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COVER EDITORIAL

The influence of ancient Greek thought on fifteenth century anatomy: Galenic influence and Leonardo da Vinci

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Abstract Leonardo da Vinci (1452–1519) can be called one of the earliest contributors to the history of anatomy and, by extension, the study of medicine. He may have even overshadowed Andreas Vesalius (1514–1564), the so-called founder of human anatomy, if his works had been published within his lifetime. While some of the best illustrations of their time, with our modern knowledge of anatomy, it is clear that many of da Vinci's depictions of human anatomy are inaccurate. However, he also made significant discoveries in anatomy and remarkable predictions of facts he could not yet discover with the technology available to him. Additionally, da Vinci was largely influenced by Greek anatomists, as indicated from his ideas about anatomical structure. In this historical review, we describe da Vinci's history, influences, and discoveries in anatomical research and his depictions and errors with regards to the musculoskeletal system, cardiovascular system, nervous system, and other organs.

Introduction

The history of medicine and the history of the study of human anatomy go hand in hand as most early physicians were anatomists and vice versa. In fact, in antiquity, there was no clear distinction between these two roles. Although Flemish physician Andreas Vesalius (1514–1564) is widely considered to be the founder of modern human anatomy, centuries later, the discovery of Leonardo da Vinci's (1452–1519) anatomical depictions and descriptions would turn this notion on its ear. Herrlinger has said anatomical illustration before Leonardo was primitive and believed there were examples in Vesalius's *De humani corporis fabrica* that he had indeed seen at least some of the illustrations from da Vinci's notebooks [4]. da Vinci's papers were published between 1898 and 1916 as facsimile editions and then in a conservation effort, in the early 1970s, all of his drawings, many with related notes, were arranged together and then published in 1979 [4]. Temporally, da Vinci's notebooks were created well before (15th versus sixteenth century) Vesalius's *De humani corporis fabrica*, which was published in 1543. da Vinci's anatomical drawings and notes were compiled during the early 1500s on 18 double-sided pages [2]. On these pages, he depicted 240 drawings and his notes on these pages were well over 13,000 words [2, 4].

Vesalius's work is so highly regarded that the history of the study of anatomy is often categorized into pre-Vesalian and post-Vesalian periods, i.e., before and after the publication of *De humani corporis fabrica*. Parenthetically, Clayton and Philo have written that if da Vinci's notebooks had been published during his lifetime or before Vesalius's 1543 work that today we would most likely refer to pre-Leonardian and post-Leonardian periods for the history of the study of human anatomy [2]. However, through close inspection of da Vinci's notebooks, one can see that while his anatomical depictions where accurate in many respects, they were often misdirected and frankly incorrect [1]. For example, Galen's teachings such as the notion that the nasolacrimal duct functions to drain tears from the heart, veins, and arteries is found in his writings. In this paper, the hypothesis is that the first century teachings of Claudius Galen (129 AD–c.200 AD) and his followers continued to influence da Vinci and the way he described and drew the human anatomy in the Middle Ages over a millennium later [4].

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Although da Vinci's anatomical illustrations were well before their time, some have pointed out that in the reality of medical illustrations and in particular in regard to human form, there was extremely little competition to his drawings [1, 4]. The anatomical drawings available during da Vinci's life were childlike and often not based on reality [9]. Older and often incorrect texts with Galenic influences that would have been freely available in da Vinci's day, as such was "widely read and circulated in the middle ages", and which could have easily influenced his concepts of human anatomy included Mondino de' Luzzi's (1275–1326) *Anathomia* published in Bologna in 1482 and Avicenna's (980–1037 AD) *Canon* [10]. In fact, we know that da Vinci was familiar with Mondino as in his collection of notebooks, he referred to the works of Mondino with reference to his descriptions of the extensors muscles of the toes [3]. da Vinci would also have been familiar with other authoritative anatomical works of the era. For example, Alessandro Benedetti (1450?–1512), a Greek scholar and medical professor at the Universities of Bologna and Padua, had published in 1497 an anatomical guide consisting of five books (*Anatomice*). These tomes dealt with the structure and dissection of the human body but lacked originality [7]. From da Vinci's notebooks, one sees that he was familiar with Albertus Magnus' (circa 1200–1280) work on anatomy, *De Animalibus.* Other extant anatomical authors that da Vinci would have known of included Achillini, Zerbi, and Benedetti the latter two of whom he mentions in his notes [11]. It is also known that da Vinci owned the following books that included anatomical descriptions: Johannes de Ketham's *Fasciculus Medicinae*, Guy de Chauliac's *Cyrurgia*, and Bartolomeo Montagnana's *Tractatus de urinarum judiciis*. Lastly, as the original Greek texts from Galen were not extant, the only known transmission of his work was via Arabic translations. Therefore, it is interesting that one of his notes stated, "have Avicenna translated" and that Avicenna, a Persian scholar, would have been well versed in Galenic medicine in his day [11]. Although not confirmed by others, O'Malley and Saunders stated that late in da Vinci's life, he acquired Galen's book (mostly Arabic translations) *De usu partium* [7]. Park also seems to think this influence likely, stating that "Fourteenth and fifteenth century medical writers relied for the most part on the relatively brief anatomical passages in Avicenna's *Canon* and on abbreviations and adaptations of the Galenic texts" [8]. These authors then boldly stated that from this point forward, da Vinci was essentially a Galenist. These authors also state that da Vinci came upon this copy of Galen's work around 1510. However, the majority of da Vinci's anatomical drawings were made between 1505 and 1510 [2–4, 7, 9].

