and Design*, London 2006
- M. Kemp and M. Wallace, *Spectacular Bodies. The Art and Science of the Human Body from Leonardo to Now*, exh. cat., London, Hayward Gallery, 2000–2001
- D. Laurenza, *De figura umana. Fisiognomica, anatomia e arte in Leonardo*, Florence 2001
- Leonardo da Vinci. Quaderni d'anatomia*, 6 vols, Christiania 1911–16
- J. P. McMurrich, *Leonardo da Vinci. The Anatomist*, Washington, D.C. 1930
- C. D. O'Malley and J. B. Saunders, *Leonardo da Vinci on the Human Body*, New York 1952
- G. Piumati, *I manoscritti di Leonardo da Vinci della Reale Biblioteca di Windsor. Dell'anatomia*, Fogli A, Paris 1898; Fogli B, Turin 1901
- J.-P. Richter, *The Literary Works of Leonardo da Vinci*, 2 vols, London 1883 (and later editions)
- J. Roberts et al., *Leonardo da Vinci. Anatomical Drawings from the Royal Collection*, exh. cat., London, Royal Academy, 1977 (and other venues / dates)
- J. B. Schulz, *Art and Anatomy in Renaissance Italy*, Ann Arbor, Mich. 1985
- E. M. Todd, *The Neuroanatomy of Leonardo da Vinci*, Santa Barbara, Cal. 1983