William Harvey and the Circulation of the Blood, 1971-72

Presented by The Royal College of Physicians of London

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William Harvey's words spoken by Leonard Goodwin.

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Colour
Duration: 00:38:30:19

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<John Curle narrates>
Sir Thomas Lewis, the distinguished physician and physiologist and Sir Henry Dale, Nobel Prize winner and at one time president of the Royal Society, were the first to have the idea of making a film to illustrate the experiments which led William Harvey to the discovery of the circulation of the blood. They made their film in time for the 1928 celebrations of the tercentenary of the publication of Harvey's book, *De Motu Cordis*. In 1957, a new film in colour was initiated by Sir Henry Dale.

<Sir Henry H Dale, introduction to camera>

For the commemoration of Harvey at the Royal College of Physicians on the 300th anniversary of his death in 1657, I found myself again concerned with the making of a film. This has been possible only through my great good fortune in being able to enlist the co-operation of colleagues whose eyes and hands and ideas are much younger than my own are now.

<Curle narrates>

Over 150 copies of this film were made and shown to thousands of students all over the world. Since 1957 the results of research have led to a slightly different account of the development of Harvey's thought and of the historical background. For this, and for technical reasons, it was decided in 1970 to make a new film.

<**Opening titles**>

<Curle narrates>

William Harvey was born at Folkestone on the 1st of April, 1578. He was educated at the King's School, Canterbury, and in 1593 when he was just over 15 years of age he went to Gonville and Caius College, Cambridge. For the next 4 years he followed the undergraduate arts course studying Latin grammar and rhetoric, logic and the classical authors and at the age of 19 took his degree as Bachelor of Arts.

After that he turned to medicine and two years later went to the University of Padua to complete his medical studies. There he received his degree as Doctor of Medicine and Philosophy on the 25th of April 1602, having passed the appropriate examinations in both these subjects as is attested by the signatures of his examiners.

After his return to London in 1603, Harvey applied to The College of Physicians for licence to practise medicine, for the college then had the right to examine and licence all who practised medicine in London and for seven miles around. This permission was given him and he was admitted as a fellow in 1607.

Two years later he became physician to St Bartholomew's Hospital, his private practice in London and in the court increased, and in 1618 he was appointed one of the physicians to the King, James I, and his ties with the royal family became closer particularly after the accession in 1625 of Charles I.

The story of how Harvey came to make the discovery of the circulation of the blood begins in Padua.

When Harvey began to study medicine at the end of the 16th century, the works of Ibn al-Nafis and Michael Servetus were unknown. The opinion generally held on the movement of the blood came from the teaching of Galen, the Greek physician of the 2nd century AD; his writings covered all aspects of medical knowledge from anatomy to therapeutics and over the centuries had acquired such authority that none dared to question the truth of his findings or opinions.

According to Galen's opinion as it was taught in the 17th century, all the blood in the body originated in the liver; the food passed into the stomach and intestines and there underwent a process known as concoction as the result of which, the refined portion of this food, called chyle, was separated off and conveyed through the portal vein to the liver. There it underwent further concoction and became venous blood. And at the same time it was endowed with 'natural spirit' and so acquired the power of imparting life and nourishment to all parts of the body.

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The different parts sucked up the nourishment brought to them and the venous blood ebbed back to the liver for fresh supplies. So a continuous movement of ebb and flow was believed to go on in the veins. From the liver, the vena cava brought the venous blood to the right ventricle of the heart. Some of it was expelled through the pulmonary artery into the lungs for their nourishment while the remainder passed through porosities in the interventricular septum into the left ventricle. There it met the air which had passed through the lungs and travelled through the pulmonary vein into the left ventricle. This inspired air was thought to have inherent in it the basic principle of life. In the left ventricle of the heart it was believed that a further concoction took place and that the venous blood and the inspired air were refined together to become arterial blood endowed with vital spirit. Arterial blood went out through the left ventricle of the heart, through the aorta and from thence into the whole body.

At the same time, the fuliginous vapours, which were thought to be given off by the concoction of blood and air in the left ventricle, were driven back through the pulmonary vein into the lungs and so breathed out of the body.

The timing of all these movements was held to coincide with the action of the heart. When the heart was in diastole it was thought to suck venous blood into the right ventricle and air into the left, and when in systole to drive up the venous blood through the pulmonary artery, arterial blood through the aorta, and fuliginous vapours through the pulmonary vein. But diastole was thought of as an active movement of dilatation and the heart was believed to be in diastole when it struck the chest wall and the apex beat occurred.