Scholars of ancient medical canon were largely influenced by da Vinci's works, especially he had access to many human cadavers for further investigation and could have overturned these earlier incorrect notions with simple dissections. Todd stated in his book devoted to da Vinci's neuroanatomical understanding:

> "It is never easy to shake off the spell-binding enchantment of tradition and Leonardo's expressed intention to read from nature was no exception. Gross errors of received opinion are repeatedly manifested in his drawings, and obvious mental blocks imposed by a certain subservience to authority continually undermine his theoretical precepts. He was never able to erase these barriers to formulate any valid general principles of neurological function" [11].

Herein, the link between errors found in da Vinci's writings and the writings of Galen will be investigated. Reasons for why the inclusion of such errors into da Vinci's notebooks occurred considering he had many human cadavers at his disposal and would have been able to see the "truth" with his own eyes via cadaveric dissection will also be explored. As Todd eloquently stated,

> "Although Leonardo never successfully unraveled himself from the bonds of traditional authority he did loosen them as his enquiring knife disclosed the true form of things to the critical eye. In this investigation he tried to discard the confused ancient texts to read from the book of nature" [11].

The importance of Galen

To better understand the atmosphere of the day, it is important to know that Galen and his teachings were considered infallible over most of the pre-Vesalian period. Galen was the most important physician of the Roman Age and came to Rome after training in Alexandria [10]. Most of the human anatomy taught by Galen was derived from his dissections of the pig and as he said, "the animal most similar to man" and monkeys and apes [10]. Galen was the reference point for medicine throughout the Arab and Christian worlds with the Arabs being directly responsible for transmitting his words via Arabic translations once the original Greek texts were no longer extant. Galen's teachings would come to Europe primarily via Islamic Spain [10]. Cordoba was the home of many important Islamic scholars who propagated Galen's philosophy and understanding of medicine and in particular, knowledge of the human anatomy. Such scholars included Averroes, which is the Latinized form of Ibn Rushd who lived from 1126 to 1198 [10]. Averroes was a defender of early Greek teachings such as those of Aristotle and Galen. After the fall of Muslim Spain, many Islamic scholars spread throughout Europe and especially to France and Italy. Here, the teachings of Galen through

the translations and teaching of these Islamic scholars continued to be accepted as gospel and spread throughout the European world. Scholars that influenced da Vinci derived from this lineage from Galen to Islamic Spain and then to Europe and specifically Italy included Mondino. Mondino trained at Montepellier and then in Bolgna [10].

Da Vinci's anatomical errors

Clearly, da Vinci made significant discoveries in anatomy. Not only did he describe certain anatomical structures for the first time, but he also recognized the true curvature of the spinal column and the true position of the fetus in utero [1, 9]. However, one has to ask why one if not the best collection of anatomical drawings of the European Middle Ages from a man well ahead of his time and who had authentic sources of research, i.e., human cadavers would illustrate anatomical structures such as those mentioned earlier in an inaccurate way and in a way that often, stemmed from the descriptions of these structures centuries earlier and as far back as Galen. Could dedication to Galenic thought still be in play for da Vinci's time? We know that although Vesalius, a century later, put together a marvelous and often considered new standard in the field of anatomy that some of his depictions still propagated Galenic thought [9]. However, ostensibly, Vesalius dissected fewer cadavers and thus had less opportunity to correct all incorrect and antiquated thoughts and erroneous descriptions about human morphology. Additionally, why were some Galenic anatomical teachings overturned by da Vinci while others continued to be embraced? These questions will be addressed by examining both primary and secondary sources on the topic of da Vinci and his knowledge of anatomy as presented in his notebooks [9].

