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HARVEY

ON THE CIRCULATION OF THE BLOOD

Dr. A. Bowie

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ON THE MOTION OF THE HEART AND BLOOD IN ANIMALS.

ON THE

MOTION OF THE HEART AND BLOOD IN ANIMALS.

By WILLIAM HARVEY, M.D.

WILLIS'S TRANSLATION, REVISED AND EDITED BY

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Throat.

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CONTENTS.

BIOGRAPHICAL INTRODUCTION.

IT has often been said that the world knows little of its greatest men, and in the case of William Harvey the statement receives a striking illustration. Two hundred and seventy years have passed since he made his great discovery of the circulation of the blood. With the progress of medical and physiological science, the lustre surrounding his name has steadily increased, and we now place it chief in the roll of those who have attained immortality through benefiting their kind.

The eldest child of Thomas Harvey and Joan Halke, he was born at Folkestone, Kent, on the 1st of April, 1578. In the printed accounts of the family, his father is styled gentleman; and upon referring to the register of William's matriculation at Cambridge, we find him designated a yeoman of Kent. He must have been a man of some substance and position, as all of his seven sons followed careers, and attained positions necessitating the possession of capital at the outset. Five of them, by name Thomas, Daniel, Eliab, Michael and Matthew, were merchants of repute in the city of London, and traded extensively with Turkey and the Levant. John, the second son, was at one time Member of Parliament for Hythe, and afterwards became King's Receiver for Lincolnshire, and Footman to His Majesty. There were two daughters, one of whom died young, and of the other nothing beyond her name is known.

Of Joan Halke, Harvey's mother, but little has been

preserved to us, and that little is derived from the inscription on a monumental slab in Folkestone Church. She is there described as having died in her 50th year, the mother of seven sons and two daughters. "A Godly harmles Woman: A chaste loveing Wife: A charitable quiet Neighbour: A co'fortable frendly Matron: A p'ovident diligent Huswyfe: A careful te'der-harted Mother. Deere to her Husband: Reverensed of her Children: Beloved of her Neighbours: Elected of God. Whose Soule Rest in Heaven: her Body in this Grave: To Her a Happy Advantage: To Hers an Unhappy Loss." Conjecture has attributed the authorship of the foregoing inscription to her son William.

At the age of ten Harvey entered the Grammar School of Canterbury, where he remained for five years. There he worked at the ordinary subjects of an English education, and acquired a good knowledge of Latin and Greek. This was essential at a time when the influence of authority was triumphant, and when even contemporary literature, to appear learned, must needs be expressed in Latin.

At sixteen we find him entered as a student at Caius-Gonvil College, Cambridge, where he spent the following three years in the study of classics, dialectics and physics. Such a course of training was then, as now, considered a fitting prelude to the study of the science and art of medicine. In 1597, being then nineteen years of age, he was made a Bachelor of Arts of his university. At that time, and indeed until quite recently, the University of Cambridge was in a very different position with regard to the teaching of medicine from what we now find. Divinity was its chief glory, and the well equipped medical school of the present was almost unrepresented, one or two professorships only being devoted to medical subjects.

As a consequence, it was the almost universal practice

in England for the intending physician to commence his studies at the University, and after having obtained his degree in arts, to prosecute his more purely medical studies on the Continent. The great medical schools of the time were those of Montpellier and Padua. Among the professors at the University of Padua were such men as Fabricius of Aquapendente,[1] and Julius Casserius, names which have come down to us as among the most renowned in medicine and surgery of the time. Of the fame of Padua's university we have much contemporary and later evidence, The writer of the "Accomplisht Physician," published in 1670, in sketching the course of the medical student, suggests that he should visit Padua, with its famous Hospital of San Lorenzo, and observe the Italian method of curing diseases by means of alterative broths, without having resort to bleeding or purging; certainly a very advanced method of treatment when compared with the too often harmful and cruel methods then prevalent among the more ignorant practitioners of the art. When the student had resided at Padua for the necessary period, our author suggests that he might then "justly aspire to a degree of Doctor in Physic, which the fame of the place should persuade him to take here, being the Imperial University for Physic of all others in the world, and where physicians pass a very exact scrutiny and severe test."

The course suggested by the "Accomplisht Physician," although published seventy-three years later, was indeed the one followed by Harvey; for we find him at Padua in 1597, enrolled under Fabricius, and doubtless attending

[1] Fabricius was consulted, in conjunction with Spigelio, a most renowned surgeon, by the Council of Ten when the famous Fra Paolo, spiritual adviser to the Republic of St. Mark, was stabbed at Venice on the 5th October, 1607. Fabricius was rewarded on the recovery of Fra Paolo by being knighted, and presented with a silver cup weighing thirty ounces, with a winged lion of St. Mark engraved upon it.

with wrapt attention to that celebrated anatomist, as he unfolded his views on the anatomy of the human body, and drew special notice to his labours on the position and structure of the valves in the veins. There can be little doubt that the seed then sown fell into suitable soil, and that to Fabricius we owe the awakening of the spirit of enquiry and observation which ended only with Harvey's life, but which, in its course, enriched the world of knowledge and of thought with one of its grandest generalizations.

When twenty-four years of age, having resided five years at Padua, he obtained the diploma of Doctor of Physic, with the licence of its University to practise and to teach the arts and medicine in every land and seat of learning. The same year he returned to England, and received the degree of Doctor of Medicine from his Alma Mater, the University of Cambridge. Two years later he married the daughter of Dr. Lancelot Brown, a well known physician, and settled to the practice of his profession in London. In 1607 he was chosen a Fellow of the College of Physicians of London.

We next hear of Harvey successfully applying, in 1609, for the reversion of the office of physician to St. Bartholomew's Hospital, then held by Dr. Wilkinson. He supported his application by King's letters recommendatory to the governors, and by a testimonial, among others, from Dr. Adkinson, President of the College of Physicians. Upon the death of Dr. Wilkinson, in the same year, Harvey was at first appointed to discharge his duties, and soon afterwards to fill the vacant post. For the next six years we hear little of him, his time being much taken up with the practice of his profession. That he was successful we cannot doubt, as he numbered among his patients such men of light and leading as Lord Chancellor Bacon, and Thomas Howard Earl of Arundel.

The year 1615 was an important one in Harvey's life, for it was then he was appointed by the College of Physicians

to deliver the lectures on anatomy and surgery, which had been founded by Dr. Richard Caldwall. In all probability almost from the first he described his views upon the circulation, for although his work on the motion of the heart and blood was not published until 1628, yet he tells us in his preface that he had been demonstrating his views for more than nine years.

Soon afterwards he must have been appointed Physician Extraordinary to the King, with the promise of Physician-in-Ordinary when it should occur. The latter position, however, he did not attain until after the death of James I., and until Charles had reigned five or six years. When it did come, his position must have been a very distinguished one. He was in close connection with the Court, and the King was interested in, and sympathized with, the investigations of his physician. On several occasions he inspected his preparations, and witnessed the dissection of some of the does supplied out of the royal forests.

In 1628 Harvey published his modest volume of eighty pages at Frankfort, in which he deals with the movement of the heart and blood. It immediately curtailed his practice as a fashionable physician; Aubrey tells us that he had heard Harvey say: "that after his book on the 'Circulation of the Blood' came out, he fell mightily in his practice; 'twas believed by the vulgar that he was crackbrained, and all the physitians were against him." Even years afterwards, the same chronicler says that "though all his profession would allow him to be an excellent anatomist, I never heard any that admired his therapeutique way. I knew several practitioners in this town that would not have given threepence for one of his bills (prescriptions) and (who said) that a man could hardly tell by his bills what he did aim at." That he should suffer detraction at the hands of the more ignorant of his profession, is in accordance with all precedent, and it can scarcely surprise us to

learn that even the intelligent section of the public should lack confidence in so bold an innovator.

Having held the office of Treasurer to the College of Physicians, he resigned it in 1629. The following year he was appointed to accompany the young Duke of Lennox in his "travels beyond seas." Nothing appears to be known as to the places visited in this journey, but it is probable that it occupied over two years. In 1632 Harvey had returned to England, and was appointed physician-in-ordinary to Charles I. The following year he accompanied the king on his first visit to his Scottish dominion, and we find the surgeons of St. Bartholomew's Hospital complaining of the absence of their colleague "by reason of his attendance on the king's majesty." The Governors of the Hospital appointed Dr. Andrews his substitute, but "without prejudice to him in his yearly fee or in any other respect."

In 1636 Thomas Howard Earl of Arundel was dispatched on an embassy to the Emperor. Harvey, who was his private physician, accompanied him, and in this manner had an opportunity of visiting many of the principal cities of Germany, and of making the acquaintance of the leaders of his profession in that country. To Caspar Hofman, one of the most obstinate of his opponents, he wrote offering to give a public demonstration of the anatomical particulars upon which his theory of the circulation of the blood was founded. This demonstration was actually carried out in Nuremberg to the satisfaction of all present excepting Hofman. It is related that as Hofman continued to urge the most futile objections, Harvey, recognizing further argument to be useless, laid down his scalpel and retired. Slegel, in his "Commentary on the Motion of the Blood," published at Hamburg in 1650, says, that although he tried to convince Hofman of the circulation of the blood, it was in vain, and he died an unbeliever of its truth.

