Leonardo and Vesalius were two important renaissance persons; Vesalius was a surgeon-anatomist who delivered innovative work on the study of the human body, Leonardo da Vinci was an artist who delivered strikingly accurate and beautiful drawings on the human body. It seems interesting to compare their basic work, verify any possible inaccuracies and look for their influence today.

Some have stated that Vesalius’s work was nothing but plagiarism from Leonardo (1, 2, 3, 4, 5), in view of the fact that vast portions of Leonardo’s notes are supposed to be missing and that, when 55 years later Vesalius presented his book on anatomy Vesalius could have had the opportunity to study Leonardo’s books. Although this possibility can never be excluded, others claim this to be unlikely (1, 3). Below we compare both masters with regard to their knowledge of muscle activity, their method and system of dissection and their order and presentation of the drawings.

The investigation consisted of a comparison between both anatomists, in particular concerning their study on the shoulder girdle and spine, by reviewing their original work (6, 7, 8, 9), as well as already existing literature on this subject (1, 5, 8-13).

The investigation led to the conclusion that the drawings mentioned meant a change in history, and were of high quality, centuries ahead of their time. Both were anatomists, both were revolutionary, only one changed history at the moment itself, while the other changed history centuries later. Leonardo has made beautiful drawings that are at a match with the drawings of today or are even better. Vesalius set the start for medicine as a science as it is until this day. Their lives differed as strongly as their impact. In the light of their time, the achievement they made was extraordinary.

Introduction

Leonardo and Vesalius were two important renaissance persons; Vesalius was a surgeon-anatomist who delivered innovative work on the study of the human body, Leonardo da Vinci was an artist who delivered strikingly accurate and beautiful drawings on the human body. It seems interesting to compare their basic work, verify any possible inaccuracies and look for their influence today.

The investigation consisted of a comparison between both anatomists, in particular concerning their study on the shoulder girdle and spine, by reviewing their original work (6, 7, 8, 9), as well as already existing literature on this subject (1, 5, 8-13).

General Technical Strategies

It is probable that Leonardo dissected himself or at least viewed and assisted dissections. It is said that he dissected from 30 to 100 corpses but more likely it were about eight corpses (2, 3, 14-21).

Based on the fact that he has never drawn a skeleton as a whole, unless from memory – we know this by the crudity of the drawings – it is assumed that Leonardo never possessed a complete skeleton – in contrast to the statement made by Moore (13). Cadavers were scarce during his life, especially during his second Milanese period (1506), when his interest in anatomy was at a
high. He is the only and the first anatomist who made use of 'force lines' - these are lines that show how the force of the muscles is spread from origin to insertion (2, 17, 21, 22-24). Also, he was the first to describe the origin and the insertion of muscles and the innervation of muscle-groups (2, 21). The first description of the agonist-antagonist function is also of his hands (21). At the time of his death, Leonardo left 50 to 55 notebooks, encompassing 12000 pages, to his pupil Melzi, about 50 to 60% of which have been lost, meaning that only about 20 notebooks still exist (4).

Vesalius is thought to have made some drawings himself, but it is also assumed that most of them were drawn by pupils of Titian, in particular Jan Stefan van Kalkar (5, 6, 25, 26). For Vesalius anatomy was the base of medicine. By doing the dissections himself, he broke with the tradition of ceremonial lecturing, when the professor read from his chair, a barber-surgeon performed the dissection and an appointer showed the bespoken structures (14, 15, 26-28).

With regard to the action of the muscles, Leonardo frequently explained the mechanism of leverage of the muscles and their place of insertion (9). Also the antagonist-agonist mechanism was described and illustrated many times – see spinal muscles. Leonardo was also the first to explain the system of pronation – supination – see humerus (7). Leonardo dissected many different animals. He frequently made references to animal anatomy. He made drawings to compare the bear and the man, the horse and the man, the bird and the man. He used the ox and the frog to explain his findings on anatomy. Leonardo met Marcantiono della Torre with whom he supposedly started a work on anatomy. This project came to a quick end because della Torre died of the plague in 1511. Probably della Torre assisted him with the dissections, although Leonardo would have done the dissections himself. He often made the mistake to divide a muscle into different fasciculi or different muscles by artificial divisions with a knife (7).

Concerning the system of dissection, flaking off cartilage can be seen in the drawings of the Fabrica, Vesalius depicted this separately. This may represent a form of chondromalacia or articular cartilages flaked off due to maceration in boiling water to prepare the bones for demonstration (6, 29). Vesalius performed himself the dissections, made comparisons with animal anatomy during his lectures, and explained his theories to his students with chalk on board (6, 14, 29).

