# Anatomy of a physiological discovery: William Harvey and the circulation of the blood

Emerson Thomas McMullen PhD

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## INTRODUCTION

Historians have dissected William Harvey's conception that the blood circulates in terms of what, how, and when. Examples of *what* they thought initially led to Harvey's mental discovery include the sameness of the blood[1] and Harvey's intelligent experimental method[2]. A currently popular view centres around the blood's quantity[3]. As for *how* Harvey did it, opinions vary widely. One is that he used an approach based on function and the hypothetico-deductive method[4]. *When* Harvey made his discovery also has been debated. Recent estimates fall between 1619 and 1628[5]. This article presents evidence that the conception process began before 1617 and that purpose was more important than function. Function describes how something works while purpose explains why it is there in the first place. The purpose of a clock, for example, is to tell time, while function explains the workings of its gears and springs.

## WHEN WAS THE DISCOVERY?

There are several places in *Exercitatio anatomica de motu cordis et sanguinis animalibus* (hereafter called *De motu cordis*), which contain clues to the time frame of Harvey's mental discovery. The first is well known. In the Dedication to Dr Argent, President of the Royal College of Physicians, Harvey wrote that he had confirmed his new views for 'nine years and more' earlier[6]. Since *De motu cordis* was first published in 1628, then 'more than nine years' had to be at least in 1618, or even earlier. Also, later in the Dedication, he stated that his 'little book' was 'complete some years ago'. This early time frame for the discovery could explain hints that some of the medical community on the continent heard rumours of Harvey's discovery by 1622[7].

After the Dedication of *De motu cordis* is the Introductory Discourse. The clue to the time frame involves Harvey's old anatomy professor at Padua. Harvey identified Hieronymus Fabricius' *De respiratione* as 'the most recently published book on the subject'. *De respiratione* was published in 1615. It is hard to know precisely what Harvey meant by 'recently', but he did not have to use the word at all. Dropping the above phrase with 'recently' in it would not have altered at all the point Harvey was making about respiration. Therefore his reference to a 1615 book as 'recent' tends to support the literal meaning of 'nine years and more'. The implication of both quotations is that Harvey had conceived of the blood's circulation earlier than conventionally thought, and that he was writing about it before 1619.

The last clue in *De motu cordis* on the time frame of the discovery is in Chapter 13. This chapter contains Harvey's discourse on the valves in the veins and the only pictures in the book. Here Harvey referred to Fabricius' work on the venous valves, and most interestingly, described his old teacher. Harvey portrayed Fabricius as 'a man advanced in years'. Harvey did not say 'who recently passed away', or something similar. Obviously Fabricius was living at the time Harvey wrote this and did not pass off the scene until 21 May 1619. Therefore, the middle of 1619 has to be an absolute upper limit for when Harvey wrote this key chapter. This early date creates difficulties for some ideas on Harvey and his discovery: one such idea is that Harvey wrote *De motu cordis* in two stages[8].

The evidence from Harvey's lecture notebook is that he had not made the discovery in 1616. This date, then, becomes an absolute lower limit. Probably, Harvey had the complete hypothesis before he started writing[9]. Thus, a possible scenario is that Harvey made the complete breakthrough in 1617 and then immediately wrote the bulk of *De motu cordis*. (The Dedication was either updated or else written much later.) If so, then Harvey's rejection of the old physiology was even earlier than 1617. Support for this early rejection comes from a study of the valves in the veins.

## THE VENOUS VALVES

The early discoverers of the valves in the veins understood their function correctly. Amatus Lusitanus (1511–1568) wrote that 'ostiola' (little doors) prevent the blood from returning, and operate like those in the heart. Andreas Vesalius (1514–1564) reported that Giovanbattista Canano (1515–1579) told him that membranes in the veins, similar to those in the heart, prevented the reflux of blood. However, Vesalius himself thought these membranes

Historian of Science, Technology and Medicine, Department of History, Georgia Southern University, Statesboro, Georgia, 30460-8054, USA

strengthened the veins[10], and because of Vesalius' somewhat negative influence, interest in the venous valves waned. This situation changed with Fabricius, Harvey's most influential teacher[11]. In 1574, Fabricius claimed to have discovered the 'valves' in the veins. He called them 'ostiola', meaning 'little doors'. (Hereafter, the term 'ostiola' will be used instead of 'little doors'.) In 1603, Fabricius published *the* definitive work on these venous membranes, *De venarum ostiolis*[12].