When Charles advanced at the head of an expeditionary force into Scotland in 1639, to allay with the sword the religious discontent prevailing there, Harvey, in virtue of his office, accompanied his royal master. An arrangement having been made, he returned to the capital, again to accompany Charles in the following year against the Covenanters of that country. He was with the King at York when the royal forces suffered the reverse at Newburn. During the complications between Charles and his parliament, Harvey remained in attendance upon the King, and although the relations between the monarch and the representatives of his subjects were of a most critical nature, yet parliament specially desired Harvey to continue in his care of the royal person. The battle of Edgehill soon afterwards followed, and if the account given by Aubrey be correct, Harvey felt little solicitude at its result. He says: "When King Charles by reason of the tumults left London he (Harvey) attended him, and was at the fight of Edge-hill with him; and during the fight the Prince and Duke of York were committed to his care. He told me he withdrew with them under a hedge, and tooke out of his pockett a booke and read. But he had not read very long before a bullet of a Great Gun grazed on the ground near him which made him remove his station." His two boy companions by the hedgeside were afterwards Charles II. and James II. There can be no doubt of Harvey's attachment to his Sovereign, but his philosophical studies were evidently more absorbing of his interest than the contentions of rival political factions. Most likely the book which proved so fascinating to the discoverer of the circulation, as he sat by the hedge on the battlefield on that cold Sunday in October, was his favourite "Fabricius' Treatise upon Generation," for we find that a few days after the battle he accompanied the King and the remnants of his army to Oxford, and there,

says Aubrey, "I remember he came several times to our college (Trinity) to George Bathurst, B.D., who had a hen to hatch eggs in his chamber, which they opened daily to see the progress and way of generation." At Oxford such a man as Harvey was likely to be well received; at once a king's physician, and author of a far-reaching discovery. Nor was the City of Colleges untrue to itself, for during the years the King made it the seat of his Court and the headquarters of his army Harvey was entertained and received with becoming dignity. The honorary degree of Doctor of Physic was conferred upon him. Merton College being deprived of its Warden owing to Sir Nathaniel Brent joining the popular party, Harvey was elected in his place at the suggestion, it has been said, of John Greaves, the learned antiquary and mathematician, and upon the special recommendation of the King. But his tenure of the Wardenship of Merton was of short duration, as upon the flight of the King and the surrender of the city in the following year to the parliamentary forces, Sir Nathaniel Brent again took possession of the College, and Harvey returned to London.

The four years of civil war with their antecedent years of political strife, no doubt contributed to make Harvey long for a more restful life, and for more congenial pursuits. At the age of sixty-eight he quitted for ever the service of the King, and sought privacy and leisure in the houses of his brothers. At the residence of Eliab, in the city, and at Roehampton, and in those of Daniel at Combe, near Croydon, in Surrey, and in the then suburban village of Lambeth, he had his own apartments, and occupied himself in composing his work on Generation. Nor was he too feeble at the age of seventy-one to undertake, in company with his accomplished friend Dr. Ent, a visit to the Continent, during which they went as far as Italy.

In 1651, when seventy-three years of age, he published

his great work on Animal Generation. The following year the College of Physicians determined to place his statue in their hall, emphasizing the general opinion that in Harvey they had the most distinguished Anatomist and Physician of his age. Harvey, about the same time, commenced the erection, at his own cost, of a very handsome addition to the college buildings. According to Aubrey it was "a noble building of Roman Architecture (of rustic work with Corinthian pilasters), comprising a great parlour, a kind of convocation house for the fellows to meet in below, and a library above." The library he furnished with books, and the museum he enriched with many specimens.

The great fire of 1666 spared little in its reckless course, and the college buildings of the physicians, with the Harveian library, parlour, statue, and all were engulfed by the destroying angel.

In 1654, at the unanimous desire of the fellows, Harvey was offered the Presidency of the College of Physicians; but on the score of failing health, and advancing years, he gracefully declined the honour of filling the foremost place among the physicians of England, and begged to propose the late president for re-election, which was at once ratified.

Although still retaining his mental activity, and continuing to lecture until within a year or two of his death, accumulating years, and frequent attacks of gout, began to make serious inroads on his health. On the 3rd of June, 1657, Aubrey tells us that at ten in the morning he found, upon attempting to speak, that he had lost the power of utterance. He was quite conscious, and feeling that his end was approaching, he sent for his nephews, and to each gave something as a memento. To Sambroke, his apothecary, he made signs to let blood for him in the tongue, without, however, any benefit; and on the evening of the same day the great soul of William Harvey took its easy flight. All that remained of him was placed in his

brother Eliab's vault in Hempstead, in Essex, and on his breast, in great letters they placed his name, DR. WILLIAM HARVEY.

So lived and so died William Harvey, whose labours in the cause of truth, and whose discoveries in the domain of physical science, must ever keep him fresh in the memory of every student of nature. From the few facts of his life which have come down to us, and which we treasure all the more because of their scarcity, we are able to form some idea of the man, although only in outline.

He was of small stature, nervous, energetic, and full of spirit. His temples and cheeks slightly hollowed; a full and thoughtful forehead; a penetrating, calm, contemplative dark round eye; lips slightly curved, determined and sensitive; just the slightest tinge of melancholy over his round olive-coloured face, backed by wavy locks of raven hue, but white for the last twenty years of his life; these make up a description quite in accordance with all that we know of his person. Simple and modest, with an aversion for pomp and circumstance, he lived on terms of the closest affection with his brothers and friends. The most cursory perusal of his works cannot fail to impress us that his mind, naturally bright, had been quickened by persistent cultivation. At once profoundly religious, and a student of nature; imaginative and laborious in the collection of facts; inquisitive and eager in the acquirement of knowledge; these characteristics were so proportioned and arranged as to constitute a singularly brilliant mind.

That he was subject to some of the weaknesses that afflict humanity, who can doubt? But from none having reached us, we may fairly enough conclude tbat they were few and slight, and amply redeemed by his nobler qualities. In him we trace the best qualities of the Englishman of his time, and we would fain hope of all time. Sincerity, manliness, patience and forbearance, were united with a

dauntless love of fact, and the power of lofty generalization. His logical mind was prepared to follow truth wherever it should lead him, and his great induction in the physics of the animal body was the reward.

Of his works but little need be here said. As has been previously remarked, he had sufficiently elaborated his views on the circulation to present them to his class so early as 1616. There is good reason for believing that he wrote his treatise on the subject before 1619, but its publication was delayed until 1628. Of the reasons for the delay we are not left in doubt, for even in 1628 he is apprehensive lest its appearance make "mankind his enemy." In 1620 Lord Bacon had published his "Novum Organum," advocating the principles upon which Harvey's induction had been built up: doubtless, the favourable reception accorded to the work of England's great chancellor, did much to encourage the modest Harvey in giving his small book to the world.

In an age of enquiry it is difficult to realize what must have been Harvey's struggles before he completely threw off the influence of authority; the manner in which he convicts the "divine Galen" of fallacious reasoning, leaves no doubt as to his solicitude in the matter.

The chief points in Harvey's induction were (1) that the blood moved in a ceaseless stream, as it were in a circle, and (2) that the heart was the great propelling power.

If we examine the views held about the circulation, before the appearance of Harvey's book, we shall find that the veins were regarded as the principal vessels of the body, and they only were believed to contain true blood. The arteries were supposed to contain only a little blood mixed with vital spirits, of which they were the channels. The liver was held to be the origin of all the veins, and the heart was regarded as the generator of vital spirits, and of heat, in addition to its being a chief cistern of the blood.

The blood was believed to be propelled by the act of inspiration, and its flow to any part of the body determined by special excitation. When Vesalius asserted that the vena cava arose from the heart, he was opposed by the greatest anatomists of his day—such great authorities as Jacobus Sylvius, Rialdus Columbus, Bartholomæus Eustachius, and Gabriel Falopius, maintaining that it arose from the liver. The pulse was thought to result from the contraction and dilatation of the arteries upon a mixture of blood and air. The air within the arteries was replenished by means of suction, the dilatation and contraction of the vessels being analogous to the action of a pair of bellows. There was thus an imaginary respiration all over the body, with the addition of lungs around the heart for the better "ventilation and refrigeration of the blood."

That the blood moved, was known previously to Harvey's time, but the discovery that its motion is in a circle is entirely Harvey's. The functions of the tricuspid valves, and those at the orifices of the aorta and pulmonary artery, had been settled by Berengarius of Carpi. Fabricius had for many years worked at, and perfected the knowledge of the valves in the veins. Berengarius in 1521, and Vesalius in 1555, had both shown that the septum dividing the two sides of the heart was unpermeable, and the passage of the blood through that muscular partition being proved to be impossible, Michael Servitus appeared upon the scene with the suggestion that the blood from the right side of the heart, in order to get into the left side, had to traverse the lungs. This has been called the lesser circulation. But in making the suggestion, Servitus had before him no anatomical evidence of the possibility of such a transit; and the only credit due to him is that of having made a very happy guess, but one which did not advance the explanation further.