Leonardo used a three-part pattern and an eight-part cinematographic view of images (25). Herein he drew the subject, as you would walk around it. A systematic, exploded view which shows the relation from one piece to another and details from each piece separately was also one of Leonardo’s techniques. Leonardo was the first to use a systematized way of illustrating human anatomy. He introduced sagittal section, coronal section and cross-sectioned anatomy (13). These techniques are still used today in anatomic atlases as those of Sobotta or Gray.

As a system of drawing Vesalius used a system of ‘continuous revelation’. In such a system, two factors change from one plate to the next: on the one hand deeper structures are progressively revealed by the removal of overlying structures, while on the other the three-dimensional relationship of the parts is shown by meticulously controlled changes of pose (25). Vesalius used this methodical manner of layered dissection combined with a minimal change of position. He drew from live images in red chalk. The skeleton drawings in the Tabulae present a lot of inaccuracies (6). The author of the drawings, Jan Stefan van Kalkar pictures a stiff skeleton with incorrect proportions, there is a misarticulation in the representation of the clavicle, the sternum consists of seven pieces, there are pelvic errors, the vertebral column is incorrectly represented, there are signs of rickets (shape of the skull, irregular long bones, enlargement of the epiphysis) (6). The drawings of the skeleton in the Fabrica equally show many errors. The skeleton is reduced to approximately four fifth of his natural size, the thorax is too short, the lumbar spine too long, the torso somewhat too short, the spinal curvatures are absent, the ribs are too horizontal due to the absent of spinal curvatures, and the pelvic tilt is reduced (6). The major difference is that Leonardo drew illustrations which outclass the illustrations of Vesalius, but in the Fabrica the illustrations were shown in a systematic way and were provided with a text to guide the viewer, whereas Leonand never structured his notes and illustrations.

Points of Interest
The Scapula

Obviously Leonardo made the drawing of the scapula himself, while in the case of Vesalius’s pictures there remains discussion about the author of these drawings (6, 25, 26). Leonardo drew the scapula relatively too long, he extended it to the tenth instead of the seventh rib due to the possession of an incomplete skeleton (Fig. 1). We can also assume that by absence of the intervertebral disks – see the spine - the scapula looks longer in relation with the rib cage. Also the too large scapula of a different skeleton may have contributed to this error. On another illustration the scapula has no spine or acromion, which is probably due to the fact that da Vinci is assumed to have drawn this view from memory (7). A summus humerus, which is the third ossicle between clavicle and acromion, can also be seen. Probably this is an un-ossified epiphysis since he omitted this in other illustrations of the scapula. Probably he derived this notion from Galen. Roth has criticized this drawing on the ground
that the coracoid process was represented as a distinct bone (7).

Leonardo used his own words for scapula, namely spatula, spatula, spatola, and padella in Greek all meaning 'broad blade' (7). Leonardo da Vinci drew a lateral, posterior, anterior, and superior view of the scapula, all in articulation with the other bones. Vesalius used a more systematic way wherein he showed the scapula in three positions: anterior, posterior and lateral. This was shown in a singular view of one distinct bone and also on a whole skeleton and with different levels of dissections of the muscles in the Fabrica. The scapula was also represented on a complete skeleton in the Tabulae anatomicae but these drawings are of poor quality, drawn by Jan Stefan van Kalkar (5, 6, 25, 26).

The Clavicle

Vesalius has a nicely drawn illustration of a clavicle as a single bone whereas Leonardo has never drawn this bone separately. Leonardo used several words for clavicle, namely forforcula, forchula, furchola, and furcula. Furca means a fork in Latin, Leonardo used this name because the two clavicles prolonge from the sternum as a fork. He also used the words suprasternal notch (furcula superior) and xiphoid (furcula inferior), referring to Mondino di Luzzi (1275-1326) who used furcula for the xiphoid. Furcula was the common name for clavicle among anatomists and surgeons (7).

In the Fabrica the clavicles are presented in three separate views, anterior-superior or external aspect, posterior, and inferior aspect. The three views of the plates in the Tabulae anatomicae of complete skeletons are recognized as poorly drawn illustrations by Jan Stefan Van Kalkar, in which the clavicle is badly represented and articulated (1, 5, 6, 25, 26).

The Humerus

Leonardo stated that you should saw bones transversely, longitudinally, intact and separated. He mentioned this on his drawings where the humerus is shown. These drawings were specifically drawn to show the pronation-supination mechanism in the forearm (7, 17, 22, 23). He also mentioned the different related proportions from one bone to another. The intermembral index here is a little less then the European average. Maybe this was caused by the use of several parts of different skeletons as cadavers where scarce at that time (7). All the bones drawn are articulated bones, in contrast to Vesalius who firstly showed all bones separately and then articulated. Leonardo used the word ‘humerus’ to refer to the shoulder and the three bones, the humerus, the clavicle, and the scapula, which obtained their names at different times (6).