A top anatomist, Fabricius might have discovered the blood's circulation. According to Galen of Pergamon (second century AD), blood ebbs and flows in the arteries, distributing the vital spirit. Blood moves similarly in the veins, nourishing the body, but with a more general outward flow from the heart as the blood, or part of it, is consumed. The discovery of ostiola unbalanced the physiological symmetry of Galen's explanation. Further, if ostiola acted like check-valves and allowed blood to flow only toward the heart, then the body's extremities would starve, in which case Galen's physiology would be obviously incorrect.

Fabricius thought that ostiola function not as one-way valves, but only as hindrances to the blood's outward flow. Based on this function, he argued that the purpose of ostiola was to slow the blood's flow, preventing it from collecting too rapidly in the body's extremities. If the blood flowed too quickly to the hands and feet, other body parts would be undernourished. Fabricius drew an analogy between ostiola and floodgates which hinder water flow in the sluices at a mill. Thus, it would appear that he explained the purpose of ostiola in terms of accepted physiology.

In reality, Fabricius modified Galen's paradigm. To keep the blood from falling down into the lower parts of limbs, Galen had hypothesized the existence of an 'attractive' power. Fabricius replaced that notion with his more mechanical explanation. In this limited way, he had developed a new physiology. Perhaps this is one reason he ended *De venarum ostiolis* by saying:

> such is the wisdom and ingenuity of Nature which by my own efforts I have discovered in this new field.

Fabricius criticized Vesalius for not going beyond careful anatomy to physiology. This is why Harvey was such a student of Fabricius. Vesalius had broken new ground in anatomy. Fabricius realized that the next frontier would be in physiology. Fabricius and Harvey did go beyond careful anatomy to physiology, but Harvey's physiology was more careful, and therefore more productive, than that of Fabricius.

Another person writing on the venous valves and the first to picture them was Salomon Alberti, a medical professor at the University at Wittenberg. In *Tres Orationes*, 1585, he illustrated the valves (Figure 1) and noted their one-way

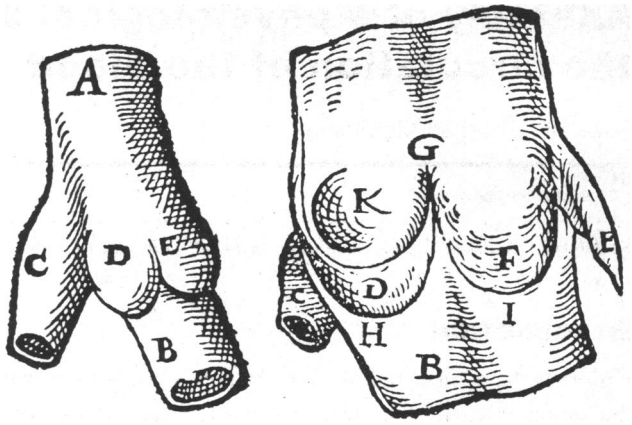


*Figure 1* **From Salomon Alberti, *Tres Orationes*, 1585, showing the outside (left picture) and inside (right picture) of part of a leg vein, with the two cusps of a bicuspid valve in the vein. These are the first drawings of a valve**

nature. He also reported the early accounts of the venous valves, including the findings of Lusitanus and Canano. Alberti had used several terms including 'valvulis' for the venous valves, but Fabricius, consistent with his own nomenclature, reported in *De venarum ostiolis* that Alberti had written 'most learnedly on the ''ostiola'' of veins'. In his anatomical lecture notes, Harvey referred to Fabricius by name six times, and to Alberti three times. Thus, early on Harvey was faced with a clear choice between ostiola, as described by Fabricius, or the one-way valves in the veins, as described by Alberti, Lusitanus, and Canano. We will see that Harvey made this choice very early.

## THE KEY TO THE DISCOVERY

Robert Boyle (1627–1691) has been called the 'Father of Chemistry'[13], and is well-known for the physical law which bears his name. What is not so well known is that he was intensely interested in medicine, and was awarded a medical degree in 1665[14]. Boyle authored medical books ranging from his important *Memoirs for the Natural History of Humane Blood, Especially the Spirit of that Liquor* (London: 1684), to several editions of remedies for laymen, *Medicinal Experiments: or a Collection of Choice and Safe Remedies, For The most part Simple and easily prepared: Very useful in Families, and fitted for the Service of Country people* (London: 3rd ed., 1696). Scattered through Boyle's works are so many remembrances relating to a conversation he had with Harvey that some scholars think Boyle had several meetings with Harvey, even though Boyle claimed only one[15].