Rialdus Columbus recognized the true action of the valves

at the orifices of the vessels in the heart, and supported the probability of the lesser circulation with more reason than Servitus. But his anatomical and physiological convictions could never permit him to make any larger generalization. He believed the vena cava to arise from the liver, and to fulfil all the functions of taking nutrient blood to the stomach, black bile to the spleen, nourishment to the intestines, and nutritive matter from the intestines to the liver, to be there elaborated into blood; truly a variety of functions to be carried on in one channel, and in opposite directions. Columbus denied the muscular nature of the heart. Andreas Cæsalpinus, of Arezzo, went considerably farther, not only asserting from the anatomical arrangement of the valves of the heart that there must be a passage for the blood through the lungs; but also recognizing the true nature of the pulmonary artery, previously called arteria venosa, which he demonstrated to be a true artery, and analogous in structure and function to the aorta. Cæalpinus certainly seems to have discovered that the blood moved in the veins, and in one direction only. Had it not been for preconceived notions, he might have reached what he certainly was in measurable distance of, but we find him believing in the permeability of the septum of the heart, and discussing the flux and reflux of the blood in the most approved Galenic style. His explanation of the blood distending the veins on the farther side of a ligature, which compresses them, was that the blood was afraid lest it should be cut off and suffocated.

Coming to our own country, does not Shakespeare make Brutus say to Portia:—

> "You are my true and honourable wife,
> As dear to me as are the ruddy drops
> That visit my sad breast;"

But neither Shakespeare, nor Cæsalpinus, nor Servitus, dreamt of the great principle of the blood's movement, nor

did others discover it until William Harvey demonstrated its necessary truth.

That there is one blood stream, common to both arteries and veins, that the blood poured into the right auricle, passes into the right ventricle, that it is from there forced by the contraction of the ventricular walls along the pulmonary artery through the lungs and pulmonary veins to the left auricle, that it then passes into the left ventricle to be distributed through the aorta to every part of the animal body: and that the heart is the great propellor of this perpetual motion, as in a circle; this is the great truth of the motion of the heart and blood, commonly called the circulation, and must for ever remain the glorious legacy of William Harvey to rational physiology and medicine in every land.

A. B.

London, *April*, 1889.

The following explanations of some technical terms which occur in this Treatise may be found useful to non-professional readers.

Anastomosis, the communication of branches of blood-vessels or of one blood-vessel with each other.

Aorta, the large artery which arises from the left ventricle of the heart, and which conveys the blood for general distribution over the body.

Arteria venosa, the pulmonary vein.

Arteriotomy, the dividing or opening into an artery.

Auricle, one of the two chambers at the base of the heart.

Bronchia, the tubes formed by the division of the windpipe, and which convey the air to the lung cells.

Cava—see *vena Cavæ*.

Chylopoietic, connected with the formation of chyle.

Cœliac, belonging to the stomach, or lower portion of the abdomen.

Coronary, applied to the blood-vessels of the heart, because they encircle the part like a crown.

Diastole, the dilatation of the heart or arteries.

Empyema, a collection of matter in the cavity of the chest.

Emulgent, applied to the vessels of the kidneys, from their supposed straining action.

Furuncle, a boil, or inflammatory swelling.

Gastric, belonging to the stomach.

Gastro-epiploic, applied to blood-vessels supplying the stomach and omentum.

Iliac, connected with the flanks.

Lipothymia, the sensation of fainting or syncope.

Mesenteric, belonging to that part of the peritoneum which covers the small intestines.

Mitral, applied to the valves between the left ventricle and left auricle, because of their shape resembling a mitre.

Parietes, the walls or sides of any cavity.

Pathology, that branch of medicine which treats of the nature and effects of diseases.

Phlebotomy, the operation of blood-letting by opening a vein.

Phlegmon, acute inflammation of the tissue immediately under the skin, generally ending in suppuration.

Physiology, the study of the laws of life and the nature and functions of the animal body.

Pulmonary, connected with the lungs.

Semeiotics, the observation of the symptoms of disease.
Semilunar valves, the three half-moon shaped valves placed at the entrance of the aorta and of the pulmonary artery.
Systole, the contraction of the heart, by which the blood is forced into the arteries.
Tabes, wasting of the body.
Therapeutics, the study of the action of drugs and their application to the treatment of disease.
Thorax, the chest.
Trachea, the windpipe.
Tricuspid valve, the valve which is placed at the opening of the right auricle into the right ventricle.
Vena arteriosa, the pulmonary artery.
Venæ cavæ, the two terminations of the general venous system which open into the right auricle.
Ventricle, one of the two cavities of the heart, which form its body; also applied to spaces in the brain.
Villi, small projections like the pile of velvet.

AN ANATOMICAL DISQUISITION

ON THE

MOTION OF THE HEART AND BLOOD

IN ANIMALS.

TO

THE MOST ILLUSTRIOUS AND INDOMITABLE PRINCE,

CHARLES,

KING OF GREAT BRITAIN, FRANCE, AND IRELAND,

DEFENDER OF THE FAITH.

MOST ILLUSTRIOUS PRINCE!

THE heart of animals is the foundation of their life, the sovereign of everything within them, the sun of their microcosm, that upon which all growth depends, from which all power proceeds. The King, in like manner, is the foundation of his kingdom, the sun of the world around him, the heart of the republic, the fountain whence all power, all grace doth flow. What I have here written of the motions of the heart I am the more emboldened to present to your Majesty, according to the custom of the present age, because almost all things human are done after human examples, and many things in a King are after the pattern of the heart. The knowledge of his heart, therefore, will not be useless to a Prince, as embracing a kind of Divine example of his functions,—and it has ever been usual with men to compare small things with great. Here, at all events, best of Princes, placed as you are on the pinnacle of human affairs, you may at once contemplate the prime mover in the body of man, and the emblem of your own sovereign power. Accept therefore, with your wonted clemency, I most humbly beseech you, illustrious Prince, this, my new Treatise on the Heart;

you, who are yourself the new light of this age, and indeed its very heart; a Prince abounding in virtue and in grace, and to whom we gladly refer all the blessings which England enjoys, all the pleasure we have in our lives.

Your Majesty's most devoted servant,

WILLIAM HARVEY.

[LONDON . . . .
1628.]

To his very dear Friend, Doctor Argent, the excellent and accomplished President of the Royal College of Physicians, and to other learned Physicians, his most esteemed Colleagues.

I have already and repeatedly presented you, my learned friends, with my new views of the motion and function of the heart, in my anatomical lectures; but having now for more than nine years confirmed these views by multiplied demonstrations in your presence, illustrated them by arguments, and freed them from the objections of the most learned and skilful anatomists, I at length yield to the requests, I might say entreaties, of many, and here present them for general consideration in this treatise.

Were not the work indeed presented through you, my learned friends, I should scarce hope that it could come out scatheless and complete; for you have in general been the faithful witnesses of almost all the instances from which I have either collected the truth or confuted error. You have seen my dissections, and at my demonstrations of all that I maintain to be objects of sense, you have been accustomed to stand by and bear me out with your testimony. And as this book alone declares the blood to course and revolve by a new route, very different from the ancient and beaten pathway trodden for so many ages, and illustrated by such a host of learned and distinguished men, I was greatly afraid lest I might be charged with presumption did I lay my work before the public at home, or send it beyond seas for impression, unless I had first proposed its subject to you, had confirmed its conclusions by ocular demonstrations in your presence, had replied to your doubts and objections, and secured the assent and support of our distinguished President. For I was most

intimately persuaded, that if I could make good my proposition before you and our College, illustrious by its numerous body of learned individuals, I had less to fear from others. I even ventured to hope that I should have the comfort of finding all that you had granted me in your sheer love of truth, conceded by others who were philosophers like yourselves. True philosophers, who are only eager for truth and knowledge, never regard themselves as already so thoroughly informed, but that they welcome further information from whomsoever and from wheresoever it may come; nor are they so narrow-minded as to imagine any of the arts or sciences transmitted to us by the ancients, in such a state of forwardness or completeness, that nothing is left for the ingenuity and industry of others. On the contrary, very many maintain that all we know is still infinitely less than all that still remains unknown; nor do philosophers pin their faith to others' precepts in such wise that they lose their liberty, and cease to give credence to the conclusions of their proper senses. Neither do they swear such fealty to their mistress Antiquity, that they openly, and in sight of all, deny and desert their friend Truth. But even as they see that the credulous and vain are disposed at the first blush to accept and to believe everything that is proposed to them, so do they observe that the dull and unintellectual are indisposed to see what lies before their eyes, and even deny the light of the noonday sun. They teach us in our course of philosophy to sedulously avoid the fables of the poets and the fancies of the vulgar, as the false conclusions of the sceptics. And then the studious, and good, and true, never suffer their minds to be warped by the passions of hatred and envy, which unfit men duly to weigh the arguments that are advanced in behalf of truth, or to appreciate the proposition that is even fairly demonstrated. Neither do they think it unworthy of them to change their opinion if truth and undoubted demonstration require them to do so. They do not esteem it discreditable to desert error, though sanctioned by the highest antiquity, for they know full well that to err, to be deceived, is human; that many things are discovered by accident, and that many may be learned indifferently from any quarter, by

an old man from a youth, by a person of understanding from one of inferior capacity.

