Leonardo da Vinci: Collective Wisdom to Scientific Observation

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Leonardo da Vinci was perhaps the most diversely talented man of all time. The drawings by Leonardo relating directly to his artistic projects constitute only a small part of his surviving corpus. The remainder were the artist's means of capturing form to record, comprehend and explain the infinite variety of experience. According to Martin Clayton, "...this was the theme of his whole career; for although Leonardo developed a very rich and powerful literary style." Clayton continues, "...he always maintained that an image transmitted knowledge more accurately and concisely than any amount of verbiage." (9) Possibly the most unique aspect of Leonardo's drawings is their paradoxical duality. They meld accepted ideas together with his own observations. Throughout the course of his life, however, the drawings evolved into pure observations, no longer mixing what he "knew" to be true with what he actually saw. (Clayton,9-10)

Leonardo's powerful, insatiable, and extraordinary visual curiosity drove him to seek meaning in both the structure and pattern of the body as microcosm and the universe as macrocosm. For him, 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. (Brown,170) 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. As the first great medical illustrator, 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. (Clayton,11) Today, his anatomical drawings continue to attract huge crowds, although most are unaware of the frequent errors they contain and their dependence on traditional authority.

This paper concerns Leonardo's drawings of the nervous system. First, we will consider the background of neuroanatomy in fifteenth-century Europe, then the development of some of Leonardo's ideas on the brain and the eye, and finally, the impact of this work on subsequent generations. 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 what Charles Gross terms a "debased medieval Aristotelianism and a corrupted Galenism" (Gross,93), beginning to draw the body accurately as he saw it.

After the death in 199 of the prominent Roman physician and philosopher, Galen, anatomical dissection for either scientific or medical reasons was absent in both Europe and Islam for over a thousand years. It began again in thirteenth-century Italy, first for forensic purposes and then as a way of illustrating Galen's anatomical works for medical students. Galen, however, did not become available to Europeans in direct translation until the sixteenth century; 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 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 the monkey or ox, his usual subjects, but not to humans. (Gross, 93-4)

The first European anatomy textbook was the forty-page Anothomia of Mondino De' Luzzi written in 1316. It was known to Leonardo at the beginning of his dissections (around 1490) and was an important source of anatomical nomenclature for him. An earlier medieval tradition of drawing diagrams of the human body in a frog-like posture was used to represent the major organs. None of these, however, is based on actual dissections. They are rather symbolic representations of Greek or Arab ideas about the body. (Gross, 94)

Accurate illustrations of the body beneath the skin began not in medical schools but in the workshops of Renaissance artists. With the growth of naturalism, artists desired more accurate knowledge of the surface musculature and used the scalpel on human cadavers to obtain it. Furthermore, there was considerable interaction between Italian Renaissance artists and medical workers. Both physicians and painters belonged to and were regulated by the Guild of Physicians and Apothecaries, as was the case for surgeons, undertakers, distillers, booksellers, and silk merchants. Painters bought their pigments at the same shops where doctors bought their medicines, and human dissections were usually open to the public. (Gross, 94-5)

Among the early artists who dissected human bodies to gain a more accurate view of the superficial muscles were Leonardo's teacher, Verrocchio, and Verrocchio's neighbor Antonio del Pollaiuolo. Later Michelangelo, Raphael, and Durer all made drawings of their dissections; Durer actually "appropriated" some of Leonardo's anatomical drawings. Leonardo's interest in anatomy presumably also began as an aid to painting, but he alone among the Renaissance artists went far deeper than the appearance of the surface musculature. (Brown, 171)

One of Leonardo's earliest anatomical drawings (ca. 1493) and one of the first to be published, in 1795, depicted sexual intercourse (Plate 1: Genito-Urinary System). It is headed, "I display to men the origin of their... cause of existence." (O'Malley-Saunders, 460) Particularly replete with errors, it consists of a contradictory collection of traditional views quite unencumbered by actual observations. According to Gross, Avicenna believed that semen, carrying the soul of the future person, came from the spinal cord, a view he presumably obtained from the Hippocratic work On Generation. The idea that semen derives from the brain and travels down the spinal cord is also found in Alcmaeon and other pre-Socratic philosophers.(96) To accommodate this view, Leonardo drew a hollow nerve from the spinal cord to the upper of two canals

in the penis. In contrast, Galen argued that sperm came from the testes (97); to accommodate that view, Leonardo drew 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 two smaller drawings in the bottom left corner of the same plate.