Boyle had interviewed Harvey about the discovery of the blood's circulation some 30 years after the event. Boyle delayed publishing the information from this meeting. These circumstances raise concerns about whether Harvey recalled the true details of the discovery, whether Boyle heard rightly

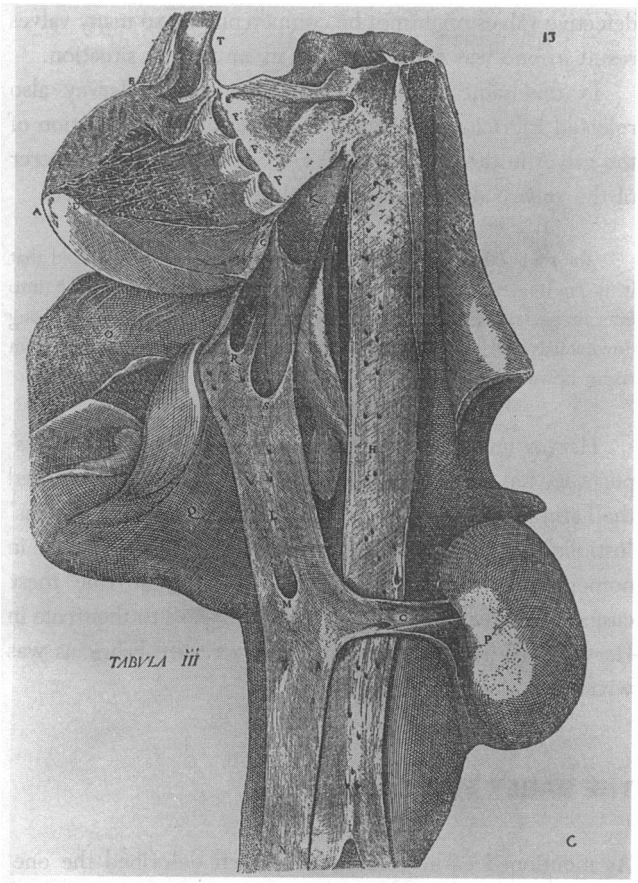


*Figure 2* **Table iii from Fabricius' *De venarum ostiolis*, 1603. Part of the heart and related vessels. In the upper left (at the origin of the bifurcated aorta) are the three semilunar cusps of the aortic valve, labelled F.F.F. In the text, Fabricius points out their close similarity to the cusps of the venous values such as those depicted in Figure 3**

what Harvey said, and whether Boyle correctly remembered the interview. All this is compounded by the fact that Boyle's two accounts of Harvey's discovery differ from each other. One account is in Boyle's *Some Considerations touching the Usefulness of Experimental Natural Philosophy*[16], dictated around 1650 (7 years before Harvey's death) but not published until 1663. In this work Boyle reported that 'the structure of the valves of the heart and veins' first influenced Harvey. Boyle did not say what it was about this structure that led Harvey to conceive of the blood's circulation. Somehow, the structure of the venous valves was linked to those in the heart.

The link involving Harvey's discovery was that heart valves allow one-way flow only, and their structure, particularly the aortic and pulmonary valves, is similar to that of venous valves. Harvey may have learned of this similarity from Fabricius. In *De venarum ostiolis*, Fabricius pointed out how the aortic valve (Figure 2) is like the venous valves (Figure 3). The only obvious difference besides size is that the aortic valve has three cusps, while the venous valves have one or two. Basically, these cusps appear the same. This comparison suggests that the venous valves are one-way, like the heart's. Harvey knew Fabricius' work well. The only pictures in *De motu cordis* are nearly identical to one of Fabricius[17]. Harvey meant it when he wrote in *Exercitationes de generatione animalium* (1651) that from among ancients he followed Aristotle, but from among contemporaries, he followed Fabricius.

The second of Boyle's accounts of Harvey's discovery is found in *A Disquisition About the Final Causes of Natural Things* (1688). Boyle dictated *Disquisition* in the 1670s to clarify and extend his earlier comments on purpose. However, Boyle stated that he never consulted his previous writings. Therefore, when he came to his Harveian example, he did not check what he had dictated earlier. Instead, he recalled the conversation with Harvey from memory. This recollection differs from what he dictated before:

> And I remember that when I asked our famous Harvey, in the only discourse I had with him, (which was but a while before he died), what were the things that induced him to think of a circulation of the Blood? He answered me, that when he took notice that *the valves in the veins of so many several parts of the body*, were so placed that they

