Leonardo da Vinci on the Brain and Eye
CHARLES G. GROSS

Leonardo Da Vinci had a deep interest in the structure and function of the body. His drawings are the oldest surviving naturalistic depictions of human anatomy. This article examines seven of his drawings of the nervous system. In the earlier ones, he is almost totally bound by medieval tradition. Later, his drawings become more closely tied to his own dissections, and he invents new ways of representing the results of anatomical investigation. NEUROSCIENTIST 3:347-354, 1997

KEY WORDS Leonardo da Vinci, History of neuroscience, Renaissance

Leonardo da Vinci’s powerful, insatiable, and extraordinarily visual curiosity drove him to seek meaning in the structure and pattern of the microcosm of the body and the macrocosm of the universe (1). For Leonardo, to draw was to understand. Throughout most of his life, he had a consuming interest in the structure and function of the eye, brain, and nervous system, and in a variety of visual phenomena, such as illusions, contrast, and color (2-6). Although he was initially led to these subjects by his painting or, as he put it, “the science of painting,” they soon became obsessions in their own right.

Leonardo (1452-1519) was the first great medical illustrator (4, 7, 8, 9). His are the earliest surviving naturalistic drawings of the internal structure of the human body. Furthermore, he introduced a number of powerful techniques for portraying anatomical structures, such as the use of “transparencies,” cross-sections, exploded figures, and three-dimensional shading (8). Today, his anatomical drawings continue to draw huge crowds, although most are unaware of their frequent errors and dependence on traditional authority.

This article concerns Leonardo’s drawings of the nervous system. First, I consider the background of neuroanatomy in 15th century Europe, then the development of some of Leonardo’s ideas on the brain and the eye, and, finally, the impact of this work. Leonardo may be the paradigmatic “Renaissance genius” with ideas about such things as airplanes, submarines, machine guns, and bicycles not to be realized until the 20th century. However, in his neuroscience, he begins solidly in the middle ages, blinded or at least blinkered, by traditional dogma. Only gradually and only partially does he free himself from a “debased medieval Aristotelianism and a corrupted Galenism” (10) and begin to draw with accuracy the open body before him (Box 1).

Neuroanatomy in the Fifteenth Century

After the death of Galen in 199, anatomical dissection for either scientific or medical reasons was absent in both Europe and Islam for over a thousand years. It began again in 13th century Italy, first for forensic purposes and then as a way of illustrating, for medical students, Galen’s anatomical works (7). Galen did not become available in direct translation until the 16th century, and so, before then, his work was presented by Avicenna and other Arab scientists, who never practiced dissection themselves. Not only were the accounts of Galen’s work indirect but Galen had never mentioned that his anatomical descriptions were almost always based on non humans; a fact that was not realized until recently. [Galen’s anatomy is remarkably accurate when applied to a monkey or ox, his usual subjects, rather than to humans (7, 15).]

The first European anatomy textbook was the 40-page Anathomia of Mondino de’ Luzzi (Mundinus) written in 1316. It was essentially a dissection guide for learning Arab accounts of Galen’s words, not for learning about the actual body. Mondino’s work went through many manuscript editions before it was finally printed in 1478 but remained unillustrated until an edition of 1521 (8, 9, 16). Mondino’s work was known to Leonardo at the beginning of his dissections (around 1490) and was an important source of anatomical nomenclature for him (7-9, 16). There was a medieval tradition of drawing diagrams of the human body in a frog-like posture, which were used to represent the major organs or venesection sites. However, none of the extant ones were drawn from actual dissections but are symbolic representations of general Greek or Arab ideas about the body, its diseases, and their treatment (8, 9, 16).