Leonardo depicts the cervix and uterus as expanded, following Avicenna. Gross contends that Avicenna believed both structures opened up during intercourse.(96) Note the large sperm entering the "penis-like" open cervix. There is a nerve from the uterus to the breast, illustrating the belief that during pregnancy the "retained menses" is carried to the breast and there stimulates the formation of milk. Another nerve runs from the testes to the heart, following Aristotle's theory of the heart as the center of sensation, a view subsequently abandoned by Leonardo and never held by Galen or most classical physician-philosophers. (97) This early drawing is typical in that it serves both as an uncritical "review of the literature" and as a program for investigation, as revealed in the words Leonardo wrote beside the drawing: "Note what the testicles have to do with the 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." (MacCurdy,110)

Leonardo's understanding of the brain shows similar progression over the years. He began with uncritical notes from contemporary sources and, finding them unsatisfactory, moved 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 (Plate 2: Central Nervous System and Cranial Nerves). (O'Malley-Saunders,330) It is a curious and uncritical blend of Arabic and medieval sources, with a minor discovery and some new techniques added in. According to Gross, the depictions of the dura mater and pia mater extending to sheath the optic nerve and the eyeball (center and lower right) are again derived from Avicenna. (99) "The lens or crystalline humor is shown central," Gross continues, "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." (101) 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. (101-2)

Leonardo must have been uncertain about the shape of the crystalline humor, because later, in his unpublished monograph on vision, he suggested and diagrammed a method for determining the shape and location of the lens: "In the anatomy of the eye in order to see the inside well without splitting its humour one should place the whole eye in a 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." (MacCurdy,156-7) 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." (O'Malley-Saunders, 330)

According to Gross, the portrayal of the ventricles as three connected spheres is not derived from Avicenna or Galen, or any other classical text. "Galen knew that the first or lateral ventricles are paired, and he provided an accurate account of the morphology of all four cerebral ventricles on the basis of his dissections of the ox." (101-2) Rather than following Galen, Leonardo depicted three circular ventricles according to the widespread medieval theory of the ventricular localization of psychological function. The lateral ventricles were collapsed into one space, the first cell or small room.(Clark,121) The sensations yielded images, and thus, the first cell was the seat of both fantasy and imagination. The second or middle cell was the site of cognitive processes, reasoning, judgement, and thought. The third cell or ventricle was the site of memory. (O'Malley-Saunders, 330)

In the bottom figure (of Plate 2) Leonardo reflects the standard medieval concept of the location of common sense in the first ventricle by showing input to it from the eyes and ears. Gross tells us to note the absence of the optic chiasm, although it had been noted by Aristotle, discussed in detail by Galen, and diagrammed repeatedly in the Arab literature. (102) The new correct anatomical feature, if somewhat exaggerated, is the frontal sinus, shown above the eye in the central and lower left figures (of plate 2). 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. (103)

A few years later, Leonardo returned to the ventricles with brilliant success, using the sculptural technique of wax injection to reveal their shape (Plate 3: Central Nervous System and Cranial Nerves). (O'Malley-Saunders,340) As he instructed: "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 memoria and through such as hole fill the three ventricles of the brain. Then, when the wax has set, take away the brain and you will see the shape of the ventricles." (MacCurdy, 179)

Gross tells us that the shortcomings of his wax cast of the lateral ventricles seen in Plate 3 were probably due to the absence of air vents in the posterior horns and the use of an unpreserved brain. The ventricle 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. (104)