When Harvey went to Padua in the autumn of 1599, the university had one of the best medical schools in the whole of Europe. It had moved to a new building in 1542 on the site of the ancient hostelry of Il Bue, the ox – the building still remains, much as it was in Harvey's time and is now the administrative centre of the university.

One of the reasons for the fame of Padua was the excellence of its teaching of anatomy and this was due to the work of Andreas Vesalius of Brussels and his successors. In 1540, when only 25, Vesalius was appointed Lecturer in Surgery and Reader in Anatomy. He was a brilliant dissector and was one of the first to point out Galen's anatomical errors. In 1543 he published the first great treatise on the anatomy of the human body, *De Humani Corporis Fabrica*; it was a systematic account of the whole subject based on innumerable dissections and was illustrated with woodcuts of great artistic value.

Vesalius did not challenge Galen's opinion on the movement of the heart and blood although he made it quite clear that he could not find any pores that penetrated through the septum of the heart, but he did not deny their existence. Vesalius was succeeded by Realdus Columbus who stayed in Padua only two years and then went to Pisa and to Rome, where he died in the autumn of 1559. His one book, *De Re Anatomica*, was published posthumously.

Columbus pointed out that current opinion on the timing of the apex beat with diastole of the heart was the reverse of the truth and that in fact the active movement of the heart was in systole. He also denied the existence of pores in the interventricular septum and of the breeding of fuliginous vapours in the left ventricle. Instead, he maintained that the blood left the right ventricle of the heart through the pulmonary artery, passed through the lungs and entered the pulmonary vein and so went into the left ventricle. He based this hypothesis on his understanding of the competence of the valves of the heart and he proved it by the simple experiment of opening the pulmonary vein to see whether it contained air or blood.

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Hieronymus Fabricius of Aquapendente, Harvey's own master, became Lecturer in Surgery and Anatomy at Padua in 1565. The permanent anatomy theatre was built in his time in 1584 on an upper floor of the university and there Harvey certainly stood to watch Fabricius' demonstrations. Fabricius was an excellent teacher and popular with the students. He did not challenge the orthodox Galenic opinion on the movement of the heart and blood; he did not believe in the truth of Columbus' findings, but he did demonstrate the valves in the veins. *De Venarum Ostiolis* was published in 1603, after Harvey had left Padua.

Fabricius believed that blood left the heart through the veins. Valves are placed in the veins with a view to checking the blood on its course and preventing the whole mass of it from slipping headlong down and escaping. He pointed out that if one tries to exert pressure on the blood, or to push it along by rubbing from above downwards, one will clearly see it held up and delayed by the valves.

Harvey may well have seen this demonstration and it may have set him thinking about the movement of the blood, for as Robert Boyle reported, it was thinking about the valves of the veins and the manner of their action that first gave Harvey the idea that the blood circulated throughout the whole body.

In 1615, Harvey was appointed by the College of Physicians as its Lumleian Lecturer in Surgery and Anatomy, and in April 1616 he gave his first full scale public anatomy in the presence of members of the college. The notes for these lectures exist in a manuscript in the British Museum and from them it's possible to know precisely how far Harvey had gone at that date towards the formulation of his new hypothesis.

By this time Harvey had read the works of Columbus and had reached the conclusion that Columbus was right and that the current belief in the timing of systole and diastole of the heart in relation to the apex beat was wrong. Harvey had performed many experiments on the action of the heart but he had no idea of the true function of the valves of the veins. He cannot, therefore, in 1616 have formulated the hypothesis on the circulation of the blood. This hypothesis was most probably formulated between 1619 and 1625 and was published in 1628 in his great work, now familiarly known as *De Mortu Cordis*. Within the compass of this short treatise, Harvey set forth his new concept – he worked not from books but from dissections. Let us hear the evidence for this concept in his own words:

<**Leonard Goodwin reads from Harvey's *De Motu Cordis***>

> It is clear that those things which are before spoken concerning the motion and use of the heart and the arteries do either seem inconvenient or obscure or admit of no possibility. Therefore it will be profitable to search more deeply into the business and to contemplate the motions of the arteries and heart not only in man but also in all other creatures that have a heart as likewise by the frequent dissection of living things to discern and search the truth.
>
> When I first applied my mind to observation that I might find out the use of the motion of the heart, I straightaway found it a thing hard to be obtained and full

of difficulty so I did almost believe that it was known to God alone and that by reason of the quickness of the motion which in some creatures appeared in the twinkling of an eye, like the pulsing of lightening. At last, using daily more search and diligence, I did believe I had hit the nail on the head, unwinded and freed myself from this labyrinth.