Accurate illustrations of the body beneath the skin began not in medical schools but in the bottegas of Renaissance artists. With the growth of naturalism in the Renaissance, artists desired more accurate knowledge of the surface musculature and used the scalpel on human cadavers to get it. Furthermore, there seems to have been considerable interaction between Italian Renaissance artists and medical workers. Both physi-

---

Box 1: Leonardo’s Drawings and Notes

Over 5000 sheets of drawings and notes by Leonardo on a fantastic range of subjects have survived, scattered in libraries around the world. Despite his plans for a number of books, including one on anatomy, none of his drawings or text were published until long after his death. By 1690, virtually all of Leonardo’s extant anatomical drawings found their way to the Royal Library in Windsor Castle, including the originals of Figures 1, 2, and 4-7. They are here referred to by the numbers assigned by Clark (11). Leonardo’s surviving texts, except for the recently rediscovered Madrid Codices (12), have been translated into English and arranged by Richter (13) and the easier-to-use MacCurdy (14).
Sexual Intercourse (Fig. 1)

This is one of Leonardo’s earliest anatomical drawings (c. 1493) and one of the first to be eventually published, in 1795 (10, 18). It is headed “I display to men the origin of their . . . cause of existence” (10) and consists of a contradictory collection of traditional views quite unencumbered by any actual observations. Avicenna (19) followed Hippocrates in believing that the “most active and thickest part” of the semen carrying the soul of the future person came from the spinal cord, and for this purpose, Leonardo draws a hollow nerve from the spinal cord to the upper of two canals in the penis. By contrast, Galen (20) argued that the sperm came from the testes, and to accommodate that view, Leonardo draws a tube from the testes to the lower canal (which was thought to be used for the passage of urine as well as semen). The two canals are shown more clearly in the two drawings in the bottom left.

Both the cervix and the uterus are shown expanded, following Avicenna, who believed both structures opened up during intercourse. Note the large sperm entering the (penis-like?) open cervix. There is a nerve from the uterus to the breast, illustrating the belief that in pregnancy the “retained menses” is carried to the breast and there stimulates the formation of milk. There is a nerve running from the testes to the heart, following Aristotle’s view of the heart as the center of sensation, a view subsequently abandoned by Leonardo and never held by Galen or most classical physician-philosophers (21).

This early drawing is typical in that it serves both as an uncritical “review of the literature” and as a program for investigation. Thus, he writes alongside the drawing:

Note what the testicles have to do with coition and the sperm. And how the foetus breathes and how it is nourished by the umbilical cord, and why one soul governs two bodies. . . and why a child of eight months does not live. . . How the testicles are the source of ardor.

And criticizes Avicenna:

Here Avicenna pretends that the soul generates the soul and the body the body and every member—in error.

Syphilis had become widespread in Italy about this time, and at the bottom of the page, Leonardo notes:
Through these figures will be demonstrated the cause of many dangers of ulcers and diseases.

Leonardo returns to the subject of this sheet in subsequent scattered notes. On sexual intercourse, he writes:

The set of causes and the parts employed therein are so repulsive that if it were not for the beauty of the faces and the adornments of the actions and the frantic state of mind, nature would lose the human species. (W19009r). The woman commonly has a desire quite the opposite of that of a man. That is, the woman likes the size of the genital member of the man to be as large as possible, and the man desires the opposite in the genital member of the woman, so that neither one nor the other ever attains his interest because Nature, who cannot be blamed, has so provided because of parturition (W19101r).

He does answer his question on the role of the “testicles in ardor”:

Testicles. . . contain in themselves ardour, that is, they are the augmenters of the animosity and ferocity of the animals; and experience shows us this clearly in the castrated animals, of which one sees the bull, the boar, the ram and the cock, very fierce animals, which after having been deprived of these testicles remain very cowardly (14).

Leonardo was the first to realize that in erection, the penis fills with blood (4). On the penis he notes that it:

confers with the human intelligence and sometimes has intelligence of itself, and although the will of man desires to stimulate it, it remains obstinate and takes its own course, and moving sometimes of itself without license or thought by the man, whether he be sleeping or waking, and many times the man is awake and it is asleep, and many times the man wishes it to practice and it does not wish it; many times it wishes it and the man forbids it. It seems therefore that this creature has often a life and intelligence separate from the man and it would appear that the man is in the wrong in being ashamed to give it a name or exhibit it . . . (14).

