The Sun of the Microcosm

William Harvey (1578–1657)

In 1628, William Harvey announced the circulation of the blood, arguably the most important discovery of the modern period in anatomy and physiology. Galen had elaborated a tripartite system in which the liver, heart, and brain each injected into the body three different spirits and, consequently, that the arteries and veins carried different substances. Drawing on careful experimental calculations of blood flow and the knowledge that the valves in the veins are placed so that blood is allowed to move freely toward the heart but not away from it, Harvey reasoned that blood was pumped to the limbs through the arteries and returned through the veins. Blood passes through the right to the left side of the heart, not via the septum, which was solid, but through the lungs. Observing that the arteries begin to fill at the moment of contraction (systole), it was also clear that blood is pumped from the heart (the sun of the microcosm) into the arteries. Diastole, on the other hand, is related to the filling of the heart.

Harvey's critics eagerly pointed out that he failed to specify a connection between the arterial and venous systems, and it was only in 1661 that Marcello Malpighi (1628–1694) first described capillaries from his microscopical observations of lung tissue. Exercitatio anatomica de motu cordis et sanguinis in animalibus *(1628: Anatomical Treatise on the Movement of the Heart and Blood in Animals)—from which this reading is taken—remains a monument to the style of the natural philosophy of the seventeenth century: the rejection of traditional authority, the emphasis on first-hand experience, and the use of analogies with mechanical devices to make sense of natural systems.*

Source: William Harvey. 1976. *An Anatomical Disputation Concerning the Movement of the Heart and Blood in Living Creatures.* Trans. Gweneth Whitteridge. London: Blackwell Scientific Publications, pp. 10–22; 29–30; 32–35; 38–40; 42–47; 50–54; 56–61; 66–68; 70–72; 74–77; 80–83; 86–87; 89–93; 100–102; 103–104; 107–110; 114–117; 120–124; 128–133.

Seeing that we are thinking of the movement, pulse, action, use and usefulness of the heart and arteries, it is of considerable importance first to set forth those things which have been published by others, and to take notice of the things which have been commonly said and taught, so that what has been rightly spoken may be confirmed and what is false corrected in the light of anatomical dissection, personal experience many times repeated, and diligent and precise observation . . .

But since the movement and composition of the heart is different from that of the lungs, and the movement and compositions of the arteries are different from that of the chest, it is probable that different uses and benefits should arise from this, and that the pulse of the heart and its use, and likewise that of the arteries, should differ greatly from that of the chest and the lungs. For, if the pulse and respiration serve the same uses, and if in diastole the arteries draw air into their cavities, as it is commonly said, and in systole send forth fuliginous vapors through the same pores of the flesh and skin, and, furthermore, if in the time between systole and diastole they contain air, at any one time they must contain either air or spirits or fuliginous[a] vapors. What then should these writers reply to Galen, who wrote a book to show that blood was naturally contained in the arteries and nothing but blood, that is, neither spirits nor air, as we can easily conclude from the experiments and arguments in the same book. And if in diastole the arteries are filled with air which they have taken in, in a greater pulse the greater will be the quantity of air entering. Therefore, if, when there is a great pulse, you immerse the whole body in a bath of water or oil, the pulse must needs be immediately either smaller or slower, seeing that it is difficult for the air to permeate into the arteries through the surrounding water of the bath, if not impossible. Moreover, since all the arteries, both the deep and the cutaneous, are distended at the same moment and with the same speed, how can the air pass through the skin, flesh and whole fabric of the body into its depths, as freely and swiftly as it can through the skin alone? And how do the arteries of the fetus draw air from the outside into their cavities through the mother's belly and the body of the womb? Or again, how do seals, whales, and dolphins, and the whole race of cetaceans and all fish in the bottom of the sea take in air through such a great mass of water, and give it out again by the swift pulse in the systole and diastole of their arteries? But to say that they suck up the air implanted in the water and return their fuliginous vapors into it, is not unlike a fiction. And if in systole the arteries drive out the fuliginous vapors from their cavities through the pores of the flesh and of the skin, why not the spirits likewise, which they say are contained there too, since spirits are much finer than sooty fumes? And if the arteries in their systole and diastole take in air and give it out again, as the lungs do in respiration, why do they not do this when a wound is inflicted by the cutting of an artery? If the trachea is cut by a wound, it is as plain as the noonday sun that the air goes in and comes out in two contrary movements. But when an artery is cut, immediately the blood is driven out by force in one continuous movement, and it is obvious that air does neither go in or come out. If the pulsations of the arteries refrigerate the parts of the body and ventilate them as the lungs do the heart itself, in what way is it commonly said that the arteries carry from the heart to each part of the body the blood crammed full of vital spirits that nourish the heat of the parts, awake this heat from slumber and restore it when it is spent? And how comes it that, if you tie the arteries, the parts are straightway not only numbed and cold, and look pale, but at last, cease to be nourished, which happens, according to Galen, because they are deprived of that heat which previously flowed out through all the parts from the heart, since it is clear from this that arteries carry heat to the parts rather than cooling and ventilation. Besides, how can diastole at

[a]In Galenic physiology, fuliginous vapours or "sooty fumes" were the byproduct of a process called "concoction," which took place in the left ventricle. Vital spirits from air were mixed with blood that seeped across the septum from the right ventricle. According to Galen, fuliginous vapors left the body by passing through the pulmonary vein to the lungs. [B.]

one and the same time draw spirits from the heart to warm the parts, and cold from outside the body? Further, although some affirm that the lungs, arteries and heart serve the same uses, yet they say that the heart is the laboratory of the spirits, that the arteries contain spirits and send them abroad, but, contrary to the opinion of Columbus,[b] they deny that the lungs make the spirits or retain them. And yet these same men affirm with Galen against Erasistratus[c] that blood is contained in the arteries and not spirits.

These opinions seem so to war with one another and to refute each other, that all of them are not undeservedly suspect. That blood is contained in the arteries, and that the arteries carry blood only, is obvious from Galen's experiment . . . from arteriotomy and from wounds, and likewise from the fact which Galen also affirms in very many places that from a cut artery in the space of one half hour, the whole mass of blood will be emptied out of every part of the body in a great and forcible profusion. The experiment of Galen is this: "If you bind the artery at both ends with a fine cord and slit it open lengthwise down the middle, you will find that what is contained in the artery between the two ligatures is nothing except blood." And so he proves that it contains only blood. From this we can argue also in the same way: If, after tying and slitting the veins in the same manner, we find in the veins the same blood that is in the arteries (a thing which I have often tried myself in dead men and in living animals), we may conclude likewise by the same reasoning that the arteries contain the same blood as the veins, and nothing but the same blood. Some, while they attempt to resolve this difficulty by affirming that the blood in the arteries is arterial blood, full of spirits, silently concede that it is the function of the arteries to carry the blood from the heart into the whole body, and that the arteries are full of blood, for blood that is full of spirits is nonetheless blood . . .