Clearly, there are examples in the writings and drawings of da Vinci that illustrate propagation of Galenic teachings. Although these were still the accepted teachings of the day, they were probably reinforced by da Vinci's mentor, Marcantonio della Tore. Della Tore is well known as being "one of the first to begin to illustrate matters of medicine by the teachings of Galen and to throw true light on anatomy" [2]. This theory of Galenic involvement is further supported by various examples in the writings of da Vinci's notebook and will be discussed later [2].

Todd captured his thoughts on Galenic influence of da Vinci by stating:

> "We see Leonardo at his worst in his pretentious early efforts to give visual reality to ancient authority on the subjects of generation or the situs of the *senso commune*. We squirm with his tortured quest to discover the true optics of vision under the delusion of preconceived notions that the image had to imprint on the optic nerve in an upright position. We are appalled when brilliant discoveries are marred by slavish repetition of Galen's errors in the same drawings, or by completely erroneous interpretation of observed facts as when he fancies lateral auxiliaries of the spinal cord in the vertebral canals" [11].

As mentioned earlier, da Vinci rendered many anatomical structures incorrectly. The following subsections discuss specific anatomical errors as described and drawn by da Vinci using a systems approach.

Musculoskeletal system

Regarding the skeletal system, da Vinci's depictions of the spine were often rudimentary and inaccurate [1]. He envisioned the vertebrae to be of uniform shape [1]. However, his depictions of the spine improved over time, guided by further dissection [1]. He even used his knowledge of physics to predict the placement of muscles and nerves necessary for realistic movement [1]. Regarding the muscular system, da Vinci believed that the diaphragm and muscles of the abdominal wall were the structures involved in generating forces that then controlled movement of the gut [2]. Additionally, his drawings of many of the facial muscles were often incorrect [2].

Cardiovascular system

For the cardiovascular system, the aortic arch is often not shown, the misconception of a rete mirabile in humans as taught by Galen is depicted, the right testicular vein originates too high from the inferior vena cava, and the heart is shown as having moderator bands on left and right sides. Interestingly, the only anatomical structure named after da Vinci is the normal moderator band of the right ventricle [2]. He described four umbilical arteries when there are only two [7]. O'Malley and Saunders describe da Vinci's understanding of blood flow as a flux and reflux phenomenon as merely a "modification of Galenical theory" [7].

On one of da Vinci's drawings showing the vascular tree of the human body, he labels one system the "Spiritual parts" based on the Galenic venous system and "Vital spirits" for the arterial system and based on the same teachings. On one picture of the heart, he uses Galen's comparison of the liver and vessels to a plant with the seed of Galen corresponding to the roots to the inferior vena cava and the branches below the hepatic veins and the stem to the upper portion and the inferior vena cava and its branches toward the heart was like a plant's fruit, an appendage to the venous tree; however, in his notes made just below this anatomical drawing, he takes on the position of Aristotle's teachings on this subject and says,

"the plant never arises from the branches for the plant first exists before he branches and the heart exist before the veins. The heart is the seed which engenders the tree of the veins these veins that have the roots in the dung, that is, the mesenteric veins which proceed to deposit the acquired blood in the liver form which the upper hepatic veins of the liver receive nourishment" [7].

Nervous system

For the nervous system, the brachial plexus is shown on some drawings as having no first thoracic spinal nerve contribution, which normally contributes to its formation (Fig. 1) although this can be an uncommon anatomical variation in human anatomy.

O'Malley and Saunders believed that da Vinci's observations of the nerves of the extremities were all based on his dissections of monkeys where he then "distorted to fit the contours of man." The ventricles of the brain, which he primarily studied in oxen by injecting them with molten wax, and the cranial nerves as they emerge from the inferior surface of the skull base were inaccurately drawn and frankly, wrong [11]. Based on da Vinci's experiments on frogs, he believed that the center of life was located in the spinal cord [7, 11].

Organs

For organs, the spleen is shown as receiving an artery from the liver, the outer lung cavity described as containing air, which was a traditional teaching of Galen, the seminal vesicle is shown too laterally placed and the penis is illustrated and described as containing two passages, one for animal spirits and one for the emission of urine [11]. Interestingly, da Vinci believed as was common in his day that semen was produced by the spinal cord (Fig. 2) [11].