My dear colleagues, I had no purpose to swell this treatise into a large volume by quoting the names and writings of anatomists, or to make a parade of the strength of my memory, the extent of my reading, and the amount of my pains; because I profess both to learn and to teach anatomy, not from books but from dissections; not from the positions of philosophers but from the fabric of nature; and then because I do not think it right or proper to strive to take from the ancients any honour that is their due, nor yet to dispute with the moderns, and enter into controversy with those who have excelled in anatomy and been my teachers. I would not charge with wilful falsehood anyone who was sincerely anxious for truth, nor lay it to anyone's door as a crime that he had fallen into error. I avow myself the partisan of truth alone; and I can indeed say that I have used all my endeavours, bestowed all my pains on an attempt to produce something that should be agreeable to the good, profitable to the learned, and useful to letters.

Farewell, most worthy Doctors,

And think kindly of your Anatomist,

WILLIAM HARVEY.

AN ANATOMICAL DISQUISITION

ON THE

MOTION OF THE HEART AND BLOOD IN ANIMALS.

INTRODUCTION.

As we are about to discuss the motion, action, and use of the heart and arteries, it is imperative on us first to state what has been thought of these things by others in their writings, and what has been held by the vulgar and by tradition, in order that what is true may be confirmed, and what is false set right by dissection, multiplied experience, and accurate observation.

Almost all anatomists, physicians, and philosophers, up to the present time, have supposed, with Galen, that the object of the pulse was the same as that of respiration, and only differed in one particular, this being conceived to depend on the animal, the respiration on the vital faculty; the two, in all other respects, whether with reference to purpose or to motion, comporting themselves alike. Whence it is affirmed, as by Hieronymus Fabricius of Aquapendente, in his book on "Respiration," which has lately appeared, that as the pulsation of the heart and arteries does not suffice for the ventilation and refrigeration of the blood, therefore were the lungs fashioned to surround the heart. From this it appears, that whatever has hitherto been said upon the systole and diastole, or on the motion of the heart and arteries, has been said with especial reference to the lungs.

But as the structure and movements of the heart differ from those of the lungs, and the motions of the arteries from those of the chest, so it seems likely that other ends and offices will thence arise, and that the pulsations and uses of the heart, likewise of the arteries, will differ in many respects from the heavings and uses of the chest and lungs. For did the arterial pulse and the respiration serve the same ends; did the arteries in their diastole take air into their cavities, as commonly stated, and in their systole emit fuliginous vapours by the same pores of the flesh and skin; and further, did they, in the time intermediate between the diastole and the systole, contain air, and at all times either air, or spirits, or fuliginous vapours, what should then be said to Galen, who wrote a book on purpose to show that by nature the arteries contained blood, and nothing but blood, and consequently neither spirits nor air, as may be readily gathered from the experiments and reasonings contained in the same book? Now if the arteries are filled in the diastole with air then taken into them (a larger quantity of air penetrating when the pulse is large and full), it must come to pass, that if you plunge into a bath of water or of oil when the pulse is strong and full, it ought forthwith to become either smaller or much slower, since the circumambient bath will render it either difficult or impossible for the air to penetrate. In like manner, as all the arteries, those that are deep-seated as well as those that are superficial, are dilated at the same instant, and with the same rapidity, how is it possible that air should penetrate to the deeper parts as freely and quickly through the skin, flesh, and other structures, as through the cuticle alone? And how should the arteries of the fœtus draw air into their cavities through the abdomen of the mother and the body of the womb? And how should seals, whales, dolphins and other cetaceans, and fishes of every description, living in the depths of the sea, take in and emit air by the diastole and systole of their arteries through the infinite mass of waters? For to say that they absorb the air that is present in the water, and emit their fumes into this medium, were to utter something very like a figment. And if the arteries in their systole expel fuliginous vapours

from their cavities through the pores of the flesh and skin, why not the spirits, which are said to be contained in these vessels, at the same time, since spirits are much more subtile than fuliginous vapours or smoke? And if the arteries take in and cast out air in the systole and diastole, like the lungs in the process of respiration, why do they not do the same thing when a wound is made in one of them, as in the operation of arteriotomy? When the windpipe is divided, it is sufficiently obvious that the air enters and returns through the wound by two opposite movements; but when an artery is divided, it is equally manifest that blood escapes in one continuous stream, and that no air either enters or issues. If the pulsations of the arteries fan and refrigerate the several parts of the body as the lungs do the heart, how comes it, as is commonly said, that the arteries carry the vital blood into the different parts, abundantly charged with vital spirits, which cherish the heat of these parts, sustain them when asleep, and recruit them when exhausted? How should it happen that, if you tie the arteries, immediately the parts not only become torpid, and frigid, and look pale, but at length cease even to be nourished? This, according to Galen, is because they are deprived of the heat which flowed through all parts from the heart, as its source; whence it would appear that the arteries rather carry warmth to the parts than serve for any fanning or refrigeration. Besides, how can their diastole draw spirits from the heart to warm the body and its parts, and means of cooling them from without? Still further, although some affirm that the lungs, arteries, and heart have all the same offices, they yet maintain that the heart is the workshop of the spirits, and that the arteries contain and transmit them; denying, however, in opposition to the opinion of Columbus, that the lungs can either make or contain spirits. They then assert, with Galen, against Erasistratus, that it is blood, not spirits, which is contained in the arteries.

These opinions are seen to be so incongruous and mutually subversive, that every one of them is justly brought under suspicion. That it is blood and blood alone which is contained in the arteries is made manifest by the

experiment of Galen, by arteriotomy, and by wounds; for from a single divided artery, as Galen himself affirms in more than one place, the whole of the blood may be withdrawn in the course of half an hour, or less. The experiment of Galen alluded to is this: "If you include a portion of an artery between two ligatures, and slit it open lengthways, you will find nothing but blood;" and thus he proves that the arteries contain blood only. And we too may be permitted to proceed by a like train of reasoning: if we find the same blood in the arteries as in the veins, after having tied them in the same way, as I have myself repeatedly ascertained, both in the dead body and in living animals, we may fairly conclude that the arteries contain the same blood as the veins, and nothing but the same blood. Some, whilst they attempt to lessen the difficulty, affirm that the blood is spirituous and arterious, and virtually concede that the office of the arteries is to carry blood from the heart into the whole of the body, and that they are therefore filled with blood; for spirituous blood is not the less blood on that account. And no one denies that the blood as such, even the portion of it which flows in the veins, is imbued with spirits. But if that portion which is contained in the arteries be richer in spirits, it is still to be believed that these spirits are inseparable from the blood, like those in the veins; that the blood and spirits constitute one body (like whey and butter in milk, or heat in hot water), with which the arteries are charged, and for the distribution of which from the heart they are provided. This body is nothing else than blood. But if this blood be said to be drawn from the heart into the arteries by the diastole of these vessels, it is then assumed that the arteries by their distension are filled with blood, and not with the surrounding air, as heretofore; for if they be said also to become filled with air from the ambient atmosphere, how and when, I ask, can they receive blood from the heart? If it be answered: during the systole, I take it to be impossible; the arteries would then have to fill while they contracted, to fill, and yet not become distended. But if it be said: during the diastole, they would then, and for two opposite purposes, be receiving both blood and air, and heat and cold, which is impro-

bable. Further, when it is affirmed that the diastole of the heart and arteries is simultaneous, and the systole of the two is also concurrent, there is another incongruity. For how can two bodies mutually connected, which are simultaneously distended, attract or draw anything from one another; or, being simultaneously contracted, receive anything from each other? And then, it seems impossible that one body can thus attract another body into itself, so as to become distended, seeing that to be distended is to be passive, unless, in the manner of a sponge, which has been previously compressed by an external force, it is returning to its natural state. But it is difficult to conceive that there can be anything of this kind in the arteries. The arteries dilate, because they are filled like bladders or leathern bottles; they are not filled because they expand like bellows. This I think easy of demonstration, and indeed conceive that I have already proved it. Nevertheless, in that book of Galen headed "Quod Sanguis continetur in Arteriis," he quotes an experiment to prove the contrary: An artery having been exposed, is opened longitudinally, and a reed or other pervious tube is inserted into the vessel through the opening by which the blood is prevented from being lost, and the wound is closed. "So long," he says, "as things are thus arranged, the whole artery will pulsate; but if you now throw a ligature about the vessel and tightly compress its walls over the tube, you will no longer see the artery beating beyond the ligature." I have never performed this experiment of Galen's, nor do I think that it could very well be performed in the living body, on account of the profuse flow of blood that would take place from the vessel which was operated on; neither would the tube effectually close the wound in the vessel without a ligature; and I cannot doubt but that the blood would be found to flow out between the tube and the vessel. Still Galen appears by this experiment to prove both that the pulsative property extends from the heart by the walls of the arteries, and that the arteries, whilst they dilate, are filled by that pulsific force, because they expand like bellows, and do not dilate as if they are filled like skins. But the contrary is obvious in arteriotomy and in wounds; for

the blood spurting from the arteries escapes with force, now farther, now not so far, alternately, or in jets; and the jet always takes place with the diastole of the artery, never with the systole. By which it clearly appears that the artery is dilated by the impulse of the blood; for of itself it would not throw the blood to such a distance, and whilst it was dilating; it ought rather to draw air into its cavity through the wound, were those things true that are commonly stated concerning the uses of the arteries. Do not let the thickness of the arterial tunics impose upon us, and lead us to conclude that the pulsative property proceeds along them from the heart. For in several animals the arteries do not apparently differ from the veins; and in extreme parts of the body, where the arteries are minutely subdivided, as in the brain, the hand, etc., no one could distinguish the arteries from the veins by the dissimilar characters of their coats; the tunics of both are identical. And then, in an aneurism proceeding from a wounded or eroded artery, the pulsation is precisely the same as in the other arteries, and yet it has no proper arterial covering. To this the learned Riolanus testifies along with me, in his Seventh Book.