But the contrary is obvious, both in arteriotomy and in wounds, for the blood comes rushing out of the arteries, leaping violently, sometimes further, sometimes nearer, by fits and starts, but the leaping of it is always in the diastole of the artery and not in the systole. From this it plainly appears that the artery is distended by the impulsion of blood. For while it is being distended, the artery cannot of itself throw out the blood with such force. Instead, according to those things which are commonly related about the use of arteries, it ought to attract air into itself through the wound . . .

These, and other difficulties like them, follow from the opinions that have been set down concerning the pulse and the use of the arteries. Perhaps those things which have been asserted concerning the use and pulse of the heart are no less entangled with very many and inextricable difficulties. Men commonly assert that the heart is the fountain and laboratory of the vital spirits by which it gives life to all the parts, and yet they deny that the right ventricle makes the spirits and say that it only provides nourishment for the lungs. And hence they say that fish have no right ventricle of the heart, and indeed that it is altogether wanting in those creatures that have no lungs, and that the right ventricle of the heart was made for the sake of the lungs.

1. Why then, I ask you, since the constitution of both ventricles is almost the same in that they have the same construction

[b]Matheus Realdus Colombo (1516–1559), a pupil of Vesalius, correctly described in 1559 the pulmonary or lesser circulation—the passage of blood from the right to the left side of the heart via the lungs. Similar views can be found in a number of other sixteenth century writers. Columbo did not recognize the significance of his achievement. [B.]

[c]Erasistratus (c. 304 B.C.–c. 250 B.C.), a late Alexandrian anatomist, contended that the arteries carry air or *pneuma*, a view that was routed by Galen (c. 130–c. 199) who showed that there was a connection between the arterial and venous systems. [B.]

of fibers, muscular bands, valves, vessels and auricles, and in dissection are both found full of blood that is in both blackish and lumpy, why, I say, should we think that they were appointed to such diverse uses, seeing that their action, motion and pulsation is the same in both? If the three tricuspid valves at the entrance into the right ventricle are a hindrance to the return of blood into the vena cava, and if the three semilunar valves in the orifice of the pulmonary artery are made to impede the regress of blood, why, since things are similarly arranged, should we deny that the valves in the left ventricle were made likewise to hinder the progress and regress of blood?

2. Why, since the valves are almost identical in size, shape and position in the left ventricle as in the right, why do they say that here in the left ventricle they hinder the progress and regress of spirits, and in the right that of blood? It seems unlikely that the same organ can possibly be adapted to hinder the motion of blood and of spirits alike.
3. And why, since the passages and vessels correspond to one another in point of size, that is the pulmonary artery and the pulmonary vein, why should the one be destined to a particular use, namely to nourish the lungs, and the other to a general use?
4. And, as Columbo[d] observed, how is it provable that so much blood is needed to nourish the lungs, for indeed this vessel, the pulmonary artery, is bigger in size than both the branches of the descending vena cava that supply the femoral veins?
5. And lastly I ask why, since the lungs are so near and the vessel so great and the lungs in continual motion, why is there need for a pulse in the right ventricle, and why is it that nature, for the sake of nourishing the lungs, found it necessary to add a second ventricle to the heart?

When they say that the left ventricle draws material from the lungs and from the right ventricle of the heart, that is to say air and blood, to prepare the spirits, and likewise distributes the spirituous blood into the aorta, and that from this left ventricle fuliginous vapors, on the one hand, are sent back through the pulmonary vein into the lungs, and, on the other, spirits into the aorta, what is it that makes the separation between them, and how is it that spirits and fuliginous vapors pass this way and that without mingling or confusion? If the mitral valves do not hinder the return of fuliginous vapors to the lungs, how can they hinder the return of air? And how do the tricuspid semilunar valves prevent the return of spirits from the aorta in the subsequent diastole of the heart? And by what manner of way do they say that the spirituous blood is distributed from the left ventricle through the pulmonary vein into the lungs, and the mitral valves not hinder it the while, seeing that they affirm that through this same vessel the air enters into the left ventricle from the lungs, the air to whose return they would have these mitral valves to be a hindrance? Good God! How do the mitral valves impede the return of air and not of blood? . . .

But, I beseech you, if the pulmonary vein were made for the conveyance of air, why does it have the constitution of a vein? Nature had need rather of pipes and those annular ones, like those in the bronchi, so that they might always stay open and not collapse, and so that they might remain altogether empty of blood lest its wetness should hinder the passage of air, a thing which is plain enough when we breathe with a whistling and a rumbling noise when the lungs are in trouble, either stuffed with phlegm from the bronchi, or at least laden with a little.

[d]In addition to his demonstration of the pulmonary circulation, Colombo published detailed descriptions of the pleura, peritoneum, and other organs. [B.]

Still less to be tolerated is that opinion which, supposing that two kinds of material, air and blood, are necessary for the making of the vital spirits, does assert that the blood seeps through hidden pores in the septum of the heart, out of the right ventricle into the left, and that the air is drawn in through the great vessel, the pulmonary vein, out of the lungs, and therefore in the septum of the heart there are many pores adapted for the exuding of blood. But, in God's truth, there are no such pores, nor can any be demonstrated.

For the substance of the septum of the heart is thicker and more compact than any part of the body except the bones and sinews. But if there were holes, how was it possible, since both the ventricles are distended and dilated at the same time, for the one to draw anything from the other, or the left draw blood from the right?