An Early Figure Showing the Ventricular Theory (Fig. 2)

As in other areas of his investigations, Leonardo’s view of the brain shows a progression over the years. He begins with uncritical notes from contemporary sources, and, finding them unsatisfactory, eventually moves on to critical inquiry and then, sometimes, to new insights.

Another one of Leonardo’s earliest anatomical drawings shows the visual input to the brain (Fig. 2). It is a curious and uncritical amalgam of Arabic and Medieval sources with a minor discovery and some new techniques thrown in (2, 4, 10, 18). The terms for the layers from hair to brain are from Avicenna through Mondino’s text, and in two cases, the Arabic terms are still in use (dura mater, pia mater). The depictions of the dura and pia extending to the sheath of the optic nerve and the eyeball (center and lower right) are again derived from Avicenna. The lens or crystalline humor is shown central, as it is in virtually all Arab and European drawings until Felix Platter (1603), the first to understand its role as a lens projecting the image onto a sensitive retina (5, 25). The lens is shown as round, although Galen and most of the Arab authorities on the eye, but not many medieval writers, had described it more correctly (25, 26). Leonardo must have been uncertain about the shape of the crystalline humor because later, in his unpublished monograph on vision (6), he suggests and diagrams a method for deter-
mining the shape and location of the lens:

In the anatomy of the eye in order to see the inside well without spilling its humour one should place the whole eye in white of egg, make it boil, and become solid, cutting the egg and the eye transversely in order that none of the middle portion may be poured out.

He never carried out this idea, as reflected in his continuing to draw the crystalline humor (lens) round and his reminder to himself to "Study the anatomy of different eyes" (25).

The portrayal of the ventricles as three connected spheres is neither from Avicenna nor Avicenna's main source Galen, nor any other Classical writer. Galen knew that the first or lateral ventricles are paired and provided a very accurate account of the morphology of all four cerebral ventricles on the basis of his dissections of the ox (20, 27). Rather, Leonardo's three circular ventricles came directly from the widespread medieval theory of the ventricular localization of psychological function. In the basic form of the theory, the faculties of the mind (derived from Aristotle) were distributed among the spaces within the brain (derived from those described by Galen). The lateral ventricles were collapsed into one space, the first "cell" or small room. This received input from all the sense organs and was the site of the "sensus communis" or common sense which integrated across the modalities. The sensations yielded images, and thus, fantasy and imagination were often located here too. The second or middle cell was the site of cognitive processes: reasoning, judgment, and thought. The third cell or ventricle was the site of memory. (For a discussion of the origins, variations, and longevity of the ventricular doctrine, see references 28–31.)

In the bottom figure, Leonardo reflects the standard medieval view of the location of the common sense in the first ventricle by showing input to it from the eyes and ears. Note the absence of the optic chiasm, although it had been noted by Aristotle, diagrammed in detail by Galen, and diagrammed repeatedly in the Arab literature, including in Alhazen's (Ibn al-Haytham) De Aspectibus, which was the standard textbook on optics in Europe until Kepler in the 16th century (25, 26, 32).

The new, and correct anatomical feature, if somewhat exaggerated, is the frontal sinus shown above the eye in the central and lower left figure. The three ways of labeling the layers of the scalp and the "unhinging" of the skull in the lower right drawing are apparently new illustration techniques.

**Injecting Wax To Reveal the Ventricles (Fig. 3)**

A few years later, Leonardo returned to the ventricles with brilliant success.

---

*Fig. 3. The ventricles based on wax injection and (lower) the rete mirabile, c.1504–1507 (W19127r).*
He used the sculptural technique of wax injection to reveal the shape of the ventricles. As he instructed (10):

Make two vent-holes in the horns of the great ventricles, and insert melted wax with a syringe, making a hole in the ventricle of the memory and through such a hole fill the 3 ventricles of the brain. Then, when the wax has set, take away the brain and you will see the shape of the ventricles. But first put narrow tubes into the vents so that the air which is in these ventricles can escape and make room for the wax which enters into the ventricles.