First then, opening the breast and cutting up the capsule which immediately surrounds the heart, you may observe that the heart moves sometimes, sometimes rests. This is more evident in the heart of colder creatures. It is also evident in the hearts of other animals, as of dogs, if you observe attentively until the heart begins to die and move faintly.

<**Curle narrates**>
From these and other observations Harvey concludes that at the moment of systole, the heart feels harder, it contracts and is lifted up and strikes the chest wall and that is when the apex beat can be felt. This was contrary to the commonly received opinion.

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Next, Harvey analysed the action of the heart and demonstrated that blood was thrown by the contraction of the auricles into the ventricles, and by the contraction of the ventricles into the arteries:

<**Goodwin reads from Harvey's *De Motu Cordis***>
There are, as it were, at one time, two motions – one of the auricles and another of the ventricles, for they are not just at one instant, but the motion of the auricles goes before and the motion of the ventricles follows.

When all things are in a languishing condition, the heart dying away, it ceases to answer by its motion and only by nodding its head seems, as it were, to give consent. And whilst by little and little the heart is dying, you may see after two or three beatings of the oracle, the ventricle will, being as it were roused, answer and very slowly and with difficulty beat once. This is especially to be observed, that after the ventricle has left beating and the auricles are beating still, if you cut away the point of the heart with a pair of scissors you shall see the blood flow from vents at every pulsation of the auricle so that from thence it appears which way the blood comes into the ventricles; not by attraction or distension of the ventricles, but sent in by the impulsion of the auricles.

There is found here with us a sort of very little fish called a shrimp, all the body of which is transparent. This little fish I have often shown in water to some of my friends so that we could clearly discern the motion of the heart.

In a hen's egg, I showed the first beginning of the chick, like a little cloud, by putting an egg, of which the shell was taken, into water, warm and clear. In the midst of which cloud there was a point of blood which did beat, so little that when it was contracted it disappeared and vanished out of our sight; and in its dilatation showed itself again red and small as the point of a needle. In so much as betwixt being seen and not being seen, as it were betwixt being and not being, it did represent a beating and the beginning of life.

<**Curle narrates**>

Harvey went on to prove that the systole of the heart coincided with the expansion or diastole of the arteries:

<**Goodwin reads from Harvey's *De Motu Cordis***>

In fishes, if at the time you see the heart stiff and contracted you cut the pipe which leads from the heart to the gills, from thence you shall see the blood forcibly thrust out. From this it is clear that the arterial diastole is at the same time with the systole of the heart and that the arteries are filled and distended by reason of the inmission[?] of blood made by the constriction of the ventricles, just as when one blows in a glove, he shall see all the fingers swell up together and assimilate this pulsation.

<**Curle narrates**>

Harvey's next step was to demonstrate how the blood passes from the right ventricle by the pulmonary artery into the lungs, and from thence by the pulmonary veins into the left auricle and left ventricle of the heart.

First he denies the existence of pores in the interventricular septum:

<**Goodwin reads from Harvey's *De Motu Cordis***>

> That opinion is not to be tolerated which does assert that the blood is drawn through the hidden pores of the mediastin of the heart out of the right ventricle into the left. By my troth there are no such pores, nor can they be demonstrated! And why, I ask you, do they have recourse to hidden, invisible, uncertain and obscure pores for the passage of the blood into the left ventricle, when there is such an open way through the pulmonary vein? Truly it is a wonder to me that they would make, or rather invent, a way through the septum of the heart which is gross, thick, hard and most compact, than through the patent pulmonary vein or else through the substance of the lungs; thin, loose, most soft and spongious.
>
> There are in the orifice of the pulmonary artery, three doors, made like a sigma or half moon, which altogether prevent the blood sent into the pulmonary artery from returning again to the heart. So, likewise, in the aorta. When they are raised up and brought together, they make a three-cornered line such as is left by the bite of a leech, so that they may prevent the reflux of blood.

<**Curle narrates**>

But the structure and action of the valves and the heart supports the view that the blood passes from the pulmonary artery through the parenchyma of the lungs into the pulmonary veins.