When I first applied my mind to observation from the many dissections of living creatures as they came to hand, that by that means I might find out the use and benefits of the motion of the heart through actual inspection with my own eyes, and not from books and the writings of other men, I straightway found it a thing hard to be obtained and full of difficulty, so that I almost believed with Fracastorius[e] that the motion of the heart was known to God alone. For I could rightly distinguish neither how systole nor diastole came to be, nor when nor where the dilatation and the constriction occurred, and that by reason of the quickness of the motion which in many creatures appeared and disappeared in the twinkling of an eye, like the passing of lightning, so that I thought that I sometimes saw systole on this side and diastole on that, sometimes quite the reverse, and sometimes the movements were changing and without order. And so I was much troubled in mind and did not know what to think, whether what I myself had concluded or whether to believe others, and I did not wonder at that which Andreas Laurentius[f] had written that the motion of the heart was like the ebbing and flowing of Euripus[g] to Aristotle.

At last, using daily more search and diligence, by often looking into many and different sorts of living creatures, by collecting and comparing many observations, I believed that I had hit the nail on the head, unwinded and freed myself from this labyrinth and had gained the knowledge I so much desired, that of the movement and use of the heart and arteries. Since then I have not been afraid both privately to my friends and publicly in my anatomical lectures, after the fashion of the Academy, to deliver my opinion on this matter . . .

First then, in the hearts of all creatures that are still living, after you have opened the chest and cut up the capsule which immediately surrounds the heart, you may observe that the heart moves sometimes, sometimes rests, and that there is a time when it moves and when it moves not.

All this is more evident in the hearts of colder creatures, as toads, snakes, frogs, snails, lobsters, crustaceans, mollusks, shrimps and all manner of little fish. Everything is also more evident in the hearts of warmer animals, like dogs and pigs, if you observe attentively until the heart begins to die and to beat more faintly and, as it were, to be deprived of life. Then you may clearly and plainly see the movements of the heart becoming slower and less frequent and its moments of stillness longer; and you may observe and distinguish more conveniently both the kind of movement that it has and

[e] Girolamo Fracastoro (*c.* 1478–1553) authored a book (1530) on syphilis, a disease that he named, which appeared in Europe at the end of the fifteenth century with the Seige of Naples by the French Army of Charles VIII. [B.]

[f]André du Laurens (1558–1609) was the author of *Historia anatomica* (1600), a Galenic medical text widely used in Harvey's time. [B.]

[g]Euripus was a long, narrow channel which was renowned in antiquity for the violent flow and reflow of its tide. [B.]

how it is made. In its moment of stillness, as in death, the heart is limp, flabby, and listless, and lies as it were drooping.

In its movement and in the time of that movement, four things are chiefly to be observed:

1. That the heart rises up and lifts itself upwards into a point, so that at that moment it strikes the chest and the beat can be felt outside.
2. That it is contracted on all sides, but more in width, so that it looks smaller in size and rather long and narrow. The heart of an eel, taken out and laid on the table or on your hand shows this clearly; or again, it is equally apparent in the hearts of little fish and of those colder animals whose hearts are conical and rather elongated.
3. That the heart being grasped in one's hand while it is in motion feels harder. This hardness arises from tension, just as, if you grasp the muscles of the forearm with one hand while they are moving the fingers, you will feel them become more tense and resisting.[h]
4. It is, moreover, to be observed in fish and colder-blooded animals, like snakes and frogs and so forth, that at that time when the heart moves, it becomes paler in color; when it lies quiet, it is to be seen richly-dyed blood-red in color.

From these things it seemed evident to me that the movement of the heart was a kind of tension in every part of it, both along the lines of all its fibers, as well as a contraction from all sides, because it seemed that in each motion it was lifted up, gained strength, decreased in size and hardened, and that this its movement was like that of the muscles when a contraction is being made along the length of the sinewy parts and of the fibers; for when muscles are moving and in action, they gain strength and become tense, from soft they become hard, they are lifted up and thickened, and so likewise the heart.

From these observations we can say with good reason that the heart, when it is in motion, is everywhere contracted down and its walls are thickened, its ventricles are narrowed and it thrusts forth the blood contained within it. This is quite clear from the fourth observation, seeing that in its contraction it becomes paler in color because it has driven out the blood it previously contained, and immediately after, in its relaxation and stillness, a purplish, blood-red color returns to the heart as the blood enters once more into the ventricles. But of this no one need have any further doubts, for, if he makes an incision into the cavity of the ventricle, he will see the blood contained in it spurt out violently with each movement or pulsation of the heart in its contraction.

So then, these things happen together at one and the same time, the tensing of the heart, the lifting up of its tip, the beat which is felt outwardly by reason of its hitting against the chest, the thickening of the walls of the heart and the forcible thrusting out of the contained blood by the constriction of the ventricles. From this appears the reverse of the commonly received opinions, namely, the belief that at the moment when the heart strikes the chest and the pulse is felt outside, that at this same moment the ventricles are dilated and filled with blood, whereas you must realize that the contrary actually happens, and that when the heart is contracted, then it is emptied. And therefore, the movement which is commonly thought to be the diastole of the heart is really the systole. So likewise, the proper movement of the heart is not diastole but systole, and the heart does not increase in strength in diastole but in systole, for then it is tensed and moves and gains strength.

[h]The idea that the heart was a muscle had been considered but rejected by Galen on the grounds that the movement of the heart is involuntary and ceaseless, whereas that of the muscles is often suspended. Galen also noted that the muscles of the heart, unlike the forearm, for example, are uniform. [B.]

Neither is it true, as is commonly believed, that the heart by any motion or distention of its own draws the blood into the ventricles, for while it is moving and contracting then it expels the blood, and while it relaxes and subsides it receives the blood in a way which will presently be made plain . . .

In the movement of the heart there occur these further things which must be observed and which relate to the movements and pulsation of the arteries.

1. At the moment when the heart is tense, makes a contraction and strikes the chest and is altogether in systole, arteries are dilated, give forth a pulse and are in their diastole. In like manner, when the right ventricle contracts and thrusts out the blood contained in it, the pulmonary artery pulsates and is dilated simultaneously with the rest of the arteries of the body.
2. When the left ventricle ceases to move, beat and be contracted, the beating of the arteries ceases; indeed, when it contracts more feebly, the pulse in the arteries is hardly to be perceived. So likewise, it happens in the pulmonary artery when the right ventricle ceases to pulsate.
3. Again, if any artery be cut or pierced, the blood is forcibly thrust out of the wound at the moment of contraction of the left ventricle. So also, if the pulmonary artery be cut, you will see the blood burst out forcibly from it at the very moment when the right ventricle becomes tense and contracts.

So likewise in fish, if you cut the vessel which leads from the heart to the gills, you will also see the blood forcibly thrust out through the cut at the very moment that the heart is tensed and contracted.