The shortcomings of his wax cast of the lateral ventricles drawn in Figure 3 were probably due to the absence of air vents in the posterior horns and the use of an unfixed brain. This method for revealing the shape of internal biological cavities was not used again until Frederick Ruysch in the 18th century, an achievement the French Academy of Sciences thought equal to Newton’s (10).

The ventral view shows a “rete mirabile” a vascular structure found in the ox, where Galen described it, but not in humans. The sulcal pattern is also that of an ox, whereas the location of the cerebellum and the form of the ventricles are closer to that of a human brain. Perhaps Leonardo injected both species, and this is a composite figure (18).

As Leonardo began to study the brain itself, his attribution of functions to the ventricles became somewhat contradictory and was eventually abandoned. In the period of this drawing, he had been dissecting out the cranial nerves and observed that the trigeminal and auditory nerves entered the central portion of the brain rather than the anterior portion. Therefore, in contrast to tradition and his previous drawing (Fig. 1), he put the common sense in the middle ventricle (now the third ventricle because the anterior ventricle was paired). The auditory and trigeminal inputs to the middle ventricle are diagrammed in the small horizontal section in the middle right of Figure 3. The visual input still went to the first ventricle before proceeding to the common sense. Now, he put intellect and “impressiva” into the first ventricle. Putting intellect at the target of the optic nerves underlies the dominant role he gave to this sense. By “impressiva,” a term never used before or after Leonardo, he meant something like sensory processing or sensation. Although the impressiva is never described as only visual, note that in this figure, it only receives visual input. Leonardo again contradicts his idea that the impressiva initially processes all the senses by having
The vagus nerve and its recurrent branch innervating the larynx, trachea and stomach, c. 1504–1506 (W19060v).

The median and ulnar nerves of the hand, c. 1504–1509. Detail of W19025v.

The frog suddenly dies when its spinal medulla is perforated; and before that he lives without head, without heart or any internal organ, or intestines or skin. It seems therefore that here lies the foundations of motion and life (W12013v).

The Optic Tract and Cranial Nerves (Figs. 4 and 5)

Figure 4 shows major advances in both illustration technique and anatomy. The upper figure uses "transparency" to show the relations among the cranial nerves, and the lower figure is an "exploded" view. Both techniques were used here for the first time, and these examples were not surpassed in anatomical drawings for centuries (8, 9).

Galen had described only seven cranial nerves, including the oculomotor but neither the trochlear or abducens (20). As shown in Figure 4 and rather more clearly in Figure 5, Leonardo's account of the cranial nerves is an advance over Galen. In Figure 5, the optic chiasm is illustrated, and above it, the olfactory nerves are shown. The other nerves appear to be the oculomotor, the abducens, and the opthalmic branch of the trigeminal (10, 17), although one observer has argued that the latter nerve is the trochlear (34).

Typically, the cranial nerve sheets contain ambitious programs for future research (34):
—Draw the nerves which move the eyes in any direction, and its muscles; and do the same with their eyelids, and with the eyebrows, nostrils, cheeks and lips, and everything that moves in a man’s face.

—Let the whole ramification of the vessels which serve the brain be made first by itself, separated from the nerves, and then another combined with the nerves.

The Vagus (Fig. 6) and Hand (Fig. 7) of an Old Man

Figure 6 is a drawing of the right vagus in an old man. How this centenarian came to be his most famous anatomical subject is described by Leonardo as follows:

And this old man, a few hours before his death told me that he had passed one hundred years, and that he found nothing wrong with his body other than weakness. And thus while sitting upon a bed in the hospital of Santa Maria Nuova in Florence, without any movement or other sign of any mishap he passed out of his life. And I made an anatomy of him in order 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 nourishes the heart, and other parts below it, which I found very dry, thin and withered. This anatomy I described very diligently and with great ease.

owing to the absence of fat and humors which greatly hinder the recognition of the parts (W19027v).