Nor let any one imagine that the uses of the pulse and the respiration are the same, because, under the influence of the same causes, such as running, anger, the warm bath, or any other heating thing, as Galen says, they become more frequent and forcible together. For, not only is experience in opposition to this idea, though Galen endeavours to explain it away, when we see that with excessive repletion the pulse beats more forcibly, whilst the respiration is diminished in amount; but in young persons the pulse is quick, whilst respiration is slow. So is it also in alarm, and amidst care, and under anxiety of mind; sometimes, too, in fevers, the pulse is rapid, but the respiration is slower than usual.

These and other objections of the same kind may be urged against the opinions mentioned. Nor are the views that are entertained of the offices and pulse of the heart, perhaps, less bound up with great and most inextricable difficulties. The heart, it is vulgarly said, is the fountain and workshop of the vital spirits, the centre from which

life is dispensed to the several parts of the body. Yet it is denied that the right ventricle makes spirits, which is rather held to supply nourishment to the lungs. For these reasons it is maintained that fishes are without any right ventricle (and indeed every animal wants a right ventricle which is unfurnished with lungs), and that the right ventricle is present solely for the sake of the lungs.

1. Why, I ask, when we see that the structure of both ventricles is almost identical, there being the same apparatus of fibres, and braces, and valves, and vessels, and auricles, and both in the same way in our dissections are found to be filled up with blood similarly black in colour, and coagulated—why, I say, should their uses be imagined to be different, when the action, motion, and pulse of both are the same? If the three tricuspid valves placed at the entrance into the right ventricle prove obstacles to the reflux of the blood into the vena cava, and if the three semilunar valves which are situated at the commencement of the pulmonary artery be there, that they may prevent the return of the blood into the ventricle; why, when we find similar structures in connexion with the left ventricle, should we deny that they are there for the same end, of preventing here the egress, there the regurgitation of the blood?

2. And, when we have these structures, in point of size, form, and situation, almost in every respect the same in the left as in the right ventricle, why should it be said that things are arranged in the former for the egress and regress of spirits, in the latter or right ventricle, for the blood? The same arrangement cannot be held fitted to favour or impede the motion of blood and of spirits indifferently.

3. And when we observe that the passages and vessels are severally in relation to one another in point of size, viz., the pulmonary artery to the pulmonary veins; why should the one be destined to a private purpose, that of nourishing the lungs, the other to a public function?

4. And, as Realdus Columbus says, is it probable that such a quantity of blood should be required for the nutrition of the lungs; the vessel that leads to them, the vena

arteriosa or pulmonary artery being of greater capacity than both the iliac veins?

5. And I ask, as the lungs are so close at hand, and in continual motion, and the vessel that supplies them is of such dimensions, what is the use or meaning of the pulse of the right ventricle? and why was nature reduced to the necessity of adding another ventricle for the sole purpose of nourishing the lungs?

When it is said that the left ventricle draws materials for the formation of spirits, air, and blood, from the lungs and right sinuses of the heart, and in like manner sends spirituous blood into the aorta, drawing fuliginous vapours from there, and sending them by the pulmonary vein into the lungs, whence spirits are at the same time obtained for transmission into the aorta, I ask how, and by what means, is the separation effected? And how comes it that spirits and fuliginous vapours can pass hither and thither without admixture or confusion? If the mitral cuspidate valves do not prevent the egress of fuliginous vapours to the lungs, how should they oppose the escape of air? And how should the semilunars hinder the regress of spirits from the aorta upon each supervening diastole of the heart? Above all, how can they say that the spirituous blood is sent from the pulmonary veins by the left ventricle into the lungs without any obstacle to its passage from the mitral valves, when they have previously asserted that the air entered by the same vessel from the lungs into the left ventricle, and have brought forward these same mitral valves as obstacles to its retrogression? Good God! how should the mitral valves prevent the regurgitation of air and not of blood?

Moreover, when they appoint the pulmonary artery, a vessel of great size, with the coverings of an artery, to none but a kind of private and single purpose, that, namely, of nourishing the lungs, why should the pulmonary vein, which is scarcely so large, which has the coats of a vein, and is soft and lax, be presumed to be made for many—three or four, different uses? For they will have it that air passes through this vessel from the lungs into the left ventricle; that fuliginous vapours escape by it from the heart into the lungs; and that a portion of the spirituous

blood is distributed to the lungs for their refreshment.

If they will have it that fumes and air—fumes flowing from, air proceeding towards the heart—are transmitted by the same conduit, I reply, that nature is not wont to construct but one vessel, to contrive but one way for such contrary motions and purposes, nor is anything of the kind seen elsewhere.

If fumes or fuliginous vapours and air permeate this vessel, as they do the pulmonary bronchia, wherefore do we find neither air nor fuliginous vapours when we divide the pulmonary vein? Why do we always find this vessel full of sluggish blood, never of air, whilst in the lungs we find abundance of air remaining?

If anyone will perform Galen's experiment of dividing the trachea of a living dog, forcibly distending the lungs with a pair of bellows, and then tying the trachea securely, he will find, when he has laid open the thorax, abundance of air in the lungs, even to their extreme investing tunic, but none in either the pulmonary veins, or left ventricle of the heart. But did the heart either attract air from the lungs, or did the lungs transmit any air to the heart, in the living dog, much more ought this to be the case in the experiment just referred to. Who, indeed, doubts that, did he inflate the lungs of a subject in the dissecting-room, he would instantly see the air making its way by this route, were there actually any such passage for it? But this office of the pulmonary veins, namely, the transference of air from the lungs to the heart, is held of such importance, that Hieronymus Fabricius of Aquapendente, contends that the lungs were made for the sake of this vessel, and that it constitutes the principal element in their structure.

But I should like to be informed why, if the pulmonary vein were destined for the conveyance of air, it has the structure of a blood-vessel here. Nature had rather need of annular tubes, such as those of the bronchia, in order that they might always remain open, and not be liable to collapse; and that they might continue entirely free from blood, lest the liquid should interfere with the passage of the air, as it so obviously does when the lungs labour from

being either greatly oppressed or loaded in a less degree with phlegm, as they are when the breathing is performed with a sibilous or rattling noise.

Still less is that opinion to be tolerated which, as a two-fold material, one aëreal, one sanguineous, is required for the composition of vital spirits, supposes the blood to ooze through the septum of the heart from the right to the left ventricle by certain hidden porosities, and the air to be attracted from the lungs through the great vessel, the pulmonary vein; and which consequently, will have it, that there are numerous porosities in the septum of the heart adapted for the transmission of the blood. But, by Hercules, no such pores can be demonstrated, nor in fact do any such exist. For the septum of the heart is of a denser and more compact structure than any portion of the body, except the bones and sinews. But even supposing that there were foramina or pores in this situation, how could one of the ventricles extract anything from the other —the left, *e.g.* obtain blood from the right, when we see that both ventricles contract and dilate simultaneously? Why should we not rather believe that the right took spirits from the left, than that the left obtained blood from the right ventricle, through these foramina? But it is certainly mysterious and incongruous that blood should be supposed to be most commodiously drawn through a set of obscure or invisible ducts, and air through perfectly open passages, at one and the same moment. And why, I ask, is recourse had to secret and invisible porosities, to uncertain and obscure channels, to explain the passage of the blood into the left ventricle, when there is so open a way through the pulmonary veins? I own it has always appeared extraordinary to me that they should have chosen to make, or rather to imagine, a way through the thick, hard, dense, and most compact septum of the heart, rather than take that by the open pulmonary vein, or even through the lax, soft, and spongy substance of the lungs at large. Besides, if the blood could permeate the substance of the septum, or could be imbibed from the ventricles, what use were there for the coronary artery and vein, branches of which proceed to the septum itself, to supply it with nourishment? And what is especially worthy of notice is

this: if in the fœtus, where everything is more lax and soft, nature saw herself reduced to the necessity of bringing the blood from the right into the left side of the heart by the foramen ovale, from the vena cava through the pulmonary vein, how should it be likely that in the adult she should pass it so commodiously, and without an effort, through the septum of the ventricles, which has now become denser by age?

Andreas Laurentius,[1] resting on the authority of Galen[2] and the experience of Hollerius, asserts and proves that the serum and pus in empyema,[3] absorbed from the cavities of the chest into the pulmonary vein, may be expelled and got rid of with the urine and fæces through the left ventricle of the heart and arteries. He quotes the case of a certain person affected with melancholia, and who suffered from repeated fainting fits, who was relieved from the paroxysms on passing a quantity of turbid, fetid, and acrid urine. But he died at last, worn out by the disease; and when the body came to be opened after death, no fluid like that he had micturated was discovered either in the bladder or in the kidneys; but in the left ventricle of the heart and cavity of the thorax plenty of it was met with. And then Laurentius boasts that he had predicted the cause of the symptoms. For my own part, however, I cannot but wonder, since he had divined and predicted that heterogeneous matter could be discharged by the course he indicates, why he could not or would not perceive, and inform us that, in the natural state of things, the blood might be commodiously transferred from the lungs to the left ventricle of the heart by the very same route.