And lastly, since in any arteriotomy the blood leaps out sometimes to a greater distance and sometimes to a less, you can find out for certain that this leaping occurs in the diastole of the arteries, at the time when the heart strikes the chest; and this undoubtedly happens at the time when the heart is seen to be tensed and contracted and to be lifted up in its systole, and at the same time and by this same movement the blood is driven forth.

From these things it is clear that, contrary to what is commonly believed, the diastole of the arteries occurs at the same time as the systole of the heart, and that the arteries are filled and distended by reason of the inflowing and inthrusting of blood made by the constriction of the ventricles; as likewise, that the arteries are distended because they are filled like waterskins or bladders, and they are not filled because they are distended like a pair of bellows. And all the arteries of the whole body pulsate for the same cause, that is, by reason of the contraction of the left ventricle of the heart, just as the pulmonary artery pulsates by reason of the contraction of the right ventricle.

Therefore, the pulsation of the arteries arises from the impulsion of blood from the left ventricle. It is after the same fashion as when one blows into a glove, all the fingers are distended at the same time and mimic the impulsion of the air . . .

Besides these things about the movement of the heart, there are others to be observed which touch the use of the auricles . . .

There are as it were at one time two motions, one of the auricles and the other of the ventricles, and they are not altogether simultaneous. But the motion of the auricles goes before and the motion of the ventricles follows. And the motion seems to begin from the auricles and to pass forward to the ventricles. When all things are already in a languishing condition, the heart dying away, both in fish and in colder-blooded animals, there intercedes between these two motions a short time of stillness, and the ventricle being as it were awakened seems to answer to the motion sometimes swifter, sometimes slower, and at last, drawing towards death, it ceases to answer by its motion and only by gently nodding its head seems as it were to give consent and, moving scarce perceptibly, seems only to give a sign of motion to the beating auricle. So the ventricles cease to beat before the auricles, so that the auricles are said to outlive them. The left ventricle ceases to beat first of all, then its auricle, then the right ventricle, last of all (which Galen also observed), all the rest now still and dying, the right auricle beats still, so that life seems to remain last of all in the right auricle. And while little by little the heart is dying, you may see after two or three beatings of the auricles, the heart will, being as it were roused, answer, and very slowly and with difficulty stir itself and beat once . . .

So that if any man will look more deeply into the truth, he will not say merely that the heart is the first thing that lives and the last that dies, but its auricles (and in snakes, fish and suchlike creatures, the part which serves as an auricle), and that its auricles have life before the ventricles and die after them . . .

I confidently believe, then, that at last, out of these and the like observations it will be found that the movement of the heart is after this manner.

First of all, the auricle contracts itself, and in that contraction throws the blood with which it abounds as the head of the veins and the storehouse and cistern of the blood, into the ventricle of the heart, which being filled, straightway the heart raises itself, tenses all its fibers, contracts the ventricles and makes a beat, by which beat it forthwith thrusts the blood sent in from the auricle out into the arteries, the right ventricle into the lungs through the vessel called the arterial vein [pulmonary artery] but which is indeed by its constitution, its function and by all else an artery; the left ventricle into the aorta and so through the arteries into the whole body.

Those two motions, the one of the auricles, the other of the ventricles, follow so hard upon each other's heels, keeping as it were, in harmony and rhythm, that they occur simultaneously and only one motion is apparent, especially in warmer animals where they are driven with a rapid motion. Nor is this otherwise done than when, in machines, one wheel moves another and they all seem to move together; or in that mechanical contrivance which is fitted to firearms where, by compressing the trigger, the flint falls, strikes forcibly upon the steel and brings forth a spark which falls onto the powder which is ignited, enters the touchhole and explodes, and the bullet flies out and pierces the mark, and all these movements by reason of their swiftness appear to happen simultaneously, as in the twinkling of an eye . . .

The motion of the heart is then after this manner and one of the actions of the heart is the very transmission of the blood and its propulsion to the extremities by the intermediacy of the arteries, so that the pulse which we feel in the arteries is nothing else but only the impulsion of blood by the heart.

Now, whether the heart besides transferring the blood giving it local movement and distributing it, adds anything further to it, as heat, or spirit, or perfection, we must enquire hereafter and consider from other observations. Let it suffice for the present that it is sufficiently shown that in the beating of the heart, the blood is transferred and brought out of the veins into the arteries through the ventricles of the heart and so distributed into the whole body . . .

One thing seems to me to have been the chief cause of doubt and mistake in this business, and that is the connection in man of the heart and the lungs. For when they had seen the pulmonary artery and the pulmonary vein likewise disappear into the lungs, they were much at a loss to see how the right ventricle should distribute the blood into the body, or how the left ventricle should draw it out of the vena cava . . .

Were they, however, as well practiced in the dissection of animals as they are experienced in the anatomy of man's carcass, this matter which keeps them all in doubt and perplexity would, in my opinion, shine forth clear and free of all difficulty.

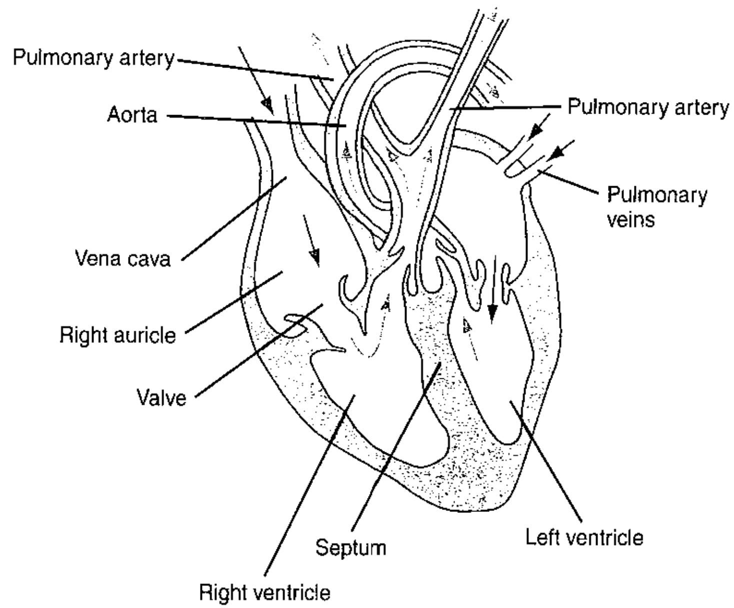

PLATE 8 Diagrammatic representation of the heart and the flow of the blood, according to Harvey.