His lack of appreciation of peristalsis in the wall of the gastrointestinal tract was evident too in his description of the ureters and of the flow of urine from the kidneys to the urinary bladder. He viewed the ureter as a simple tube through which fluids flowed as a result of gravity and even demonstrated in a series of diagrams the effects of various bodily positions on the flow of urine from the kidneys to the urinary bladder [7]. In his descriptions and illustrations of the liver, he incorrectly demonstrated it as having five lobes as Galen had taught. O'Malley and Saunders believed da Vinci was most erroneous anatomical descriptions were those of the male and female reproductive organs (Fig. 3) [7]. They sum up these descriptions by saying these were "treated with a curious mixture of fact and fancy."

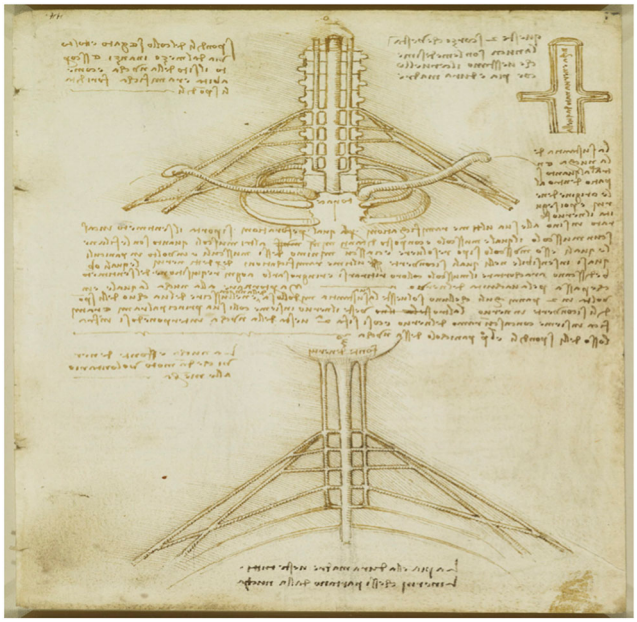

Fig. 1 da Vinci's sketch of the brachial plexus. Note that the brachial plexus is formed by only C5 to C8 and that there is no T1 contribution

Vascari (1568) wrote on the life and works of da Vinci [2]. In the book, Vascari suggests that da Vinci was most likely influenced by Galenic teaching via his supposed collaborations (1510–1511) with Marcantonio della Torre at the University of Pavia [2]. della Torre was a leading figure in his day for reviving Galenic teachings. Vascari notes that della Torre would have had access to Arabic translations or Latin translations of the Arabic of the extant writings of Galen and as a professor, most likely would have influenced those under his mentorship such as da Vinci [2]. However, as da Vinci

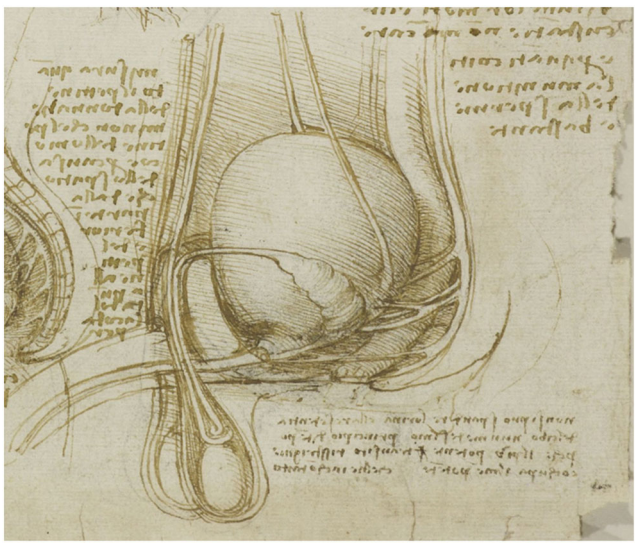

Fig. 2 da Vinci's drawing of the male pelvic organs. Note the odd shape and size of the rectum behind the enlarged urinary bladder. The seminal vesicle is misplaced, and the spinal cord extends into the penis as da Vinci believed that semen arose from the spinal cord and was then transmitted through the penis [11]

