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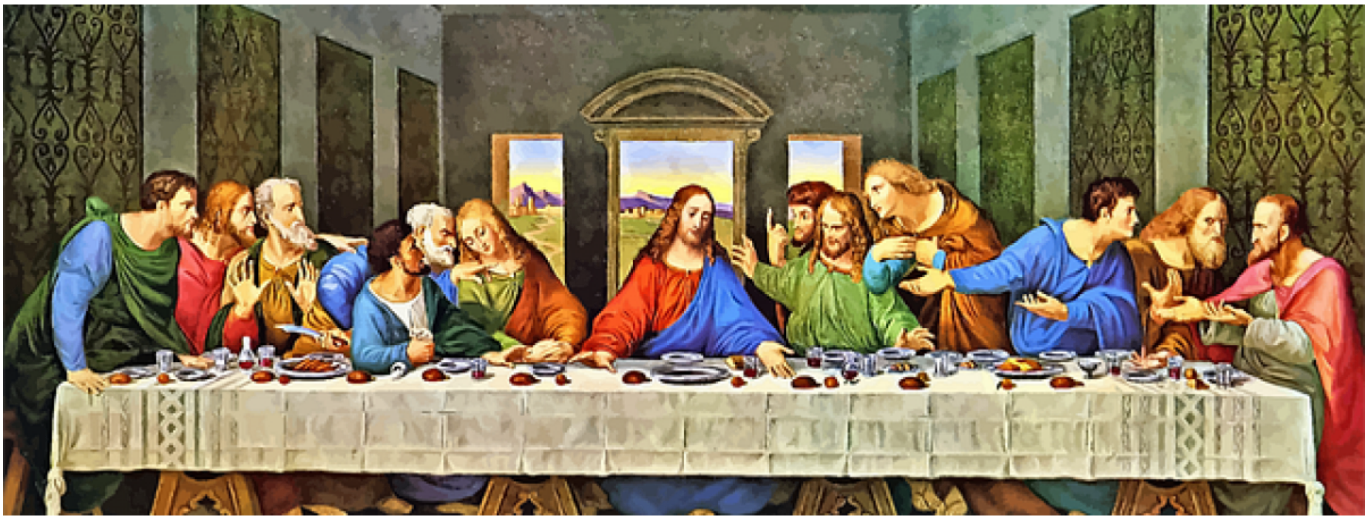

Artist, architect, anatomist and engineer, Leonardo da Vinci is remembered in history as 'the most varied genius who ever lived'.(Shoja et al, 2013: 1126)

He displayed a relentless curiosity, wondering at everything from the flight of birds, to the development of the foetus in the womb, and the origins of wind and clouds (Wood, 1972 [3]).

His painting of the Mona Lisa is the most celebrated portrait of all time, and his illustrations of the heart have gained the Royal seal of approval: the Royal Collection owns a series of his annotated cardiovascular diagrams; HRH The Prince of Wales has written a glowing introduction in the acclaimed 'Heart of Leonardo' (Wells, 2013 [4]), praising da Vinci's detailed and clear-sighted drawings, and recognising their role in anticipating discoveries that are only now being realised.

Yet da Vinci himself said:

'I have wasted my hours. I have offended God and mankind because my work did not reach the quality it should have'.

(Napolitano, 2011 [5])

We will see how many of his works remained unfinished; several of his engineering designs didn't work, and error persisted in his cardiovascular diagrams. It is for this reason that Dr Kenneth Keele, physician, medical historian and founder of the Leonardo da Vinci Society, summarised da Vinci's work as:

'the epitome of greatness in failure'.

(Keele, 1952 [6]: 122)

In this article, we will contrast the greatness of his discoveries alongside his errors and omissions, beginning with his early years, which shaped and prepared him for his later anatomical works. I will draw on the unparalleled text by Keele (1952) [6], having a copy of this valued book, of which only 1000 were printed.

The early years

Illegitimate, uneducated and cut off from his father's inheritance, da Vinci's childhood was defined more by deprivation than greatness. His father, Ser Piero da Vinci, was a wealthy notary; his mother, Caterina, a 16-year-old peasant girl (Wells, 2013 [4]). Da Vinci was abandoned by his father for the first years of his life, but then taken by his father to live in Vinci (hence the surname) to provide a child in his childless marriage (Shoja et al, 2013 [7]).

Denied a formal education and an inheritance because of his illegitimacy, da Vinci was keenly aware of his short-comings. He stated:

'I am fully aware that the fact of my not being a man of letters may cause certain arrogant persons to think that they may with reason censure me, alleging that I am a man ignorant of book learning'.