First of all then, in fish which have but one ventricle of the heart, they having no lungs, the matter is clear enough. For it is certain that the bladder of blood set at the base of the heart and analogous to an auricle sends the blood into the heart, and that the heart then clearly sends on the blood again through the pipe or artery or vessel analogous to an artery; and this can be confirmed before our eyes either by looking at, or by the cutting of that artery from which the blood then leaps forth at every pulsation of the heart.

Next, it is not difficult to see the same thing in all animals that have but one ventricle, or as it were but one, as toads, frogs, snakes and lizards, which, although they are said in some manner to have lungs because they have a voice (about the wonderful contrivance of their lungs and about other things of this kind I have very many observations by me, but this is not the place for them) yet it is plainly to be seen from actual inspection that in them the blood is transferred in the same way from the veins into the arteries by the pulsation of the heart and the way of it open, clear and manifest, presenting no difficulty and no occasion for doubt. For, in these animals the case is as it might be in man were the septum of his heart perforated or taken away or one ventricle made out of the two; that done, I believe no man would then doubt by which way the blood could pass out of the veins into the arteries.

And first, I prove that in the more perfect and warmer-blooded animals and in those come to age, as in man, the blood passes from the right ventricle of the heart through the pulmonary artery into the lungs, and from there, through the pulmonary vein into the left auricle and then into the left ventricle of the heart. First, I will show that this may be so, and then that it is indeed so . . .

What men are these then, whom I hear denying that the blood, indeed the whole mass of the blood, can pass through the substance of the lungs quite as well as the nutritive juice through the liver, deeming it a thing impossible and in no wise to be believed? . . .

The parenchyma of the liver and that of the kidneys likewise is denser by far than that of the lungs, which is of a much finer texture, and spongy in comparison with that of the kidneys and liver.

In the liver there is nothing that impels, no driving force; in the lungs, the blood is kicked on by the pulse of the right ventricle of the heart and by this impulsion of the blood the vessels and porosities of the lungs needs must be distended. Besides, as Galen says . . . in respiration the lungs rise and fall, by which motion it follows of necessity that their porosities and their vessels are opened and shut, just as it happens in sponges and in all other things having the constitution of a sponge, when they are squeezed and then expand again. The liver, on the contrary, lies still and has never been seen to be expanded or constricted in this way.

Lastly, since there is no one but affirms that the juice of all the food that is eaten can pass through the liver into the vena cava, as well in man as in an ox or in the largest animals, and they are all forced to affirm it because, for there to be any nutrition, the food must pass some way and go into the veins and there is no other way but this, why then should they not likewise believe this of the passage of the blood through the lungs in men come to age, upon the same arguments?[i] And with Columbus, a most skillful and learned anatomist, believe and assert the same from the largeness and structure of the vessels of the lungs, and because the pulmonary vein and likewise the ventricle are always full of blood which must needs have come hither out of the veins and by no other path but through the lungs, as both he and I from the things which we have already said, from our own eyesight and from other arguments, believe to be most plain . . .

Therefore, I maintain that that which is done through most open ways in the greater number of animals and in all while they are still growing, as is plainly to be seen from dissection, is accomplished in these animals when they are grown through hidden porosities in the lungs and the tiny holes in their vessels, and that this is equally clear both from Galen's words and from what I have already said. From this it follows that although one ventricle of the heart, namely, the left, were sufficient for the distribution of blood throughout the whole body and for its drawing forth from the vena cava, just as indeed it does happen in all those creatures that have no lungs, yet nature, desiring the blood itself to be percolated through the lungs, was forced to add the right ventricle by whose pulsation the blood should be driven through the very lungs out of the vena cava into the receptacle of the left ventricle. And in this sense only it is to be said that the right ventricle was made for the sake of the lungs and on account of the transference of the blood and not for the sake of nutrition. For it is altogether inconsistent with reason to suppose that the lungs should have a greater need of such an abundance of food and that supplied by force and so much more pure and full of spirit, as being immediately conveyed from the ventricles of the heart, than either the most pure substance of the brain or the most resplendent and divine constitution of the eyes or the flesh of the heart itself, which is more directly nourished through the coronary artery . . .

Thus far, then, there are perhaps some who will say that they agree with me about the passing of the blood out of the veins into the arteries, and about the ways through which it goes, and how it is sent on and distributed by the beating of the heart, having been persuaded of it already, either by the

[i]Galen believed that food matter left the intestines as "chyle," which traveled through the mesenteric veins to the liver, where it was transformed into blood. [B.]

authority of Galen or by the arguments advanced by Columbus and by others. But now what remains to be said about the abundance of this blood which passes through, and where it comes from, though they be things most worthy of consideration, when I shall say them, so new and unheard of are they, that not only do I fear some mischief to myself from the malice of certain persons, but I am likewise afraid lest I have all men to my enemies, so much does custom and doctrine once absorbed and deeply rooted, like second nature, weigh with all men and the revered appearance of antiquity constrain them . . .

Now truly, when I had many times and seriously considered with myself the varied means of searching, and how many there were both from the dissection of living creatures for experiment's sake, and from the opening of arteries, as well as from the symmetry and great size of the ventricles of the heart and of the vessels which go into it and go out from it (for nature who makes nothing in vain would not have allotted to those vessels so comparatively large a size to no purpose), and from the carefully balanced and exquisite contrivance of the valves and fibers and from the rest of the fabric of the heart, and from many other things, and when I had for a great while turned over in my mind these questions, namely, how great was the abundance of the blood that was passed through and in how short a time that transmission was done, and when I had perceived that the juice of the food that had been eaten could not suffice to supply the amount of the blood—indeed, more, we would have veins empty and altogether drained dry and arteries, on the other hand, burst open with the too great inthrusting of blood, unless this blood should somehow flow back out of the arteries once more into the veins and return to the right ventricle of the heart—I began to think to myself whether it might not have a kind of movement as it were in a circle. And this I afterwards found to be true, and that the blood is thrust forth and driven out of the heart through the arteries into the whole structure of the body and into all its parts by the pulsation of the left ventricle of the heart, just as it is driven into the lungs through the pulmonary artery by the beating of the right ventricle, and that it flows back again through the veins into the vena cava and into the right auricle, just as it returns from the lungs through the pulmonary vein into the left ventricle of the heart, as I have already explained.