Vesalius’s drawings show the epiphysis of the humerus un-united, due to the fact that for the drawings a skeleton of a young male of 16-17 years was prepared (1, 5, 6). An anterior and posterior view of the humerus is presented, whereas in the beginning of the Fabrica an overview of the different types of bones can be found, in which the humerus is included. There is also a longitudinally sawed humerus represented in the Fabrica, proving to Vesalius the existence of the cancellous bone, the medullary canal and the compact cortex (6).

In the Tabulae and the Fabrica the skeleton was reduced approximately to four fifth of its natural size and besides other inaccuracies the arm was too long, namely the forearm too long for the humerus, the humerus too short and so the intermembral index too low for a European type. These inaccuracies have two reasons. One is the fact that Jan Stefan Van Kalkar made the drawings in the Tabulae (6, 25, 26), and a second reason can be found in the mechanism of the demonstration of skeletons – mounting the spine on a rigid bar, and hereby flattening out the curvature of the spine (6, 29).

The Sternum

While revolutionary on various aspects, the two masters stayed loyal to Galen’s division of the sternum in seven in stead of three parts, because according to Galen there should be as many parts as attached costal cartilages.
Leonardo described eight true ribs instead of seven, and included the xiphoid with the sternebrae. Hence by these two changes he challenged Galen’s anatomy (6, 7). As with the scapula, Leonardo showed the sternum articulated on the skeleton.

Vesalius on the other hand explained in his notes that he did never see seven parts of the sternum. He also stated that the number of pieces largely varied in different specimens. An explanation of the number of sternal pieces in the depiction may be given by the fact that this drawing is engraved early in the progress of the book, before Vesalius was seriously challenging Galen’s theories (6). Vesalius shows the sternum separately and articulated on the skeleton in *the Fabrica*. In the three plates of the Tabulae Sex a sternum can be seen, these drawings however being of poorer quality.

The Spine
Leonardo did notice the curvatures of the back, in contrast to Vesalius. For the first time, the sacrum was correctly made up of five vertebrae (7, 18, 21, 30). Intervertebral disks were however not depicted by Leonardo, which was probably the result of washing and preparation of the skeleton. Moreover in between thoracic vertebra two and three, Leonardo added an additional spinal process without a vertebral body (Fig. 2).

Leonardo used different words to describe vertebrae: *spondyle, vertebra* – used by surgeons –, and *trochantier* were all three words which meant ‘turning movement’ and were used by medieval anatomists. For the spinal cord the word *nucha* was used, but this has two meanings, namely nape of the neck – *nugrah* (Arabic for neck), and spinal cord – *nucha* (Arabic for spinal cord). The word *alcatin* was also used; it means loins, lumbar vertebrae (Avicenna), sacrum (Mundinus), and pelvis (6). Leonardo’s drawing of the cervical vertebrae is a very accurate drawing, but without explanation or text. Considering his knowledge of mechanics, the question why the drawing remained without text, remains unanswered. An explanation could be the loss of a part of his notebooks (4). Leonardo described the movement of the neck in four directions, flexion, extension, and lateral tilt. In the drawings of the vertebrae, Leonardo used three frontal views, anterior, posterior, and lateral, and two sectional views, superior and inferior (24).

Vesalius’s work is characterized by the absence of curves in the spine (Fig. 3). This was due to the hitherto used method of articulation. The bones of the skeleton were cooked and washed, after which the vertebrae were put on an iron bar that didn’t show the natural curves of the back (29). Vesalius thoroughly described the mechanics of neck and head and hereby proved the fault of Galen (7). Vesalius added a three-piece sacrum, added a three-piece coccyx and mentioned it could be un-ossified to harmonize with Galen. He also showed a six-piece sacrum where as a defence – against Fallopius – he stated that the skeleton came from a very perfect model and that he therefore used it for illustration, although he knew for certain that the sacrum should have four segments. The occipital bone was shown in one piece in contrast to Galen who applied his findings on quadrupeds to human anatomy (6).

The epiphysis of the centre of the vertebrae is un-united in *the Fabrica*; this was again due to the fact that for the drawings the skeleton of a young male of 16-17 years was used as a model (17, 31). In the presentation of the lumbar vertebrae the anticlinal spine – accessory anaphysed process – made clear to Vesalius that Galen was incorrect and had derived much of the human anatomy from apes and dogs (5, 6, 29).

The shoulder musculature
Leonardo was the first to show the correct insertion of the deltoid muscle. He however divided it in different fasciculi by making different artificial divisions with his knife. He regarded the four different fasciculi as different muscles. In some drawings the posterior portion of the deltoideus is shown as a slip separated from the rest of the muscles. Leonardo believed that muscles like the deltoid or the pectoral muscle contained different fascicule, which got fused in robust objects. It is known that
muscles look like fasciculi at contraction and that variation can also be found in rare cases. Leonardo’s belief can be explained by the paucity of his subjects. Leonardo coined the deltid muscle musculo del spalla, spalla meaning shoulder, and variably used, just as humerus also referred to the shoulder (7). Vesalius illustrated the deltoideus correctly.