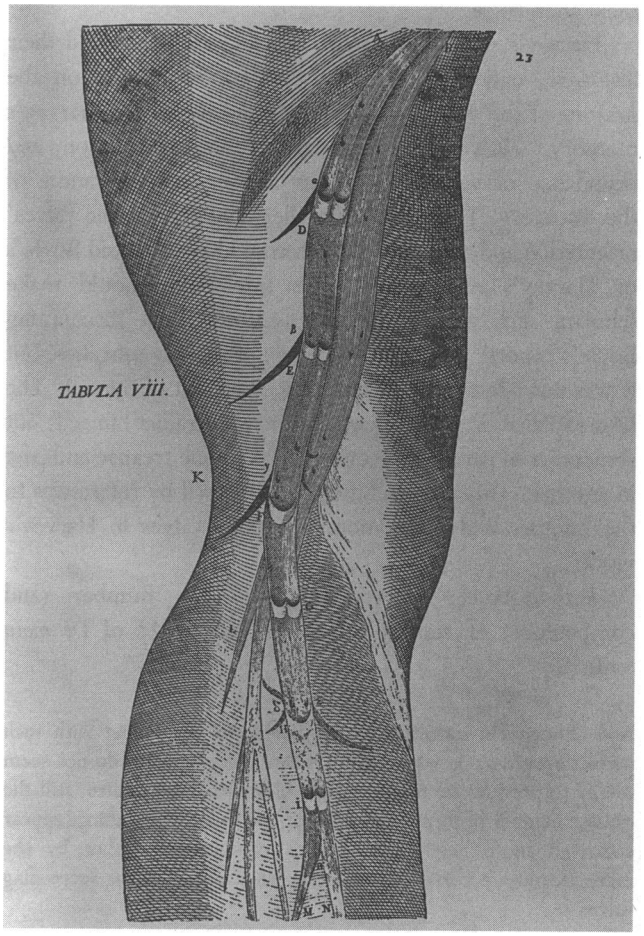


*Figure 3* **Table viii from Fabricius' *De venarum ostiolis*. The valves in a bifurcated leg vein. Fabricius noted the likeness of their single and double cusps to the triple cusps of the aortic valve as pictured in Figure 2**

gave free passage to the blood towards the heart, but opposed the passage of the venal blood the contrary way: he was invited to imagine, that so provident a cause as *nature had not plac'd so many valves without design*: and no design seemed more probable, than that, since the blood could not well, because of the interposing valves, be sent by the veins to the limbs, it should be sent through the arteries, and return through the veins, whose valves did not oppose its course that way [emphasis added][18].

In this account, Harvey initially made his discovery by observing the orientation of the venous valves and asking, in effect, why so many?

Since not all veins have valves, one could argue that the valves are not that abundant. Harvey did not share this perception: he was struck by their quantity. He twice mentioned the abundance of these valves in the above passage. This led to the implied question of why there are no valves in the arteries? In contrast to the other Boyleian account, Harvey initially did not ask about the venous valves or their structure, but about their orientation and relative abundance. Some historians have noted the role of the venous valves[19] or their orientation[20] in Harvey's discovery, but none have pointed out the significance Harvey placed on their abundance.

Harvey's stress on both the valves' *orientation* and their *abundance* undercuts the idea that later emphasis on the *structure* of the venous valves influenced Boyle's or Harvey's memory. Harvey's observation of the orientation and abundance of venous valves are unique remembrances of the discovery. There was no earlier emphasis on the valves' orientation and abundance which could have affected Boyle's or Harvey's recollection. This fact alone should make scholars such as J J Bylebyl cautious about discounting Boyle's report[21]. Boyle was capable of making mistakes, but it was not like him to invent an account out of thin air. The best explanation is that Boyle did not contradict himself, but remembered part of the conversation in one treatise and part in another. This interpretation is supported by references to the number and orientation of venous valves in Harvey's works.

For instance, Harvey discussed the number (and competence) of venous valves in Chapter 13 of *De motu cordis*:

And although in some places the valves, by not acting with such perfect accuracy, or where there is but a single valve, do not seem totally to prevent the passage of the blood from the centre, still the greater number of them plainly do so; and then, where things appear contrived more negligently, this is compensated either by the more frequent occurrence or more perfect action of the succeeding valves . . .

Where a valve might be 'contrived more negligently', or, where there is but a single valve, such situations are compensated for by the abundance of valves. A few single or defective valves might not be competent, but so many valves result in one-way flow, creating an anomalous situation.

In this same section of *De motu cordis*, Harvey also rejected Fabricius' explanation because of the orientation of the valves in the jugular veins. He wrote that the discoverer of the valves 'did not rightly understand' their purpose:

. . . for their office is by no means explained when we are told that it is to hinder the blood, by its weight, from all flowing into inferior parts; for the edges of the valves in the jugular veins hang downwards and are so contrived that they prevent the blood from rising upwards . . .