We may call this motion circular in the same way in which Aristotle says that the air and the rain imitate the circular motion of the heavens.[j] For the Earth being wet evaporates by the heat of the Sun; the vapors being drawn upwards condense and being condensed descend again in raindrops and wet the Earth. In this way, here on Earth all generation is accomplished, and so too from the circular movement of the Sun, its approach and recession, proceed the beginnings of storms and meteors.

So in all likelihood it happens in the body that by the movement of the blood all the parts are fed and nourished, fostered and quickened, by blood that is warmer, perfected, vaporous, full of spirit and, so to speak, alimentative; that on the other hand in the parts the blood becomes cold and coagulated and as it were enfeebled, when it returns to its beginning, the heart, as to the fountain or inmost shrine of the body to recover its perfection. There again by natural heat, powerful and vehement, as it were the treasure of life, it is again made liquid and is dispensed again from there through the body, fraught with spirits, as with balm, and these things depend upon the motion and pulsation of the heart.

So is the heart the first principle of life and the sun of the microcosm, just as the Sun deserves equally to be called the heart of the world, by whose virtue and pulsation the blood is moved, made perfect, quickened and preserved from corruption and lumpiness,

[j]This paragraph appears to indicate that Harvey knew nothing about the Copernican hypothesis. [B.]

and this familiar household god performs his office for the whole body by nourishing, cherishing and quickening, being the foundation of life and the author of all things.[k] But of these things it will be more appropriate to speak when we come to enquire of the final cause of this kind of movement.

Hence, it is that since the veins are certain ways and vessels carrying blood, there are two kinds of blood vessels, the vena cava and the aorta, not by reason of their position on this side and on that of the heart, as Aristotle thought, but by reason of their office, and not as is commonly supposed by reason of their composition, seeing that in many creatures, as I have said, a vein does not differ from an artery by the thickness of its coat, but they are differenced by their office and by their use. A vein and an artery, as Galen observed, were both called veins by the ancients and not unjustly, because the latter, the artery, is a vessel carrying blood away from the heart into the whole of the body, while the former, the vein, is a vessel bringing the blood back again from the body into the heart; the artery is the way from the heart, the vein the way to it. The vein contains blood that is more crude, spent and now become unfit for nutrition; the artery, blood that is concocted, perfected and alimentative . . .

Let us suppose, either theoretically or experimentally, how much blood the left ventricle may contain in its contraction, or how much the heart contracts itself, and how much blood is thrust out into the great artery, for in the systole there is always some blood thrust out as I proved before, and all men acknowledge that it is so, convinced by the structure of the valves. Let us put up as a reasonable guess that a fourth, fifth or sixth part, and at least an eighth, is sent to the artery.

Therefore, let us suppose that in a man there is sent forth at every beat of the heart half an ounce or three drams[l] or one dram which cannot possibly return to the heart by reason of hindrance of the valves.

The heart in one half hour makes about a thousand pulses; in some men, indeed, and at some times, two, three or four thousand. Now multiply the drams and you will see that in one half hour either one thousand times three drams or two drams, of five times one-hundred ounces, or some such proportionate quantity of blood, is passed through the heart into the arteries, that is, always in greater quantity than can be found in the whole of the body . . .

So, having calculated according to the least amount of blood that we may suppose to be transmitted and multiplied it by the number of pulsations, it would seem that the whole quantity of the mass of blood passes through the heart from the veins to the arteries, and likewise through the lungs . . .

But indeed, even if the blood passes through the lungs and heart in the smallest quantity that may be, a far greater abundance of it is conveyed into the arteries and the whole body that can possibly be supplied by the food we eat or in any other way whatsoever, unless it return again round a circuitous course.[m]

[k]Later in 1651, when Harvey published his embryological work *De generatione animalium* (On the Generation of Animals), the heart came to be seen as less important than the blood itself. Experimental study of the sequence in which organs appear in chick embryos had persuaded Harvey that the blood is formed before the heart and vessels. Where this extravagant passage celebrates the heart as the basis of life, in his later work it is the blood which is the preserver of the body and the element in which the vital principle (the sensible soul) has its dwelling place. [B.]

[l]The Apothecaries or Troy weight, which Harvey employs in this first application of quantitative analysis in physiology, was widely used throughout Europe: 3 scruples = 1 dram; 8 drams = 1 ounce; 12 ounces = 1 pound. [B.]

[m] The Galenists insisted that blood was formed in the liver from food consumed, and distributed by the veins to nourish the parts of the body according to their needs. If the heart pumps in a short period of time more blood than is necessary for nutrition—indeed, more than the weight of a human being—it is clear that it must be the same blood circulating throughout the body. [B.]

This also is clearly to be seen by any who watch the dissection of living creatures, for not only if the great artery be cut, but, as Galen proves, even in man himself, if any artery—even the smallest—be cut, in the space of about half an hour the whole mass of blood will be drained out of the whole body, as well out of the veins as out of the arteries . . .

Ligatures are either tight or middling tight. By a tight ligature, I mean one in which the limb is so tightly bound all round by a narrow band or a noose that you cannot see the arteries beat anywhere beyond the ligature; such a one as we use in the amputation of limbs when we foresee an efflux of blood, or again in the gelding of animals and the excision of tumors, for by it the accession of nutriment and heat is entirely interrupted and we see the testicles and great sarcoses wither and die away and afterwards drop off.

By a middling-tight ligature I mean one in which the limb is compressed all round but without causing pain, and such that it allows the arteries to beat a little beyond it; such a one as is used in the drawing and letting of blood, for though the ligature be made above the elbow, yet you can feel the arteries beat a little in the wrist if the ligature be properly made for phlebotomy.

Now, let there be an experiment made on a man's arm either by employing a narrow band such as they use in blood-letting or by compressing the arm rather firmly with the hand; and this is more conveniently done in a lean man and one whose veins are rather large and when the extremities are warm, the body having been heated by exercise, and a greater quantity of blood is in the extremities and the pulsation more violent, for then everything will appear more clearly.