Since, therefore, from the foregoing considerations and many others to the same effect, it is plain that what has heretofore been said concerning the motion and function of the heart and arteries must appear obscure, inconsistent or even impossible to him who carefully considers the entire subject, it will be proper to look more narrowly into the matter, to contemplate the motion of the heart and arteries, not only in man, but in all animals that have

[1] Lib. ix, cap. xi, quest. 12. [2] De Locis Affectis. lib. vi, cap. 7.

[3] [A disease of the chest characterized by the formation of pus in the pleural cavity.—Ed.]

hearts; and also, by frequent appeals to vivisection, and much ocular inspection, to investigate and discern the truth.

CHAPTER I.

THE AUTHOR'S MOTIVES FOR WRITING.

When I first gave my mind to vivisections, as a means of discovering the motions and uses of the heart, and sought to discover these from actual inspection, and not from the writings of others, I found the task so truly arduous, so full of difficulties, that I was almost tempted to think, with Fracastorius, that the motion of the heart was only to be comprehended by God. For I could neither rightly perceive at first when the systole and when the diastole took place, nor when and where dilatation and contraction occurred, by reason of the rapidity of the motion, which in many animals is accomplished in the twinkling of an eye, coming and going like a flash of lightning; so that the systole presented itself to me now from this point, now from that; the diastole the same; and then everything was reversed, the motions occurring, as it seemed, variously and confusedly together. My mind was therefore greatly unsettled, nor did I know what I should myself conclude, nor what believe from others. I was not surprised that Andreas Laurentius should have written that the motion of the heart was as perplexing as the flux and reflux of Euripus had appeared to Aristotle.

At length, and by using greater and daily diligence and investigation, making frequent inspection of many and various animals, and collating numerous observations, I thought that I had attained to the truth, that I should extricate myself and escape from this labyrinth, and that I had discovered what I so much desired, both the motion and the use of the heart and arteries. From that time I have not hesitated to expose my views upon these subjects, not only in private to my friends, but also in public, in my anatomical lectures, after the manner of the Academy of old.

These views, as usual, pleased some more, others less; some chid and calumniated me, and laid it to me as a crime that I had dared to depart from the precepts and opinion of all anatomists; others desired further explanations of the novelties, which they said were both worthy of consideration, and might perchance be found of signal use. At length, yielding to the requests of my friends, that all might be made participators in my labours, and partly moved by the envy of others, who, receiving my views with uncandid minds and understanding them indifferently, have essayed to traduce me publicly, I have been moved to commit these things to the press, in order that all may be enabled to form an opinion both of me and my labours. This step I take all the more willingly, seeing that Hieronymus Fabricius of Aquapendente, although he has accurately and learnedly delineated almost every one of the several parts of animals in a special work, has left the heart alone untouched. Finally, if any use or benefit to this department of the republic of letters should accrue from my labours, it will, perhaps, be allowed that I have not lived idly, and, as the old man in the comedy says:

> For never yet hath any one attained
> To such perfection, but that time, and place,
> And use, have brought addition to his knowledge;
> Or made correction, or admonished him,
> That he was ignorant of much which he
> Had thought he knew; or led him to reject
> What he had once esteemed of highest price.

So will it, perchance, be found with reference to the heart at this time; or others, at least, starting hence, with the way pointed out to them, advancing under the guidance of a happier genius, may make occasion to proceed more fortunately, and to inquire more accurately.

CHAPTER II.

OF THE MOTIONS OF THE HEART, AS SEEN IN THE DISSECTION OF LIVING ANIMALS.

In the first place, then, when the chest of a living animal is laid open and the capsule that immediately surrounds the heart is slit up or removed, the organ is seen now to move, now to be at rest;—there is a time when it moves, and a time when it is motionless.

These things are more obvious in the colder animals, such as toads, frogs, serpents, small fishes, crabs, shrimps, snails and shell-fish. They also become more distinct in warm-blooded animals, such as the dog and hog, if they be attentively noted when the heart begins to flag, to move more slowly, and, as it were, to die: the movements then become slower and rarer, the pauses longer, by which it is made much more easy to perceive and unravel what the motions really are, and how they are performed. In the pause, as in death, the heart is soft, flaccid, exhausted, lying, as it were, at rest.

In the motion, and interval in which this is accomplished, three principal circumstances are to be noted:

1. That the heart is erected, and rises upwards to a point, so that at this time it strikes against the breast and the pulse is felt externally.

2. That it is everywhere contracted, but more especially towards the sides, so that it looks narrower, relatively longer, more drawn together. The heart of an eel taken out of the body of the animal and placed upon the table or the hand, shows these particulars; but the same things are manifest in the hearts of small fishes and of those colder animals where the organ is more conical or elongated.

3. The heart being grasped in the hand, is felt to become harder during its action. Now this hardness proceeds from tension, precisely as when the forearm is grasped, its

tendons are perceived to become tense and resilient when the fingers are moved.

4. It may further be observed in fishes, and the colder blooded animals, such as frogs, serpents, etc., that the heart, when it moves, becomes of a paler colour, when quiescent of a deeper blood-red colour.

From these particulars it appeared evident to me that the motion of the heart consists in a certain universal tension—both contraction in the line of its fibres, and constriction in every sense. It becomes erect, hard, and of diminished size during its action; the motion is plainly of the same nature as that of the muscles when they contract in the line of their sinews and fibres; for the muscles, when in action, acquire vigour and tenseness, and from soft become hard, prominent and thickened: in the same manner the heart.

We are therefore authorized to conclude that the heart, at the moment of its action, is at once constricted on all sides, rendered thicker in its parietes and smaller in its ventricles, and so made apt to project or expel its charge of blood. This, indeed, is made sufficiently manifest by the preceding fourth observation in which we have seen that the heart, by squeezing out the blood it contains becomes paler, and then when it sinks into repose and the ventricle is filled anew with blood, that the deeper crimson colour returns. But no one need remain in doubt of the fact, for if the ventricle be pierced the blood will be seen to be forcibly projected outwards upon each motion or pulsation when the heart is tense.

These things, therefore, happen together or at the same instant: the tension of the heart, the pulse of its apex, which is felt externally by its striking against the chest, the thickening of its parietes, and the forcible expulsion of the blood it contains by the constriction of its ventricles.

Hence the very opposite of the opinions commonly received, appears to be true; inasmuch as it is generally believed that when the heart strikes the breast and the pulse is felt without, the heart is dilated in its ventricles and is filled with blood; but the contrary of this is the fact, and the heart, when it contracts [and the impulse of the apex is conveyed through the chest wall], is emptied.

Whence the motion which is generally regarded as the diastole of the heart, is in truth its systole. And in like manner the intrinsic motion of the heart is not the diastole but the systole; neither is it in the diastole that the heart grows firm and tense, but in the systole, for then only, when tense, is it moved and made vigorous.

Neither is it by any means to be allowed that the heart only moves in the line of its straight fibres, although the great Vesalius, giving this notion countenance, quotes a bundle of osiers bound in a pyramidal heap in illustration; meaning, that as the apex is approached to the base, so are the sides made to bulge out in the fashion of arches, the cavities to dilate, the ventricles to acquire the form of a cupping-glass and so to suck in the blood. But the true effect of every one of its fibres is to constringe the heart at the same time that they render it tense; and this rather with the effect of thickening and amplifying the walls and substance of the organ than enlarging its ventricles. And, again, as the fibres run from the apex to the base, and draw the apex towards the base, they do not tend to make the walls of the heart bulge out in circles, but rather the contrary; inasmuch as every fibre that is circularly disposed, tends to become straight when it contracts; and is distended laterally and thickened, as in the case of muscular fibres in general, when they contract, that is, when they are shortened longitudinally, as we see them in the bellies of the muscles of the body at large. To all this let it be added, that not only are the ventricles contracted in virtue of the direction and condensation of their walls, but farther, that those fibres, or bands, styled nerves by Aristotle, which are so conspicuous in the ventricles of the larger animals, and contain all the straight fibres, (the parietes of the heart containing only circular ones,) when they contract simultaneously, by an admirable adjustment all the internal surfaces are drawn together, as if with cords, and so is the charge of blood expelled with force.

Neither is it true, as vulgarly believed, that the heart by any dilatation or motion of its own, has the power of drawing the blood into the ventricles; for when it acts and becomes tense, the blood is expelled; when it relaxes and

sinks together it receives the blood in the manner and wise which will by-and-by be explained.

CHAPTER III.

OF THE MOTIONS OF ARTERIES, AS SEEN IN THE DISSECTION OF LIVING ANIMALS.