Harvey understood Fabricius' explanation for the valves' purpose, but saw no support for it. In this chapter he used the Latin term 'valvulas' (or a form of it) and not Fabricius' 'ostiolis' to identify the cusps in the veins. This difference in nomenclature accurately reflects the different role these cusps have in Fabricius' physiology compared to their role in Harvey's. When and why did Harvey realize Fabricius was wrong?

## THE EARLY EVIDENCE

As mentioned earlier, Salomon Alberti described the one-way nature of the valves in the veins and used the Latin term 'valvulis' for them. Immediately following the section on the venous valves, he wrote about the ileocaecal valve located between the small and large intestines. Alberti used the terms 'valva' and 'valvulas' for this valve. Harvey read this section and in his lecture notebook, *Prelectiones Anatomiae Universalis* (1616), he compared the function of the ileocaecal valve to that of the valves in the veins:

WH Those who say as Sal[omon] Alb[erti] that there is within [the bowel] a membrane which closes the passage as in the veins[22].

The context of this passage is that the ileocaecal valve stops reverse flow. (Harvey incorrectly used 'membrane' to describe the function of this sphincter valve. Since Alberti also had used 'membrane' to describe the venous valves, it is obvious that Harvey envisioned a functional connection between the two types of one-way valves.) Of interest to us is that Harvey treated the one-way nature of the venous valves as a given. He compared the ileocaecal valve to the venous valves and not vice versa[23]. Further, he was not just referring to what someone else was saying: he denoted his acceptance of this check-valve operation in his customary fashion by putting his initials next to the passage. Therefore, prior to 1616, Harvey had accepted that the membranous valves in the veins basically stop reverse flow. This implies that the old explanations of the blood's motion had to be incorrect.

In addition, Harvey mentioned the abundance and orientation of the venous valves later in his *Prelectiones*. Writing before he hypothesized the blood's circulation, Harvey remarked that:

WH Wherefore there are many valves in the veins opposed to the heart; the arteries have none except at the exit from the heart.

This important early observation has a lot packed in it. Analysing the above passage, we find that part of it encapsulates Boyle's reports about the discovery, and part relates to what Harvey later wrote about the venous valves in *De motu cordis*:

1 There is more emphasis on the valves' abundance than on their structure
2 There is a link to the heart, (the aortic valve 'at the exit from the heart'. This similarity of the venous and cardiac valves had been noted earlier by Alberti, Canano, and Lusitanus)
3 There is a contrast between the venous system and the arterial
4 This comparison points out the lack of physiological symmetry between veins and arteries. (In *De motu cordis*, Harvey wrote: 'Let it be added that there are no valves in the arteries (save at their roots) . . . .' This difference from the venous valves is only implied in the Boyle reports)
5 All venous valves have the same orientation, ( 'opposed to the heart' )

The broader context of the above passage from *Prelectiones* involves the heart's pulse, not the blood's circulation. However, what is important here again is Harvey's nomenclature. He wrote 'valvulas', not Fabricius' 'ostiola' for the valves in the veins. Later, Harvey would freely copy Fabricius' picture because it was accurate (compare Figures 4 and 5). In *Prelectiones*, Harvey is not using Fabricius' terminology because, even at this early date, he already doubts Fabricius' explanation.

## ANATOMY OF A REJECTION

There are several possible ways Harvey could have come to realize Fabricius was wrong about the function and purpose of the venous valves. One was through the influence of Salomon Alberti, as previously discussed. Another was the similarity of venous valves to the one-way heart valves. He knew this either from his own dissections, or from Alberti, Canano, and Lusitanus, or from Fabricius' pictures (see