(Shoja et al, 2013 [7]: 1130)

The first glimmer of greatness occurred in his late teenage years when da Vinci was accepted under the tuition of Verrochio, a master Italian painter. Here he met formidable artists such as Pollaiuolo, Botticelli and Uccello, and began to display his artistic talents (Ruggiero, 2008 [8]).

His early work

Da Vinci was, first and foremost, an artist and an engineer. His later success as an anatomist, however, drew richly on these talents. It is noted that:

'Leonardo first approached anatomy through art'.

(Keele, 1952 [6]: 33)

His aesthetic drawing of a skull in 1489 (at the age of 37) stands out for the way in which it combines art and anatomy (Keele, 1952 [6]). His eye for engineering design allowed him to view the human body as a machine, allowing him to make unprecedented conclusions about the mechanics of the heart and the hydraulic principles underlying the functions of the cardiac valves. He recognised the human foot as a masterpiece of engineering and a work of art.

His artistic and engineering talent was, however, not without flaw: his attempts at flight failed, he regarded the Mona Lisa as unfinished, he never completed his vast 'Adoration of the Magi', and his 'Battle of Anghiari' was overpainted by Vasari (Jones, 2012 [9]).

His drawings of the cardiovascular system

As with William Harvey a century later, da Vinci was influenced by the teachings of Galen and Mondino with reference to the workings of the heart and vessels. He is thought to have dissected up to 30 corpses, and, like Harvey, sought to understand afresh what he saw upon dissection, rather than merely using the dissection to prove Galenic theory (Cowan, 2016 [10]). Unlike Harvey, however, he is thought never to have witnessed a beating heart in situ, and this may explain the persistence of some error in his descriptions (Keele, 1952 [6]).

Many of da Vinci's cardiovascular drawings may have been lost: he refers to 'the hundred and twenty books I have composed' (Keele, 1952 [6]: 32), but none of these books has ever been found. He admits to not having the time to publish his work. Nevertheless, 5000 drawings remain, of which 190 refer to anatomical subjects, with about 100 featuring the cardiovascular system (Wells, 2013 [4]). Any cardiac nurse viewing his work today will agree that da Vinci's drawings of the heart and vessels are rarely equalled by modern anatomical illustration.

Greatness in cardiology

Da Vinci's discoveries about the heart and vessels were undoubtedly great, but he himself acknowledged that his findings were only great because of the awesome nature of the subject matter being studied, saying:

‘how in words can you describe this heart without filling a whole book?’.

(Shoja et al, 2013 [7]: 1130)

Harvey also expressed awe in his work, seeing something of God's glory and omnipotence in the design of the heart (Leake, 1929 [11]). Could similar wonder at the heart inspire cardiac nurses in their learning, and perhaps even in discovery?

Most important revelations

Da Vinci's most important revelations about the heart were as follows:

‘The heart is a principal muscle, in respect of force, and it is much more powerful than the other muscles’.

(Keele 1952 [6]: 43)

Obvious to modern anatomists, it is hard to believe that the heart was once considered to be flesh rather than muscle. Galen had recognised longitudinal, transverse and oblique fibres in the heart, but did not consider it to be a muscle, since he reasoned that all muscles require rest: something that the heart hardly does (Callentine, 2016 [12]). Both Galen and da Vinci were unaware of the spiral formation of myocardial tissue: Harvey was the first to witness this after dissection of a boiled heart (Leake, 1929 [11]).

The heart does not produce a mystical ‘natural heat’.

Galen's description of what happened to the blood in the heart is fascinating: the heart is seen as a furnace, ‘boiling the blood’ so that it changes from purple to red as it heats up (Cowan, 2016 [10]). Galen imagines some occult, intrinsic heat originating in the heart. The mechanicallyminded da Vinci, however, was the first to suggest that frictional forces generate heat, and he reasoned that the movement of the blood in the contracting heart created heat through friction (Wells, 2013 [4]).

The heart consists of four chambers: the atria are distinct structures rather than dilatations of the vena cava and pulmonary veins.

Once discovered, da Vinci's engineering background led him to question their function. He suggested that the atria (or ‘upper ventricles’ as he referred to them) contracted alternately to the ventricles, in a flux and reflux cycle, mixing the blood to heat it (Keele, 1952 [6]): it is, of course, now recognised that blood does not reflux from the ventricles on systole, owing to the cardiac valves.