If you then make a tight ligature, drawing it as hard as it can be endured, you may observe first that beyond the ligature, that is towards the hand, the artery does not beat either in the wrist or anywhere else. Next, that the artery above the ligature immediately swells higher in its diastole and beats more and higher and more vehemently, and beside the ligature itself, swells with a kind of tide as if the blood did strive to burst open the barrier to its flow and unlock the passage which is stopped, and that the artery appears to be fuller there than normal. Lastly, you will see that the hand will retain its usual color and condition and only in the course of time begin to grow somewhat cold, and that nothing whatsoever is drawn into it.

After this ligature has continued a while, let it be suddenly loosened into a ligature of middling tightness, such as I said they use in the letting of blood. It is to be observed that the whole hand is immediately imbued with color and distended, and that its veins become swollen and lumpy, and in the space of ten or twelve pulses of the artery you will see that the hand is exceedingly full with the much blood that is driven and forced into it and that a great quantity of blood is quickly drawn by that middling-tight ligature without either pain or heat or the flight from a vacuum or any other cause mentioned above.

If at the very moment of the slackening of the ligature, any one will carefully put his finger on the pulsating artery beside the ligature, he will feel the blood as it were slipping underneath his finger.

Moreover, he on whose arm the experiment is made, from the moment of the loosening of the ligature from tight to middling tight, will plainly feel the heat and blood entering the arm below it in time with the pulse, as if some obstacle had been removed, and he will have the sensation of something passing along the course of the arteries and suddenly dilating them and distributing itself here and there through his hand, and immediately his hand will become hot and distended.

Just as in a tight ligature the arteries above it are distended and pulsate and those below do not, so on the contrary in a middling-tight ligature the veins below it swell and become resistant but not so those above, and the arteries below it become smaller.

Indeed, if you were to compress those swollen veins, unless you did it very strongly, you would scarcely see either the blood being diffused or the veins distended above the ligature.

We may, therefore, advance the following argument. When in a middling-tight ligature we see the veins swollen and distended and the hand very full of blood, where does this come from? For either the blood comes through the veins or the arteries below the ligature, or through the hidden porosities of the flesh. From the veins it cannot come; through hidden porosities still less; therefore it needs must come through the arteries as I have said. That it cannot come through the veins is evident seeing that the blood cannot be squeezed back above the ligature unless you take the ligature quite away, when on a sudden all the veins are seen to subside and unburden themselves into the upper parts, the hand to grow white and all the previously gathered swelling and blood to vanish apace upwards.

He himself will perceive this better whose wrist or arm has been bound in this way for some time and whose hands in consequence have become swollen and somewhat colder, he indeed will feel, after the untying of the middling-tight ligature, something cold creeping up to his elbow or armpits, that is, along with the returning blood. This return of cold blood to the heart, when the ligature is untied after blood-letting, I have been inclined to think was the cause of fainting which we have seen happen even in strong men and chiefly at the moment of the untying of the ligature and which is commonly said to be occasioned by the "turning" of the blood.

Moreover, when immediately upon the loosening of a tight ligature into a middling-tight one, we see that by the emission of blood through the arteries, the veins included under the ligature forthwith begin to swell and not the arteries. This is a sign that the blood flows from the arteries into the veins and not contrariwise, and that there is either an anastomosis of the vessels, or that there are porosities in the flesh and solid parts which are pervious to the blood. Again, a sign that very many veins communicate with each other is this, that when a middling-tight ligature is made above the elbow, many veins all together rise up and swell, but a passage for the blood being opened out of one little vein with a lancet, they all immediately subside and unburden themselves into that little one and almost all flap down straightaway . . . .

The famous Hieronymus Fabricius ab Aquapendente,[n] a most learned anatomist, a man advanced in years and worthy of respect, or else Jacobus Silvius, as the learned Doctor Riolan would have it, first described these membranous valves in the veins as exceedingly thin, raised small portions of the inner coat of the veins and shaped in the figure of a sigma or half-moon. They are situated at diverse distances from one another, differently in different men, growing out from the sides of the veins and looking upwards towards the roots of the veins, and facing inwards towards the central hollow channel of the vein.

Both the valves, for they are for the most part in pairs, face each other and touch one another and so stick together with their tips that they are apt to be joined, so that if anything should slip through from the root of the veins into the branches, or from the larger branches into the smaller, they would altogether stop its passage. And they are so placed that the horns of the one that comes after look towards the middle of the curved part of the one above it, and thus they continue to alternate.

[n]Harvey studied medicine at Padua under Fabricius (1537–1619), who discovered the valves in the veins in 1574. Though he only published his findings in 1603, they were certainly known to Harvey before he departed for England in 1602. Fabricius' description of the venous system made a profound impression on Harvey. The function of the valves, according to Fabricius, was to retard the flow of the blood flow, so that the tissues could absorb nutrients. [B.]

The discoverer of these valves did not rightly understand their use and other writers have added nothing. For their use is not to prevent the whole mass of the blood from falling downwards by its own weight into the lower parts of the body. There are indeed in the jugular veins valves looking downwards and preventing the blood from being carried upwards. They do not look upwards everywhere but always towards the roots of the veins and everywhere towards the region of the heart. I myself, and others too, have on occasion found them in the renal veins and in the mesenteric branches looking respectively towards the vena cava and the portal vein . . .

But valves were made entirely lest the blood should move from the greater veins into the lesser and so tear or swell them, that it should not go from the center of the body to the extremities, but rather from the extremities to the center. Therefore, to this movement the delicate valves easily open a way, but the contrary movement they entirely arrest. And they are so positioned and arranged that if anything is not stopped in its passage by the horns of the upper ones, but slips as it were through a chink, it is caught in the convexity of the next one which is set transversely, and there it stays and can pass no further.

I have very often found in dissecting veins that if, beginning from the root of the vein, I put a probe towards the small branches, with all the skill I could, it could not be further driven by reason of the hindrance of the valves. But on the contrary, if I put it from the outer branches towards the root it passed very easily. In many places, a pair of valves, one on each side, is so sited and adjusted that when they are raised up, they close with one another in the middle of the hollow channel of the vein and join together so exactly, convexity to convexity and extremity to extremity, that you can neither see with your eyes nor in any way discover any crevice or conjunction. But on the contrary, they yield a passage to a probe inserted from the outside inwards, and like flood-gates which stay the course of rivers, are most easily pushed aside. These valves are so constituted that they hinder the movement of the blood outwards from the heart and the vena cava, and when in many places they are raised up towards each other and exactly closed, they altogether prevent and arrest it. Nor will they suffer the blood to move anywhere away from the heart, neither upwards to the head nor downwards to the feet, nor to the sides nor arms, but such indeed is their constitution that they stop and resist all movement of the blood which is begun in the greater veins and ends in the lesser. Yet any movement which begins in the small veins and ends in the greater, they obey and provide a free and open way for it.