Plate 4: Optic Chiasm and Cranial Nerves (O'Malley-Saunders,342) shows major advances in both illustration technique and anatomy. The upper figure uses transparency to show the relationships among the cranial nerves, and the lower figure is an exploded view. Both techniques are used here for the first time. Anatomical drawings did not surpass the clarity of these for centuries. (Clark,56) According to Gross, Galen had described only seven cranial nerves, including the oculomotor but neither the trochlear nor the abducens. As shown in Plate 3 and rather more clearly in Plate 4, Leonardo's description of the cranial nerves is more accurate than that of Galen. "Here the optic chiasm is illustrated and the olfactory nerves are shown above it. The other nerves appear to be the oculomotor, the abducens, and the ophthalmic branch of the

trigeminal, although one observer contends that the latter is the trochlear."(106-7)

Leonardo wrote extensively about light, vision, and the optics of the eye in both an unpublished monograph and in many scattered notes and drawings. Although the camera obscura or pinhole camera had been known since late antiquity and was used by Renaissance artists, Leonardo was the first to note its similarity to the eye. Gross writes that, "...he vehemently rejected the implication of this similarity, however; namely that an inverted image was projected onto the back of the eye and conveyed to the brain." (110) 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 veritical and ready to be transported to the brain. In fact, he developed about eight such schemes, two of which are shown in Plate 5. Leonardo actually proposed to build a model to test the lower optical arrangement "...with his own eye at the site of the optic nerve head of the model." (111) This is a prime example of Leonardo attempting to prove what he thinks he knows, rather than record what he actually sees.

It is ironic that Leonardo, who presumably easily read his own left-to-right reversed writing, found it inconceivable that the brain could interpret an inverted image. One hundred years later, Kepler was the first to accept that the image on the back of the eye was indeed inverted since "geometrical laws leave no choice," and, anyhow, he said what goes on beyond the retina was not his concern but that of "philosophers." (Gross,112)

As we have seen, it took a long time for Leonardo's drawings to evolve into pure observations, and even some of his later studies still struggled with separating what he had accepted to be true and what actually lay before him. Leonardo's fame as an artist-anatomist spread throughout northern Italy. Today he is credited with "spearheading the new creative anatomy," and developing the naturalistic techniques that led to the birth of modern anatomy. (Brown,173-4)

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Plate 1: Genito-Urinary System

Plate 2: Central Nervous System and Cranial Nerves

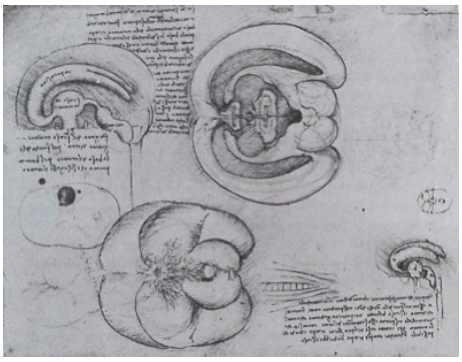

Plate 3: Central Nervous System and Cranial Nerves

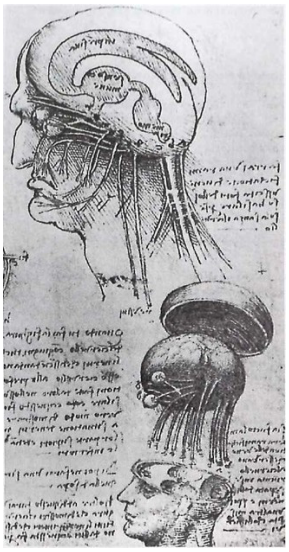

Plate 4: Optic Chiasm and Cranial Nerves

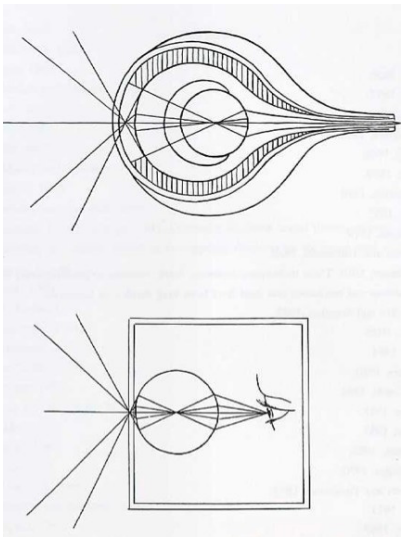

Plate 5: Two Optic Diagrams