Cardiac valves have been described since 275 BC; yet they were not thought to play an important role in a pre-Harvey concept of the vascular system in which blood was thought to ebb and flow, rather like the waves of the sea (Woodward, 2009 [13]). Da Vinci, however, made exquisite glass models of the valves (being particularly fascinated by the aortic valve) (Shoja et al, 2013 [7]). He watched the flow of grass seeds, carried in water, through his models, and observed lateral vortices of fluid, curling back to shut the valves from the side and below. This closure mechanism has since been confirmed (Bellhouse and Bellhouse, 1968 [14]).

Air does not enter the heart from the trachea.

Galen had proposed this idea, reasoning that this would allow cooling of the heart. Da Vinci disproved this theory by dissection, and also by inflating the lungs and proving that air did not enter the pulmonary veins (Keele, 1952 [6]).

Knowing that the left ventricle did not receive air from the lungs challenged ideas given for the relative thickness of the left ventricular wall. It was originally proposed that this was necessary to ‘balance’ the heavier contents of the right ventricle (imagined to lack the air thought to be present in the left ventricle) (Keele, 1952 [6]). Da Vinci, however, did not offer any other viable reason for left-ventricular wall thickness.

A new understanding of the vascular system as a 'vascular tree' with many branches.

Da Vinci linked the movement of the heart to the pulsation of an artery, and accurately portrayed the vessels of the body as a magnificent 'vascular tree' with many branches. Even today, this can be graphically observed in the controversial Body Worlds exhibition, in which the German anatomist Dr von Hagens displays perfect castings of the entire network of blood vessels in a human body (Body Worlds, 2017 [15]).

Several instances indicating pioneering discoveries of pathology.

'Il vecchio' (the old man) is an oftencited example of da Vinci's interest in death and disease. He describes watching an apparently healthy, yet frail, centenarian, die before his eyes and then performing his autopsy: he describes the 'thickened coat' found inside the man's vessels, likening it to an old orange, in which the peel becomes thicker and the pulp diminishes (Wells, 2013 [4]). Such insight into atherosclerosis becomes even more astonishing when da Vinci tries to suggest its cause as excessive nourishment from the blood (just as we now ascribe a role for cholesterol in atheroma).

Da Vinci also makes drawings of an atrial septal defect (Shoja et al, 2013 [7]) and suggests increased blood flow to the head as causes of headache and epistaxis (Keele, 1952 [6]). Most intriguingly, keen-eyed observers have discovered a yellowish spot on the left upper eyelid and back of the right hand of the Mona Lisa (Ose, 2008 [16]). The subject for the Mona Lisa died at the age of 37: could this be an early documented case of familial hypercholesterolemia?

Failure in cardiology

Sometimes da Vinci's skill as an engineer hindered his physiological understanding: having long studied water currents in rivers and the seas, he saw no reason why blood could not also ebb and flow in a single vessel, supporting Galen's theory (Woodward, 2009 [13]). Furthermore, his overriding desire to see the heart as the central heater of the body meant that he did not credit the heart with its key role in blood ejection. Instead, he talked about a small quantity of blood 'escaping' from the heart during systole, and soon losing its propulsive motion owing to opposing currents within the vessel (Keele, 1952 [6]).

Galenic theory also stated that blood passes across the septum into the left heart, through tiny pores (Harris, 1916 [17]). Da Vinci struggled to see these pores, but rather than deny their existence, he said they were almost imperceptible. Dr Keele raises the possibility that respect for authority prevented him from disputing this theory (Keele, 1952 [6]). As cardiac nurses, do we dare to challenge opinion when evidence supports us?

Da Vinci wondered about the origin of the heartbeat and wrongly identified a possible papillary muscle in the left ventricle (Keele, 1952 [6]). Other errors include his thoughts that arteries were relatively less important than veins, and, most surprisingly, that the foetus does not have a heartbeat (Wells, 2013 [4]).

Conclusion

Opinion will remain divided about da Vinci's greatness in the field of cardiology. That his drawings were accurate and inspiring though must surely be accepted when one sees the legacy of his work in cardiology today. His drawings have inspired recent three-dimensional virtual models of the heart (Schleich et al, 2009 [18]), and prosthetic heart valves have been designed using his diagrams as a guide (Shoja et al, 2013 [7]).

Meanwhile, the da Vinci surgical system allows minimally invasive, very precise heart surgery. Its safety and efficacy have been proven for mitral valve repair (Nifong et al, 2003 [19]), and for atrial septal defect closure, even with concomitant tricuspid repair (Onan et al, 2014 [20]). How many of today's cardiologists will still inspire design in their field nearly 500 years after their death?

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