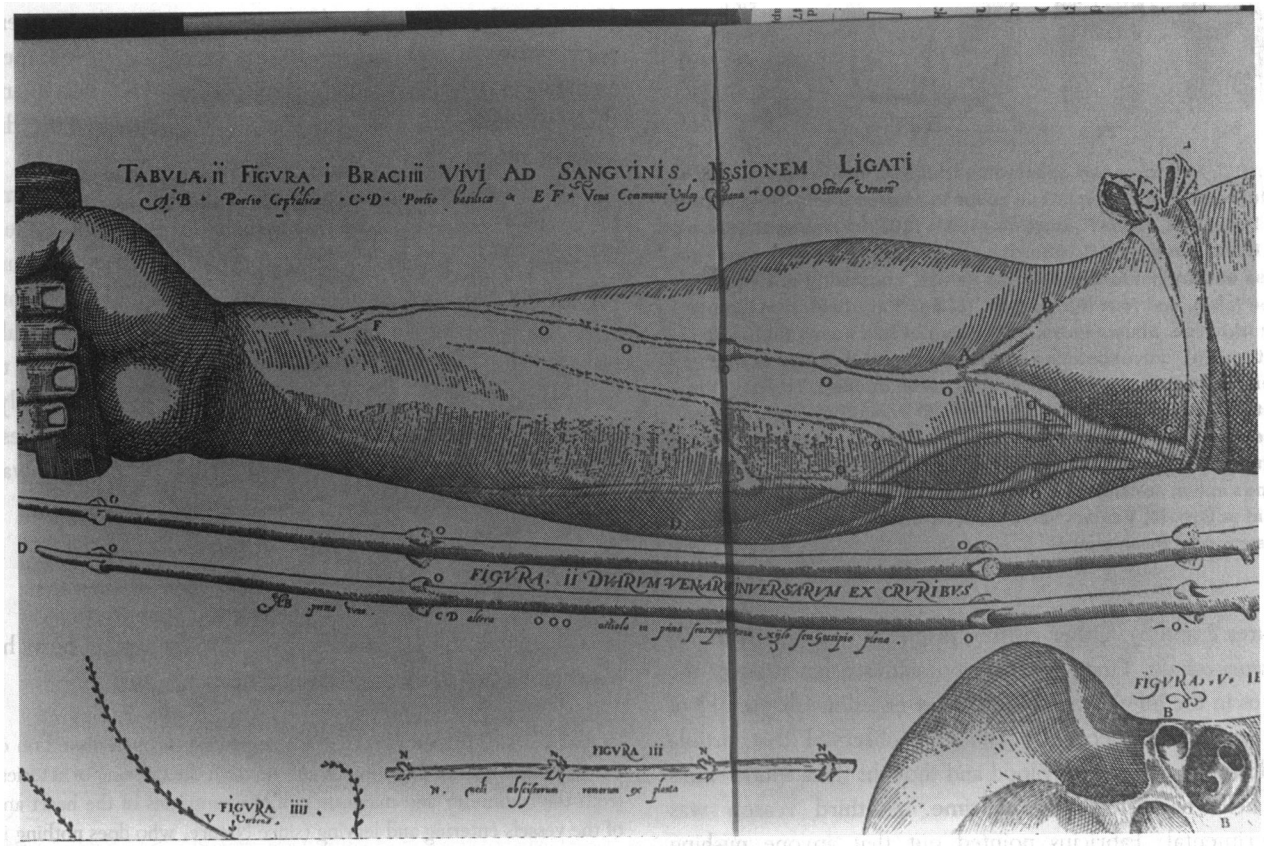


*Figure 4* **Part of Table ii from Hieronymus Fabricius' *De venarum ostiolis*. Figure ii improves on Alberti's picture (Figure 1 of this paper). It shows the veins in an arm and two leg veins turned inside-out. The valves are cusps on the vein's wall. They are membranes which open when blood flows against their edges, as depicted**

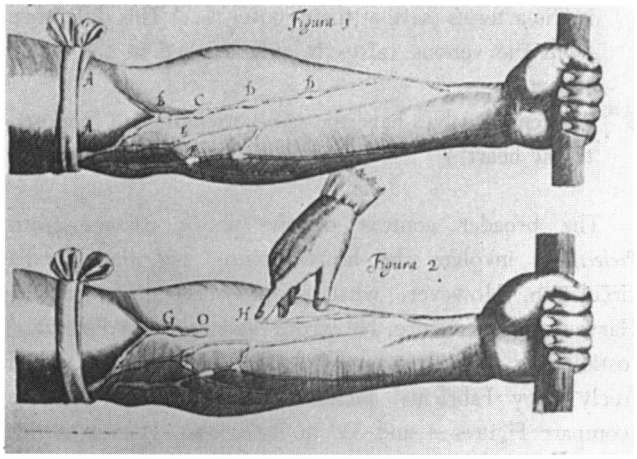


*Figure 5* **Two of the four figures from the only illustration in William Harvey's *De motu cordis*, 1628. With the text, they provide a demonstration that the venous valves are one-way. Harvey's text on this demonstration derives from Fabricius' *De venarum ostiolis*. The muscular arm at the top is nearly a mirror image of that in Figure 4 of this paper**