In connexion with the motions of the heart these things are further to be observed having reference to the motions and pulses of the arteries:

1. At the moment the heart contracts, and when the breast is struck, when in short the organ is in its state of systole, the arteries are dilated, yield a pulse, and are in the state of diastole. In like manner, when the right ventricle contracts and propels its charge of blood, the pulmonary artery is distended at the same time with the other arteries of the body.

2. When the left ventricle ceases to act, to contract, to pulsate, the pulse in the arteries also ceases; further, when this ventricle contracts languidly, the pulse in the arteries is scarcely perceptible. In like manner, the pulse in the right ventricle failing, the pulse in the pulmonary artery ceases also.

3. Further, when an artery is divided or punctured, the blood is seen to be forcibly propelled from the wound at the moment the left ventricle contracts; and, again, when the pulmonary artery is wounded, the blood will be seen spouting forth with violence at the instant when the right ventricle contracts.

So also in fishes, if the vessel which leads from the heart to the gills be divided, at the moment when the heart becomes tense and contracted, at the same moment does the blood flow with force from the divided vessel.

In the same way, when we see the blood in arteriotomy projected now to a greater, now to a less distance, and that the greater jet corresponds to the diastole of the artery and to the time when the heart contracts and strikes

the ribs, and is in its state of systole, we understand that the blood is expelled by the same movement.

From these facts it is manifest, in opposition to commonly received opinions, that the diastole of the arteries corresponds with the time of the heart's systole; and that the arteries are filled and distended by the blood forced into them by the contraction of the ventricles; the arteries, therefore, are distended, because they are filled like sacs or bladders, and are not filled because they expand like bellows. It is in virtue of one and the same cause, therefore, that all the arteries of the body pulsate, viz., the contraction of the left ventricle; in the same way as the pulmonary artery pulsates by the contraction of the right ventricle.

Finally, that the pulses of the arteries are due to the impulses of the blood from the left ventricle, may be illustrated by blowing into a glove, when the whole of the fingers will be found to become distended at one and the same time, and in their tension to bear some resemblance to the pulse. For in the ratio of the tension is the pulse of the heart, fuller, stronger, and more frequent as that acts more vigorously, still preserving the rhythm and volume, and order of the heart's contractions. Nor is it to be expected that because of the motion of the blood, the time at which the contraction of the heart takes place, and that at which the pulse in an artery (especially a distant one,) is felt, shall be otherwise than simultaneous: it is here the same as in blowing up a glove or bladder; for in a plenum, (as in a drum, a long piece of timber, etc.) the stroke and the motion occur at both extremities at the same time. Aristotle,[1] too, has said, "the blood of all animals palpitates within their veins, (meaning the arteries,) and by the pulse is sent everywhere simultaneously." And further,[2] "thus do all the veins pulsate together and by successive strokes, because they all depend upon the heart; and, as it is always in motion, so are they likewise always moving together, but by successive movements." It is well to observe with Galen, in this place, that the old philosophers called the arteries veins.

[1] De Anim., iii, cap. 9. [2] De Respir., cap. 20.

I happened upon one occasion to have a particular case under my care, which plainly satisfied me of this truth: A certain person was affected with a large pulsating tumour on the right side of the neck, called an aneurism, just at that part where the artery descends into the axilla, produced by an erosion of the artery itself, and daily increasing in size; this tumour was visibly distended as it received the charge of blood brought to it by the artery, with each stroke of the heart: the connexion of parts was obvious when the body of the patient came to be opened after his death. The pulse in the corresponding arm was small, in consequence of the greater portion of the blood being diverted into the tumour and so intercepted.

Whence it appears that wherever the motion of the blood through the arteries is impeded, whether it be by compression or infarction, or interception, there do the remote divisions of the arteries beat less forcibly, seeing that the pulse of the arteries is nothing more than the impulse or shock of the blood in these vessels.

CHAPTER IV.

OF THE MOTION OF THE HEART AND ITS AURICLES, AS SEEN IN THE BODIES OF LIVING ANIMALS.

Besides the motions already spoken of, we have still to consider those that appertain to the auricles.

Caspar Bauhin and John Riolan,[1] most learned men and skilful anatomists, inform us from their observations, that if we carefully watch the movements of the heart in the vivisection of an animal, we shall perceive four motions distinct in time and in place, two of which are proper to the auricles, two to the ventricles. With all deference to such authority I say, that there are four motions distinct in point of place, but not of time; for the two auricles move together, and so also do the two ventricles, in such

[1] Bauhin, lib. ii, cap. 21. Riolan, lib. viii, cap. 1.

wise that though the places be four, the times are only two. And this occurs in the following manner:

There are, as it were, two motions going on together; one of the auricles, another of the ventricles; these by no means taking place simultaneously, but the motion of the auricles preceding, that of the heart following; the motion appearing to begin from the auricles and to extend to the ventricles. When all things are becoming languid, and the heart is dying, as also in fishes and the colder blooded animals, there is a short pause between these two motions, so that the heart aroused, as it were, appears to respond to the motion, now more quickly, now more tardily; and at length, when near to death, it ceases to respond by its proper motion, but seems, as it were, to nod the head, and is so slightly moved that it appears rather to give signs of motion to the pulsating auricle, than actually to move. The heart, therefore, ceases to pulsate sooner than the auricles, so that the auricles have been said to outlive it, the left ventricle ceasing to pulsate first of all; then its auricle, next the right ventricle; and, finally, all the other parts being at rest and dead, as Galen long since observed, the right auricle still continues to beat; life, therefore, appears to linger longest in the right auricle. Whilst the heart is gradually dying, it is sometimes seen to reply, after two or three contractions of the auricles, roused as it were to action, and making a single pulsation, slowly, unwillingly, and with an effort.

But this especially is to be noted, that after the heart[1] has ceased to beat, the auricles however still contracting, a finger placed upon the ventricles perceives the several pulsations of the auricles, precisely in the same way and for the same reason, as we have said, that the pulses of the ventricles are felt in the arteries, to wit, the distension produced by the jet of blood. And if at this time, the auricles alone pulsating, the point of the heart be cut off with a pair of scissors, you will perceive the blood flowing out upon each contraction of the auricles. Whence it is

[1] [It will be observed that Harvey, when he speaks of the "heart," invariably refers to the ventricles, and not to the organ as a whole.—Ed.]

manifest that the blood enters the ventricles, not by any attraction or dilatation of the heart, but by being thrown into them by the pulses of the auricles.

And here I would observe, that whenever I speak of pulsations as occurring in the auricles or ventricles, I mean contractions: first the auricles *contract*, and then and subsequently the heart itself *contracts*. When the auricles contract they are seen to become whiter, especially where they contain but little blood; but they are filled as magazines or reservoirs of the blood, which is tending spontaneously and, by its motion in the veins, under pressure towards the centre; the whiteness indicated is most conspicuous towards the extremities or edges of the auricles at the time of their contractions.

In fishes and frogs, and other animals which have hearts with but a single ventricle, and for an auricle have a kind of bladder much distended with blood, at the base of the organ, you may very plainly perceive this bladder contracting first, and the contraction of the heart or ventricle following afterwards.

But I think it right to describe what I have observed of an opposite character: the heart of an eel, of several fishes, and even of some [of the higher] animals taken out of the body, pulsates without auricles; nay, if it be cut in pieces the several parts may still be seen contracting and relaxing; so that in these creatures the body of the heart may be seen pulsating and palpitating, after the cessation of all motion in the auricle. But is not this perchance peculiar to animals more tenacious of life, whose radical moisture is more glutinous, or fat and sluggish, and less readily soluble? The same faculty indeed appears in the flesh of eels, which even when skinned and embowelled, and cut into pieces, are still seen to move.

Experimenting with a pigeon upon one occasion, after the heart had wholly ceased to pulsate, and the auricles too had become motionless, I kept my finger wetted with saliva and warm for a short time upon the heart, and observed, that under the influence of this fomentation it recovered new strength and life, so that both ventricles and auricles pulsated, contracting and relaxing alternately, recalled as it were from death to life.

Besides this, however, I have occasionally observed, after the heart and even its right auricle had ceased pulsating—when it was *in articulo mortis* in short—that an obscure motion, an undulation or palpitation, remained in the blood itself, which was contained in the right auricle, this being apparent so long as it was imbued with heat and spirit. And indeed a circumstance of the same kind is extremely manifest in the course of the generation of animals, as may be seen in the course of the first seven days of the incubation of the chick: A drop of blood makes its appearance which palpitates, as Aristotle had already observed; from this, when the growth is further advanced and the chick is fashioned, the auricles of the heart are formed, which pulsating henceforth give constant signs of life. When at length, and after the lapse of a few days, the outline of the body begins to be distinguished, then is the ventricular part of the heart also produced; but it continues for a time white and apparently bloodless, like the rest of the animal; neither does it pulsate or give signs of motion. I have seen a similar condition of the heart in the human fœtus about the beginning of the third month, the heart being then whitish and bloodless, although its auricles contained a considerable quantity of purple blood. In the same way in the egg, when the chick was formed and had increased in size, the heart too increased and acquired ventricles, which then began to receive and to transmit blood.

And this leads me to remark, that he who inquires very particularly into this matter will not conclude that the heart, as a whole, is the primum vivens, ultimum moriens—the first part to live, the last to die—but rather its auricles, or the part which corresponds to the auricles in serpents, fishes, etc., which both lives before the heart and dies after it.