Galen had described in accurate detail the right and left branches of the vagus, known in Leonardo’s time as the “reversive” nerve (20). Figure 6 shows the right branch innervating the larynx, trachea, esophagus, and stomach. Leonardo’s interest in the vagus may have been stimulated by Galen’s brilliant demonstration that cutting the innervation of the larynx by the recurrent branch of the vagus eliminated vocalization in the pig. In the adjacent text, Leonardo mentions that the left nerve may innervate the heart. This gives him the occasion to withdraw his earlier Aristotelian belief (21) that the heart is the beginning of life (W19034v):

The heart is not the beginning of life but is a vessel made of dense muscle vivified and nourished by an artery and vein as are the other muscles. It is true that the blood and the artery which purges itself in it are the life and nourishment of the other muscles.

The rest of the text is mostly questions for future research:

Note in what part the left reversive nerve turns and what office it serves. And note the substance of the brain whether it is softer or denser above the origin of the nerve than in other parts. [According to Galen (20), the sensory nerves and the sensory parts of the brain were softer and the motor nerves and the motor parts of the brain were harder. Thus, Leonardo is asking whether the nerve is sensory or motor.] Observe in what way the reversive nerves give sensation to the rings of the trachea and what are the muscles which give movement to the rings to produce a deep, medium or shrill voice. . . . Count the rings of the trachea.

Figure 7, also from the centenarian, shows the distribution of the median and ulnar nerves to the palmar aspect of the hand. Unlike the more complicated situation in Figure 6, this drawing is very accurate.

Optics of the Eye (Fig. 8)

Leonardo wrote extensively about light, vision, and the optics of the eye both in an unpublished monograph and in many scattered notes and drawings (6, 25, 35–37). Although the camera obscura or pin-hole camera had been known since late antiquity and was used by Renaissance artists, Leonardo was the first to note its similarity to the eye (25, 38). However, he vehemently rejected the implication of this similarity, namely, that an inverted image was projected on the back of the eye and conveyed to the brain. To avoid this unacceptable inversion, he tried to develop an optical scheme in which the image was inverted twice in the eye, thereby ending up vertical and ready to be transported to the brain. In fact, he developed about eight such schemes (6, 37). One is shown in Figure 8. Leonardo actually proposed to build a model to test this optical arrange-
ment with his own eye at the site of the optic nerve head of the model.

It is ironic that Leonardo, who presumably easily read his own left-right reversed writing, could have found it inconceivable that the brain could interpret an inverted image. A hundred years later, Kepler was the first to accept that the image on the back of the eye was indeed inverted because “geometrical laws leave no choice,” and anyhow, what goes on beyond the retina was not his concern but that of “philosophers” (25).

Influence of Leonardo on the Course of Neuroscience

Leonardo had planned to publish his “120” anatomical notebooks” (Box 3) first alone and then as part of a textbook in collaboration with Marc Antonio del Torre, an anatomist and Professor of Medicine. However, del Torre died in 1511, before their text was finished (or, as far as we know, started.) Leonardo’s anatomical drawings had to wait over 200 years for publication. However, a number of his contemporaries are known to have seen and admired them (55). Durer actually copied several of them as did several less well-known artists (8, 39). Leonardo’s fame as an artist-anatomist spread throughout northern Italy, and today, he is credited with “spearheading the new creative anatomy” (39) and developing the naturalistic techniques that soon made possible Vesalius (1514–1564) and the birth of modern anatomy (4, 7, 39).

Acknowledgments

All figures are courtesy of Princeton University Library. I thank Greta Berman for her help and M. Graziano, N. Rebmann, P. Johnson-Laird, and P. Azzopardi for their comments on an earlier draft.

References