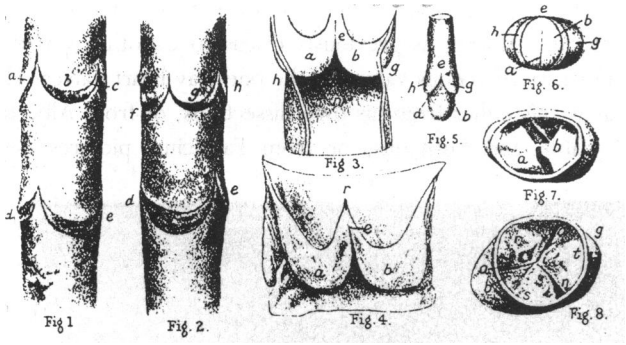


*Figure 6* **Fabricius had observed a tricuspid venous valve in an ox. Pictured here are the multiple cusps in a horse's vein (from Figures 1–8 Pettigrew, *Trans R Soc Edin*, 1863–1864, by kind permission of the Royal Society of Edinburgh). (1)–(2) External jugular veins of horse shown inside-out. Depicts valves, consisting of two (de), three (abc), and four (fgh) cusps. (3) Section of external jugular vein of horse. Shows valve, consisting of two cusps (ab), with dilations (g), corresponding to the sinuses of Valsalva in the arteries. (4) External jugular vein of horse opened. To show the relation of the cusps (ab) above (re). (5) Portion of femoral vein distended with plaster of Paris. Shows dilations (hg) in the course of the vessel corresponding to the position of the valve. (6) Shows venous valve, consisting of two cusps (ab), in action. (7) The same, not in action. (8) Venous valve from external jugular of horse, consisting of three cusps**

Figures 2 and 3). Other reasons originate with Fabricius' *De venarum ostiolis*. First, was the anomalous orientation of the valves in the jugular veins, as Harvey noted in Chapter 13 of *De motu cordis*. Secondly, Fabricius observed that ostiola could hold back venous blood and thought thick blood could be held back for a long time. A third reason was experimental. Fabricius pointed out that anyone pushing 'the blood down through the veins would feel the resistance and power of the ostiola'. Finally, Fabricius reported that triple ostiola had been found in veins of oxen (similar to those of the horse, as pictured in Figure 6). Yet, in his own words, the triple cusps in the heart 'prevented reflux of blood'. Obviously the door was open, so to speak, for anyone to reason that the tricuspid venous valve could stop blood flow in the ox's vein, just as the tricuspid cardiac valve did in the heart. Even if the venous valves were not 100% competent, their *abundance* effectively stopped reverse flow.

The above are reasons that could have led Harvey to reject Galen's and Fabricius' explanations on the movement of the blood. Any one of them, or a combination of them, or all of them could have triggered Harvey's rejection. Whatever the exact reasons, by 1617 Harvey had made the conceptual leap. As the venous valves prevent the reflux of the blood, he had to reject the old physiology. Yet, Harvey had no immediate replacement physiology. Therefore, he was not ready to publicize his doubts.

Years later, when Boyle asked Harvey what first induced him to think that the blood circulates, Harvey remembered correctly. His answer in *Disquisition*, about the abundance and orientation of the venous valves, expanded on one statement from *Prelectiones*. Also in this statement is the link between the structure of the venous and cardiac valves that Boyle referred to in *Considerations*. Thus, both reports which Boyle dictated about Harvey are supported by Harvey's early lecture notes. This support reconciles Boyle's accounts of Harvey's discovery: the keys to rejecting the current paradigm were both the orientation of venous valves, their abundance (which, in total, prevented reverse flow), and their similarity to the one-way heart valves (which did prevent reverse flow).

Like Lusitanus, Canano, and Alberti, Harvey, at the time he wrote *Prelectiones*, understood the function of the valves, but not their purpose. Using purpose in anatomy and physiology was part of Harvey's method and those before him. He followed 'the way of the anatomists'[24] and would not stop just knowing the function of the valves. He had to address their purpose, just as Fabricius had (incorrectly) described the function and explained the purpose of these valves. Harvey's search for the purpose of the one-way venous valves involved other 'investigations'.

## HARVEY'S HYPOTHESIS

In Chapter 8 of *De motu cordis*, Harvey wrote how he hypothesized that the blood circulates:

In truth, when, from a variety of investigations through dissection of the living in order to experiment and through the opening of arteries, from the symmetry and magnitude of the ventricles of the heart and of the vessels entering and leaving (since Nature, who does nothing in vain, would not have needlessly given these vessels such relatively large size), from the skillful and careful craftsmanship of the valves and fibres and the rest of the fabric of the heart, and from many other

things, I had very often and seriously thought about, and had long turned over in my mind, how great an amount there was, that is to say how great the amount of transmitted blood would be [and] in how short a time that transmission would be effected, . . . I began privately to think that it might rather have a certain movement, as it were, in a circle, . . .[25]

While there is much in this passage, an important part is Harvey's list of a 'variety of investigations' which led to his hypothesis. It includes:

1 Vivisections and experiments
2 The symmetry and magnitude of the heart ventricles and associated vessels
3 The skilful and careful craftsmanship of the heart valves as well as other parts of the heart
4 Many other things
5 The amount and transmission time of the blood transmitted by the heart

Of interest in (2) listed above is the comparatively large size of the heart vessels. The ventricles were discovered long ago, and nothing appeared abnormal about them. Nevertheless, Harvey judged that they were too large for their role in the current physiology. Since he thought that purposeful nature 'does nothing in vain', he had to find a different explanation for this anomaly.