But that this truth may the more clearly shine forth, let the arm of a living man be tied above the elbow (Fig. 1, AA) as if it were to let blood [Plate 9]. There will appear at intervals, especially in country people and those who are swollen veined, certain little nodes or swellings (BCDDEF), not only where there is a branching (EF), but likewise where there is none (CD). These nodes are made by the valves. When they have appeared like this on the outside of the hand or forearm, if you press on the node with your finger or thumb (Fig. 2, O) and draw the blood downwards from that node or valve to the next (Fig. 2, H), you will see that no blood can follow, the valve quite hindering it, and that the portion of the vein (Fig. 2, HO) between the node and the finger you moved down is quite obliterated and yet full enough above the node or valve (OG). Now, if you retain the blood so drove down and the vein emptied (H), and with the other hand press downwards in the direction of the valve (Fig. 3, K), the upper part of the vein being full (O), you will find that by no means can it be forced or driven beyond the valve (O); but the more you try to do this, the more you will see the vein swollen and distended at the node or valve (O), and yet below it the vessel remains empty (Fig. 3, HO).

Hence, since anyone can try this experiment in many different places, it appears

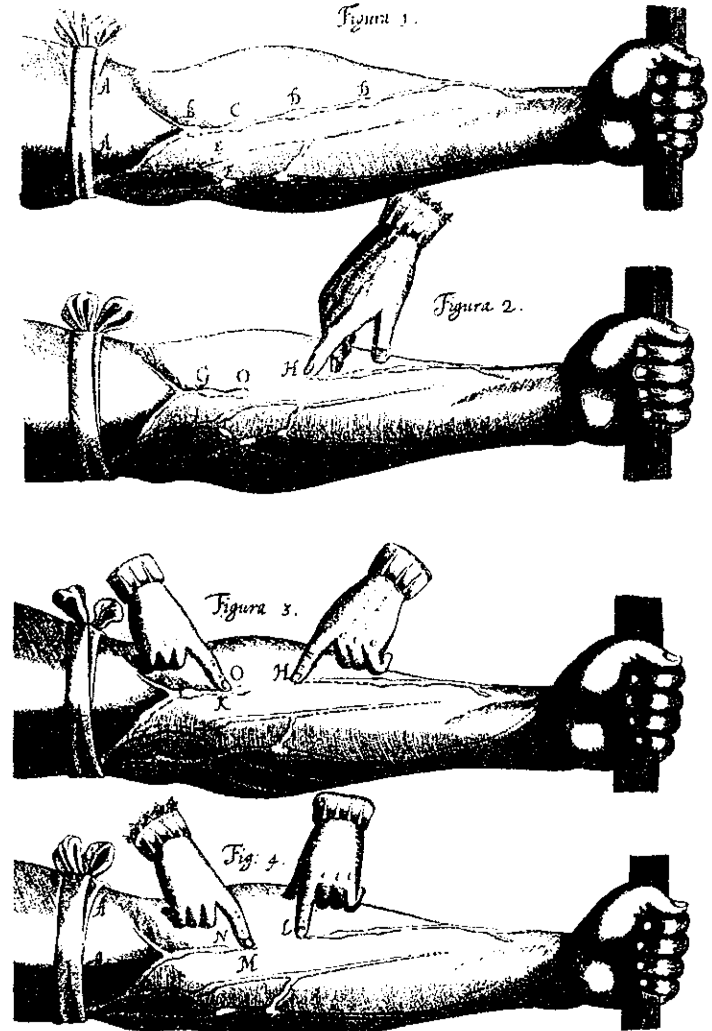

PLATE 9 Harvey's demonstration that the blood undergoes a motion in a circle. When the arm is ligated above the elbow (Figure 1), nodes appear at the sites of the valves in the veins. When blood is pressed out of the vein (Figure 2) between O and H, and a finger is placed at H, the vein remains empty. When a second finger presses down along the vein in the direction of O (Figure 3), the vein remains empty. Finally, if a finger is placed at L (Figure 4), and a second finger presses along the vein from L to N, the vein remains empty. On this basis, Harvey concluded that the blood must flow throuth the veins back to the heart. From *De motu cordis* (1628).

that the function of the valves in the veins is the same as that of the three sigmoid valves which are made in the orifice of the aorta and pulmonary artery, namely to shut so exactly that they do not allow the blood passing through to turn back again.

Furthermore, tying the arm again as before (AA), and the veins swelling, if you hold the vein at some distance below any node or valve (Fig. 4, L), and then with your finger (M) drive the blood upwards and above the valve (N), you will see that part of the vein (LN) remains empty and that the blood cannot return backwards through the valve (as in Fig. 2, HO). But taking away your finger (H), you will see it filled again from below (and be again as in Fig. I, DC). From these things then it is certain and obvious that the blood moves in the veins upwards from the lower parts to those above, and towards the heart and not in the contrary direction. And although in some places there are valves which are not closed so precisely, or where there is but only one valve, and so do not seem to prevent entirely the flow of blood from the center, yet for the most part it is evident that they do so, or at least, what seems negligently performed in one place appears to be compensated for either by the frequency or careful contrivance of the valves that follow in due order, or by some other way, so that the veins are open and patent ways for the blood returning to the heart but are entirely closed to blood going outwards from the heart . . .

Now at last allow me to put forward my opinion concerning the circulation of the blood and to state it formally to all men.

Seeing that the following premises been proved by logical arguments and ocular demonstrations that the blood passes through the lungs and heart by the pulse of the ventricles, and is driven in and sent into the whole body and there creeps into the veins and porosities of the flesh, and through the veins themselves returns from all parts, from the circumference to the center, out of the tiny veins into the greater, and from thence comes into the vena cava and at last into the auricle of the heart, and in so great abundance, with so great an outflowing and inflowing, from hence through the arteries to that place, from there through the veins and back again, that it cannot be furnished by those things that we eat, and in far greater abundance than is necessary for nourishment; it must of necessity be concluded that the blood is driven into a round by a circular motion in living creatures, and that it moves perpetually; and that this is the action or function of the heart, which by pulsation it performs; and lastly, that the motion and pulsation of the heart is the only cause . . .

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