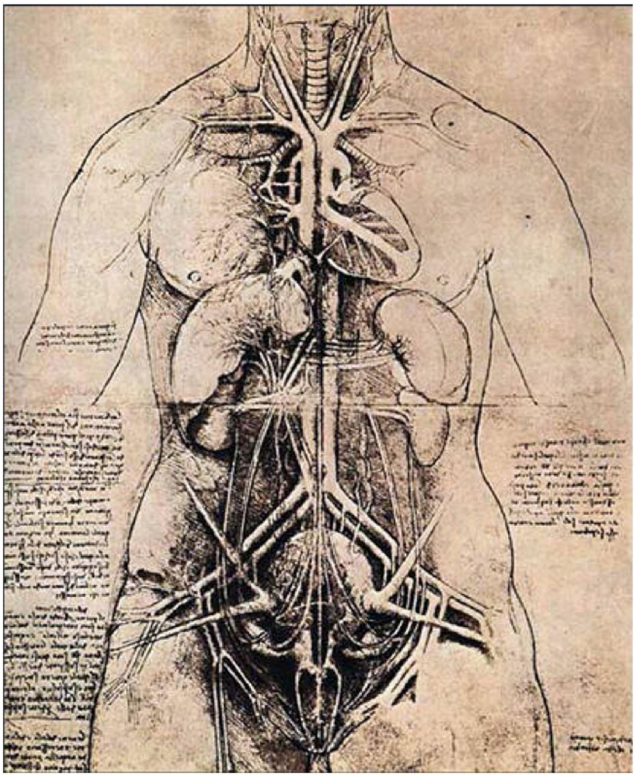

Fig. 3 da Vinci's drawing of organs of the female body. Note the abnormal uterus and its odd extensions. This representation is more in line with what would be found in a female cow [7]

rarely referenced anyone in his writings, this direct connection is difficult to confirm [2]. Moreover, many of da Vinci's anatomical descriptions and illustrations were not made in Galenic anatomical tradition [2, 9].

Some might point to a poor ability to dissect as leading to some of da Vinci's "mistakes." However, the tremendous accuracy of most of his anatomical drawings and the details that only a thorough dissection of the human body would avail make this unlikely [1]. Additionally, a diary entry on 10 October 1517 by Antonio de Beatis, a secretary for Cardinal Luigi d'Aragona, mentions how da Vinci's peers felt about his works.

> "This gentleman has written in great detail on anatomy, with illustration 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" [2].

Additionally, da Vinci also dissected animals and depicted these in his notebooks. Illustrations of various animals include those of dogs, oxen, and cows [2]. As Galen only dissected animals and extrapolated these findings to humans, da Vinci might have done the same. It is known that he often tried to make his findings in anatomy fit with the accepted understanding of the physiology of his day [1, 2]. For example, when trying to elucidate the flow of blood to and from the heart (not fully understood until William Harvey's publication *De motu cordis* published in 1628), he realized that the left side of the heart pumped blood into the arteries of the body and that the valves on this side prohibited back flow during contraction [2]. However, he never expanded this understanding to include the right side of the heart and its function in receiving venous blood from the body and pumping it to the lungs and that this blood then returned to the left side of the heart to be circulated [2]. What he did do was deduce that blood must intermix between the arteries and veins so that there was not overfilling of one over the other [2]. This deduction required that these vessels interconnect at their very ends [2]. This deductive reasoning on the part of da Vinci might have been one reason for some of his inaccurate drawings of human anatomy, i.e., not seen with his own eyes during dissection and deduced as being the same or at least similar to what he had seen in his anatomical dissections of various animals [2].

With regard to da Vinci being influenced by earlier anatomical knowledge, especially Galenic, Todd stated,

> "Accordingly, it was hardly a *carta rasa* on which Leonardo recorded his anatomical findings; however, the dubious quality of his anatomical inheritance was inordinately negative as a base of inspiration. However, the examiner will find little originality in any of the anatomical illustration available to Leonardo aside from the topographical representations of the human figure by his artistic peers. All medical illustration was characterized by a servile adherence to tradition scarcely improved by centuries of pale imitation" [11].

da Vinci began his study of the human body from the viewpoint of an artist and not from the vantage point of a physician. This for an artist was necessary not only to visualize the human form but also to understand its more deeply located structures so that that the surface and underlying substance might be more vividly depicted. In other words, to best capture the surface of his figures, understanding what contributes to this topography would be important. da Vinci's anatomical drawings were in the tradition that began with the Italian painter Giotto (1267–1337) which displaced conventionalism and aimed at a more natural and realistic representation and thus made Giotto an early figure of the Renaissance [11]. But to create such magnificent anatomical drawings, demanded not only the skill to sketch accurately, but also the unique ability of meticulous dissection and representation of the structures that were displayed. This artistic influence "flowed in the other direction as well. Artistic renderings assumed more space in

anatomical texts and their quality greatly improved as printing techniques became more sophisticated" [5, 9, 11].