For Harvey, it followed that the 'relatively large size' of the ventricles and their conduits made it likely that blood was abundant in the body. However, it appears that this abundance was a *derivative* factor from the prior consideration of the conduits' large size. If the blood's quantity initially led to the circulation hypothesis, then this quantity would explain the vessels' large size. In which case, Harvey would have said so—but he did not. Instead, he wrote that:

since Nature, who does nothing in vain, would have needlessly given these vessels such relatively large size.

The ventricles and their conduits have been designed large and the question is for what purpose?

Only now is Harvey ready to address the blood's quantity. Quantity is important, but of the many factors involved, the text provides no justification that it was prior. Also, Harvey did not calculate amounts of blood. Rather, he deduced from the comparatively large size of the vessels that an abundance of blood is involved. This abundance does become important and poses questions of its own. One is the purpose-based question, why is there *so* much blood passing through the heart in *so* short a time? Thus it seems that the quantity of blood was one of the last factors Harvey considered.

When Harvey finally realized the implications of the blood's quantity, the conception of the blood's circulation started to come into focus. Apparently, he then understood why the orientation of all the valves was opposed to the heart: the valves allowed circulation in one direction only. The entire hypothesis finally became crystal clear to Harvey and he had his discovery. He now had to convince everyone else. Only during this later context of justification did Harvey make his famous 'calculation' of the quantity of blood, which was really more of a thought-experiment than a calculation.

## CONCLUDING REMARKS

Harvey sought to solve nature's mysteries. He dissected and vivisected. He studied the slowed-down heartbeats of dying animals. He experimented with tourniquets both loosely and tightly applied. He examined simple and compound hearts. If Harvey had discovered the capillaries, then he would have recognized an anomaly. However, this discovery was made later, with an improved microscope. Instead, Harvey joined his mass of accumulated data with the idea of purpose to reason that the orientation and abundance of venous valves and their similarity to the one-way cardiac valves demolished Fabricius' and Galen's physiology. Harvey had previously mentioned these keys to his discovery in *Prelectiones* (1616). After rejecting the old paradigm, Harvey sought the right explanation. He eventually hypothesized, perhaps as early as 1617, that the blood circulates. Whatever the exact date, he certainly had written about his discovery by the middle of 1619.

Harvey made additions to his lecture notebook, *Prelectiones*, at various times up to at least 1626. One of these later additions is a short entry on the discovery of the circulation. This addition is a main reason why many recent scholars think Harvey discovered the blood's circulation in a later time frame. Yet Harvey did not record anything else about the circulation or correct earlier erroneous statements based on the old physiology. His relative silence on an important discovery especially perplexed the late Gweneth Whitteridge. Concerning *Prelectiones*, she wondered:

If Harvey used this manuscript, as the additions to it imply, up to at least 1626, we may well ask why it contains no references to the crucial experiments by which the circulation was proved and why all statements which are inconsistent with the hypothesis of the circulation are left uncorrected[5].

Her line of questioning is based on her estimate that Harvey's full discovery of the circulation was in 1625. This article has shown that both the discovery of the circulation and the composition of *De motu cordis* was earlier than thought. That is why Harvey did not bother updating his *Prelectiones*. He was already writing *De motu cordis* and recording the crucial experiments and all else concerning the

discovery in it. Therefore, we should not be surprised that Harvey's lecture notebook contained only one additional comment about his discovery. (He may have made this entry prior to, and for, his January 1618 lecture.)

With his discovery of the blood's circulation, Harvey also became the discoverer of the real purpose of the venous valves. These valves now became important for demonstrating that the blood circulated. Harvey only had to show that they were one-way. The experiments with the veins in a ligated arm (see Figure 5), were a convenient way to do this. Applying a tourniquet to the upper arm was the first step in the common medical practice of bleeding a patient. Anyone could then see the number of valves and, by experiment, demonstrate that the function of the valves allows blood to flow only toward the heart. The next question is why?/for what purpose? The answer is that the valves allowed one-way flow toward the heart because that was the direction the blood was moving in its circulation. Thus, the orientation, one-way nature, and relatively large number of venous valves not only became important in proving the hypothesis that the blood circulates, but also were keys to the initial discovery, as Harvey related to Boyle years later.

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