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So Harvey confirmed the work of Realdus Columbus, but in 1628 he had not devised any experiment to prove that the septum was indeed a solid wall. This he did not do for another 23 years. In 1651 he described the experiment in a letter written to the German physician Paul Marquart Schlegel:

<**Goodwin reads from Harvey's letter to Marquart Schlegel**>

> It may be well here to relate a crucial experiment which I lately performed. Having tied the pulmonary artery, the pulmonary vein and the aorta and then opened the left ventricle of the heart, we passed a tube through the vena cava into the right ventricle; and having filled an ox's bladder with warm water, we attached it to the tube and forcibly injected the better part of a pound of water into the right auricle and ventricle. What happened? The right ventricle and auricle were enormously distended but not one small drop of blood or water escaped through the hole in the left ventricle. Next we untied the aforesaid ligatures and then inserted the same tube into the pulmonary artery and tied a tight ligature behind it to prevent any reflux of water into the right ventricle. We then pushed the water from the bladder towards the lungs. Immediately a torrent of water mixed with blood gushed forth from the hole in the left ventricle.

<**Curle narrates**>

Harvey set out in *De Motu Cordis*, the evidence on which is based his hypothesis that blood circulates throughout the whole body:

<**Goodwin reads from Harvey's *De Motu Cordis***>

> When I had often and seriously considered with myself what great abundance of blood there was, as witnessed by my dissections and experiments on living creatures, by the opening of the arteries and many ways of searching; by the symmetry and magnitude of the ventricles of the heart, and of the vessels which go into it and go out from it; as likewise by the careful artifice of the valves and fibres and of the rest of the fabric of the heart, and by many other things. And when I had long time considered with myself how great abundance of blood was passed through and in how short a time that

> transmission was done and whether or no the juice of the nourishment which we receive could furnish this or no, and how it could be that the veins were not quite emptied and drained and the arteries on the other hand not burst open with too much intrusion of blood unless this blood did pass back again some way, out of the arteries into the veins, and return into the right ventricle of the heart; I began to bethink myself if it might not have a motion, as it were, in a circle.

<**Curle narrates**>

The first proof of the circulation of the blood is a quantitative experiment and although Harvey's calculations may seem rough and ready, the experiment is important for it was almost the first time in the history of physiology that an argument of this kind was used:

<**Goodwin reads from Harvey's *De Motu Cordis***>

> Let us suppose how much blood the left ventricle contains in its dilatation when it is full, say 2 ounces. I have found in a dead man above 2 ounces. Let us suppose likewise how much less the heart may contain when it does contract itself, and from thence how much blood is thrust out into the aorta. So let us imagine that, in a man, there is sent forth in every pulse of the heart at least 1 drachm of blood, which by reason of the hindrance of the valves cannot return to the heart. The heart in one half hour makes above 1000 pulses. Now, multiply the drachms transfused through the heart into the arteries and you will always find a greater quantity than is found in the whole body. So likewise in a sheep in whose body for the most part is not contained above 4 pounds of blood, for I have tried it.

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<**Curle narrates**>

Harvey's next experiments were designed to prove that the arteries received blood from the veins in no other way than by transmission through the heart:

<**Goodwin reads from Harvey's *De Motu Cordis***>

> If anyone cut up a live snake, he shall see the heart beat calmly, distinctly, for more than a whole hour. The vena cava enters the lower part of the heart, the artery comes out at the upper part. Now, taking hold of the vena cava with a pair of forceps, and the course of the blood being stopped a little way beneath the heart, you shall perceive to be presently almost emptied that place which is betwixt your forceps and the heart; the blood being exhausted by the pulse of the heart, and the heart will be of a far lighter colour, and it is lesser too in its dilatation for want of blood, and at last beats more faintly. So soon again as you let go the vein, both colour and bigness return to the heart. Unless you will deny your own eyesight you must needs affirm the recourse of blood to the heart.
>
> Afterwards, if you do leave the vein and do grasp or bind the artery a little way from the heart, you shall on the contrary see it swell vehemently there where it is compressed, and that the heart is swelled beyond measure and does acquire a purple colour and that it is at last oppressed with blood so that you would think it would be suffocated, but letting go the artery that the heart does return to its normal constitution, colour and bigness.

<**Curle narrates**>

Harvey had now to prove that the blood returned to the heart through the veins. The actual connections between arteries and veins he never saw for in his day no lens of sufficient power of magnification was available. He merely deduced that the extremities of arteries and veins must conjoin either directly or indirectly through the porosity of the tissues.

A description of the capillary blood vessels, first seen by Malpighi, was published in 1661, four years after Harvey's death.