Soon, da Vinci's enthusiasm for dissection led him to the study of anatomy as a discipline in its own right. He was considered a polymath of the Renaissance and is known to have studied botany, mathematics, geology, astronomy, philosophy, and anatomy both animal and human. His knowledge of human anatomy was known in his day. For example, 2 years before his death, da Vinci was visited by Cardinal Luigi d'Aragon who stated,

> "This gentleman has written of anatomy with such detail showing by illustrations the limbs, muscles, nerves, veins, ligaments, intestines, and whatsoever else there is to discuss in the bodies of men and women, in a way 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 30 bodies both of men and women of all ages" [9].

da Vinci recorded in his drawings precisely what he had observed and attempted to combine structure with function. His dissections were carried out in the hospital of Santa Maria Nuova in Florence and later in Santo Spiritu Hospital in Rome [9]. On the topic of anatomical knowledge through human dissection, da Vinci stated,

> "… while in order to obtain an exact and complete knowledge of these I have dissected more than ten human bodies … And as one single body did not suffice for so long a time, it was necessary to proceed by stages with so many bodies as would render my knowledge complete; and this I repeated twice over in order to discover the differences. But though possessed of an interest in the subject, you may perhaps be deterred by natural repugnance, or if this does not restrain you then perhaps by the fear of passing the night hours in the company of these corpses quartered and flayed, and horrible to behold, and if this does not deter you then perhaps you may lack the skill in drawing essential for such representation…Concerning which things, whether or not they have all been found in me, the one hundred and twenty books which I have composed will give their verdict yes or no. In these I have not been hindered either by avarice or negligence, but only by want of time" [6].

These words of da Vinci indicate that his anatomical investigations were calculated and deliberate. It is not evident from these comments that he tried to "cut corners" with his dissections but rather sought the truth. However, as he indicates in the last sentence of the excerpt above, time ("by only by want of time") could have been a factor and in a day and age where modern features that inhibit human decay such as embalming fluids and refrigeration were not available, perhaps time was a significant and limiting factor and da Vinci may have simply "filled in the gaps" with ideas or teachings that were Galenic. Based on his comments above, it is not clear at all that there was any direct pressure from established anatomical teaching, i.e., Galenic that guided his descriptions and renditions so the human anatomical knowledge of his day could have knitted together his direct anatomical findings when certain areas or features were not observed by him directly. This notion is supported by examples where he directly contradicted Galenic thought. One such example is that da Vinci opposed Galen's view that the liver is the source of the vena cava. Another example of how da Vinci did not accept everything known from antiquity related to anatomical principles was that he argued that Aristotle's view that the origin of the vena cava was the heart was incorrect.

From da Vinci's quote above, it is clear that it was written during the earlier part of his life because of the prior reference to having dissected 30 human bodies 2 years before his death [6]. From the annotations in his notebooks, one learns that he had planned on writing a book devoted to anatomy [6]. The large number of anatomical drawings and extensive writings in his notebooks would have probably been included in such a text. At da Vinci's death on 2 May 1519, he bequeathed all his manuscripts and drawings to his beloved disciple, Francesco Di Melzi, who kept them secured for almost 50 years [6]. Following the death of Melzi in 1570, the manuscripts were passed on to his nephew Orazio [6].

Unlike his contemporaries, it was da Vinci alone who pursued the study of the human body with such thoroughness that he quickly transcended the needs of the artist and drifted into the scientific pursuit of anatomy for its own end. His scientific rectitude was one of the first to bring Galenic anatomical teachings to the light. The anatomically incorrect drawings and descriptions occasionally found in his notebooks include clear examples of anatomy that was counter current to Galenic teachings so that one cannot conclude that da Vinci was consciously influenced by these first-century ideas. However, with limited time to dissect human cadavers and having ostensibly only dissected around 30 bodies, it is plausible that da Vinci simply and subconsciously substituted the prevailing Galenic thought, e.g., five lobes of the liver, the presence of a rete mirabile in humans, and the notion of an outer lung cavity described as containing air, into gaps in his dissection knowledge of the anatomy of the human body. The lack of modern techniques e.g., refrigeration for extending the longevity of cadaveric dissection very likely contributed to such anatomical substitutions. Therefore, a direct influence of Galenic teachings on da Vinci's anatomical work is not supported by the available evidence and known historical facts.

Conflict of interest The authors declare that they have no conflicts of interest.

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