As in other muscle groups Leonardo equally divided the great pectoral muscle into fasciculi, probably because his most important subject was a 100-year old male. As mentioned before on some individuals this may represent a normal variation. Vesalius’s representation of the pectoralis major is a more correct vision of the muscle.

As a consequence of his division of larger muscle-groups into fasciculi, Leonardo divided the pectoralis minor into three or two fasciculi as he also regarded the trapezius and the pectoralis major. The pectoralis is used as an elevator of the ribs of the chest at inspiration in combination with the serratus posterior, according to Leonardo (7). Vesalius illustrated the pectoralis minor correctly.

Leonardo drew the subclavius upside down; aside some correct illustrations (6). Vesalius illustrated the subclavius correctly.

The latissimus dorsi gives internal rotation of the humerus, as Leonardo correctly explained (7). Vesalius illustrated the latissimus dorsi correctly.

Leonardo confused the scaleni muscles in some of his drawings, but he also showed a correct representation. Vesalius extended the scalenus anterior muscle further then the first rib in one of his plates of the Fabrica, to prove hereby that Galen’s anatomy was largely derived from dogs and apes. He depicted the muscle correctly in other plates to show the difference (Fig. 4). Also the extension from the rectus abdominis is visible in the illustration, another variation Galen derived from dogs and depicted by Vesalius (5, 6).

Leonardo regarded the serratus posterior superior and anterior group as important for respiration and rotation of the chest. He failed to find the scapular border of these muscles, and regarded them important for stabilisation of the thorax during contraction of the diaphragm. In one of his drawings, the muscles of the anterior are attached too low (7). The serratus posterior superior and inferior are crudely represented in the Fabrica of Vesalius; this was due to the method of illustrating in woodcut.
Leonardo beautifully illustrated the trapezoidal space, formed by the humerus, teres minor, major, and the long head of the triceps (Fig. 5-6). He regarded them as important for the extension of the humerus. Together with the latissimus, the teres major acts as internal rotator of the humerus, he stated (7). Vesalius depicted the teres major beautifully, but the teres minor was not recognized until after the publication of Fallopius (6).

The trapezius muscle consists of three fasciculi in Leonardo’s drawings – spinal, acromial, and clavical. Sometimes the upper position of the trapezius was prominent, the muscle incompletely drawn and the lower half omitted. Leonardo regarded this muscle as important for respiration (7). Vesalius illustrated the trapezius correctly.

The spinal muscles where regarded as important for respiration and stabilisation of the neck by Leonardo, the sacrospinalis and iliocostalis were both synergists and fixation muscles. The iliocostalis – sacrospinalis are separated, and in between them is the quadratus lumborum. Leonardo used this muscle to explain his antagonist-agonist theory. Leonardo paid much attention to the muscles that held the spine upright, comparing it with the ropes of a mast (7).

Vesalius depicted the quadratus lumborum, psoas major, iliopsoas, splenius, semispinalis capitis, rectus capitis posterior minor, as well as the oblique and recti muscles of the occipital region. The three elements of the sacrospinalis can be seen, namely the spinalis, the longissimus, and the iliocostalis. Vesalius seemed very confused concerning the arrangement of the deeper spinal muscles (6).

Vesalius illustrated the insertion of the biceps tendon on the labrum glenoidale; Leonardo used this picture to explain the action of the nerves and the muscles. The biceps was called pesce del braccio, which means ‘fish of the arm’ (7). Vesalius illustrated the biceps correctly.

The long head of the triceps arises incorrectly from the base of the spine of the scapula in one of Leonardo’s drawings (7). Vesalius illustrated the triceps correctly.

Leonardo showed the brachialis arising from his distal two-thirds origin of the humerus to the coracoid process and regarded this correctly as the only flexor of the forearm (7). Vesalius illustrated the brachialis correctly.

Leonardo drew the levator scapulae, together with the rhomboidei to explain the importance of these muscles in relaxation or contraction for the form of the back and the position of the scapula (7). Vesalius illustrated the levator scapulae correctly.

**Comment**

As a vast part of Leonardo’s notes got lost, leaving the existing books incomplete, there can never be certainty about his overall knowledge of anatomy. Maybe he corrected some errors in other notes, which are known to be lost. The fact that we studied ancient books and pictures leaves much chance for loss of information as well as incorrect representation and translation. In the studied reprints of *De Humani Corporis Fabrica* (9) and *On Human Anatomy* (8) we limited our research to the shoulder girdle and the spine. This leaves place for other publications on other regions of the human body, or a review of the systemic differences between the two authors.

**Conclusion**

Leonardo was the first to use a deliberate system of illustration of human anatomy. He introduced sagittal
References

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