<**Goodwin reads from Harvey's *De Motu Cordis***>

> Some experiments are to be taken notice of by which it is clear that the blood doth enter into every member through the arteries and doth return by the veins. Let there be an experiment made in a man's arm, and indeed it is most

conveniently done in a lean man, the body having been heated by exercise and the pulse full. If you do then make a hard ligature, drawing it as straight as any may endure it, you may first observe that beyond the ligature the artery does not beat. After this ligature has continued a while and that in a sudden it is a little untied into a middle sort, such as I say they use in letting of blood, it is to be observed that the whole hand is straightaway imbued with colour and distended, and that the veins of it become swelled and lumpy and in the space of 10 or 12 pulses of the artery, you will see the hand to be exceeding full with the much blood that is driven and forced into it.

<**Curle narrates**>
Another simple experiment to determine the direction of flow in the two sets of vessels, Harvey describes in his second letter to Jean Riolan, written in 1648.

<**Goodwin reads from Harvey's letter to Riolan**>

> Cutting of a vein, anybody may see the nearer part of it towards the heart let out no blood, but the further part poured abundantly. Cutting an artery, but a little blood flows from the further part, but the nearer part shoots forth blood with violent force as if it were out of a spout.

<**Curle narrates**>
In 1637, a new kind of fire engine was used in London. Harvey saw it working and the sight suggested to him the analogy between the heart's action and that of a pump. In his letter to Riolan, he describes the manner in which the blood spurts from a cut artery at every contraction of the heart, saying:

<**Goodwin reads from Harvey's letter to Riolan**>

> Just as water by the force and impulsion of a fire engine is driven aloft through pipes of lead, and we may observe and distinguish all the forcings of the engine, even though it be a good way off in the flux of the water when it passes out, the order, beginning, increase, end and vehemence of every stroke, even so it is with the blood from the orifice of a cut artery. It remains

that we do explain which way the blood flows back from the extremities through the veins into the heart.

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The most famous Hieronymus Fabricius of Aquapendente, a most learned anatomist, did first delineate the membranous valves in the veins, being exceeding thin raised 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, looking upwards towards the roots of the veins and for the most part in pairs.

I have often found that in dissection, if beginning from the root of the vein I did put in 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. On the contrary, if I did put the probe from the outer branches towards the root, the valves give way and like floodgates in rivers are most easily pushed aside. The valves were solely made lest the blood should move from the greater veins into the lesser, that the blood should not go from the centre of the body to the extremities, but rather from the extremities to the centre.

But that this truth may the more clearly appear, let the arm of a man be tied above the elbow as if it were to let blood, there will appear at intervals certain little nodes or swellings. These nodes are made by the valves. If you draw down blood with your thumb or finger from beyond a valve and hold it thus, you will see that no blood can follow, the valve is quite hindering it. If you retain the blood so drove down and do press downward with t'other hand, the upper part of the vein being full, you shall find that by no means can it be forced or driven beyond the valve. Taking away the finger you first applied, you shall immediately see the vein filled again from below. Again, put your finger below any valve and press the vein that no blood may go from the hand upwards, then squeeze with your finger the blood upwards to the valve. Then taking away your finger suffer the vein to be filled up again from below. And then pressing again with your finger in the same place, squeeze out the blood again and do this 1000 times in a little space. Now if you reckon the business, how much blood has been pushed above the valve, you shall find so much blood passed by this means, through a little part of a vein, that you will find yourself perfectly persuaded concerning the circulation of the blood and its swift motion.

And now we may bring forth our opinion concerning the circulation of the blood. Seeing it is confirmed by reasons and ocular experiments that the blood does pass through the lungs and heart by the pulse of the ventricles, and is driven and sent into the whole body and does creep into the veins and porosities of the flesh, and through them return from the little veins into the greater, from the circumference to the centre, from whence it comes at last into the vena cava and into the auricle of the heart in so great abundance with so great an outflowing and inflowing. From hence through the arteries thither, from thence through the veins hither back again so that it cannot be furnished by those things which we do take in and in far greater abundance than is necessary for nourishment, it must be of necessity concluded that the blood is driven into a round by a circular motion in creatures and that it moves perpetually and hence does arise the action and function of the heart which by pulsation it performs. And lastly that the motion and pulsation of the heart is the only cause.

<**Curle narrates**>
When Harvey died in 1657, his new theory of the circulation of the blood had won general acceptance. He was well aware that its consequences would be far-reaching, and so it has proved.

<**End credits, in addition to those listed at the beginning of the transcription**>

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