Nay, has not the blood itself or spirit an obscure palpitation inherent in it, which it has even appeared to me to retain after death? and it seems very questionable whether or not we are to say that life begins with the palpitation or beating of the heart. The seminal fluid of all animals—the prolific spirit, as Aristotle observed, leaves their body with a bound and like a living thing; and

nature in death, as Aristotle[1] further remarks, retracing her steps, reverts to where she had set out, and returns at the end of her course to the goal whence she had started. As animal generation proceeds from that which is not animal, entity from nonentity, so, by a retrograde course, entity, by corruption, is resolved into nonentity; whence that in animals, which was last created, fails first; and that which was first, fails last.

I have also observed, that almost all animals have truly a heart, not the larger creatures only, and those that have red blood, but the smaller, and pale-blooded ones also, such as slugs, snails, scallops, shrimps, crabs, crayfish, and many others; nay, even in wasps, hornets, and flies, I have, with the aid of a magnifying glass, and at the upper part of what is called the tail, both seen the heart pulsating myself, and shown it to many others.

But in the pale-blooded tribes the heart pulsates sluggishly and deliberately, contracting slowly as in animals that are moribund, a fact that may readily be seen in the snail, whose heart will be found at the bottom of that orifice in the right side of the body which is seen to be opened and shut in the course of respiration, and whence saliva is discharged, the incision being made in the upper aspect of the body, near the part which corresponds to the liver.

This, however, is to be observed: that in winter and the colder season, exsanguine animals, such as the snail, show no pulsations; they seem rather to live after the manner of vegetables, or of those other productions which are therefore designated plant-animals.

It is also to be noted that all animals which have a heart, have also auricles, or something analogous to auricles; and further, that wherever the heart has a double ventricle there are always two auricles present, but not otherwise. If you turn to the production of the chick *in ovo*, however, you will find at first no more than a vesicle or auricle, or pulsating drop of blood; it is only by and by, when the development has made some progress, that the heart is fashioned: even so in certain animals not destined to

[1] De Motu Animal., cap. 8.

attain to the highest perfection in their organization, such as bees, wasps, snails, shrimps, crayfish, etc., we only find a certain pulsating vesicle, like a sort of red or white palpitating point, as the beginning or principle of their life.

We have a small shrimp in these countries, which is taken in the Thames and in the sea, the whole of whose body is transparent; this creature, placed in a little water, has frequently afforded myself and particular friends an opportunity of observing the motions of the heart with the greatest distinctness, the external parts of the body presenting no obstacle to our view, but the heart being perceived as though it had been seen through a window.

I have also observed the first rudiments of the chick in the course of the fourth or fifth day of the incubation, in the guise of a little cloud, the shell having been removed and the egg immersed in clear tepid water. In the midst of the cloudlet in question there was a bloody point so small that it disappeared during the contraction and escaped the sight, but in the relaxation it reappeared again, red and like the point of a pin; so that betwixt the visible and invisible, betwixt being and not being, as it were, it gave by its pulses a kind of representation of the commencement of life.

CHAPTER V.

OF THE MOTION, ACTION, AND OFFICE OF THE HEART.

From these and other observations of a similar nature, I am persuaded it will be found that the motion of the heart is as follows:

First of all, the auricle contracts, and in the course of its contraction forces the blood, (which it contains in ample quantity as the head of the veins, the store-house and cistern of the blood,) into the ventricle, which being filled, the heart raises itself straightway, makes all its fibres tense, contracts the ventricles, and performs a beat, by which beat it immediately sends the blood supplied to it by the auricle into the arteries. The right ventricle

sends its charge into the lungs by the vessel which is called vena arteriosa, but which, in structure and function, and all other respects, is an artery. The left ventricle sends its charge into the aorta, and through this by the arteries to the body at large.

These two motions, one of the ventricles, the other of the auricles, take place consecutively, but in such a manner that there is a kind of harmony or rhythm preserved between them, the two concurring in such wise that but one motion is apparent, especially in the warmer blooded animals, in which the movements in question are rapid. Nor is this for any other reason than it is in a piece of machinery, in which, though one wheel gives motion to another, yet all the wheels seem to move simultaneously; or in that mechanical contrivance which is adapted to fire-arms, where the trigger being touched, down comes the flint, strikes against the steel, elicits a spark, which falling among the powder, ignites it, when the flame extends, enters the barrel, causes the explosion, propels the ball, and the mark is attained—all of which incidents, by reason of the celerity with which they happen, seem to take place in the twinkling of an eye. So also in deglutition: by the elevation of the root of the tongue, and the compression of the mouth, the food or drink is pushed into the fauces, when the larynx is closed by its muscles and by the epiglottis. The pharynx is then raised and opened by its muscles in the same way as a sac that is to be filled is lifted up, and its mouth dilated. Upon the mouthful being received, it is forced downwards by the transverse muscles, and then carried farther by the longitudinal ones. Yet all these motions, though executed by different and distinct organs, are performed harmoniously, and in such order, that they seem to constitute but a single motion and act, which we call deglutition.

Even so does it come to pass with the motions and action of the heart, which constitute a kind of deglutition, a transfusion of the blood from the veins to the arteries. And if anyone, bearing these things in mind, will carefully watch the motions of the heart in the body of a living animal, he will perceive not only all the particulars I have mentioned, viz., the heart becoming erect, and

making one continuous motion with its auricles; but farther, a certain obscure undulation and lateral inclination in the direction of the axis of the right ventricle, as if twisting itself slightly in performing its work. And indeed everyone may see, when a horse drinks, that the water is drawn in and transmitted to the stomach at each movement of the throat, which movement produces a sound and yields a pulse both to the ear and the touch; in the same way it is with each motion of the heart, when there is the delivery of a quantity of blood from the veins to the arteries, a pulse takes place, and can be heard within the chest.

The motion of the heart, then, is entirely of this description, and the one action of the heart is the transmission of the blood and its distribution, by means of the arteries, to the very extremities of the body; so that the pulse which we feel in the arteries is nothing more than the impulse of the blood derived from the heart.

Whether or not the heart, besides propelling the blood, giving it motion locally, and distributing it to the body, adds anything else to it,—heat, spirit, perfection,—must be inquired into by-and-by, and decided upon other grounds. So much may suffice at this time, when it is shown that by the action of the heart the blood is transfused through the ventricles from the veins to the arteries, and distributed by them to all parts of the body.

The above, indeed, is admitted by all, both from the structure of the heart and the arrangement and action of its valves. But still they are like persons purblind or groping about in the dark, for they give utterance to various, contradictory, and incoherent sentiments, delivering many things upon conjecture, as we have already shown.

The grand cause of doubt and error in this subject appears to me to have been the intimate connexion between the heart and the lungs. When men saw both the pulmonary artery and the pulmonary veins losing themselves in the lungs, of course it became a puzzle to them to know how or by what means the right ventricle should distribute the blood to the body, or the left draw it from the venæ cavæ. This fact is borne witness to by Galen,

whose words, when writing against Erasistratus in regard to the origin and use of the veins and the coction of the blood, are the following:[1] "You will reply," he says, "that the effect is so; that the blood is prepared in the liver, and is thence transferred to the heart to receive its proper form and last perfection; a statement which does not appear devoid of reason; for no great and perfect work is ever accomplished at a single effort, or receives its final polish from one instrument. But if this be actually so, then show us another vessel which draws the absolutely perfect blood from the heart, and distributes it as the arteries do the spirits over the whole body." Here then is a reasonable opinion not allowed, because, forsooth, besides not seeing the true means of transit, he could not discover the vessel which should transmit the blood from the heart to the body at large!

But had anyone been there in behalf of Erasistratus, and of that opinion which we now espouse, and which Galen himself acknowledges in other respects consonant with reason, to have pointed to the aorta as the vessel which distributes the blood from the heart to the rest of the body, I wonder what would have been the answer of that most ingenious and learned man? Had he said that the artery transmits spirits and not blood, he would indeed sufficiently have answered Erasistratus, who imagined that the arteries contained nothing but spirits; but then he would have contradicted himself, and given a foul denial to that for which he had keenly contended in his writings against this very Erasistratus, to wit, that blood in substance is contained in the arteries, and not spirits; a fact which he demonstrated not only by many powerful arguments, but by experiments.

But if the divine Galen will here allow, as in other places he does, "that all the arteries of the body arise from the great artery, and that this takes its origin from the heart; that all these vessels naturally contain and carry blood; that the three semilunar valves situated at the orifice of the aorta prevent the return of the blood into the heart, and that nature never connected them with

[1] De Placitis Hippocratis et Platonis, vi.

this, the most noble viscus of the body, unless for some most important end;" if, I say, this father of physicians concedes all these things,—and I quote his own words,—I do not see how he can deny that the great artery is the very vessel to carry the blood, when it has attained its highest term of perfection, from the heart for distribution to all parts of the body. Or would he perchance still hesitate, like all who have come after him, even to the present hour, because he did not perceive the route by which the blood was transferred from the veins to the arteries, in consequence, as I have already said, of the intimate connexion between the heart and the lungs? And that this difficulty puzzled anatomists not a little, when in their dissections they found the pulmonary artery and left ventricle full of thick, black, and clotted blood, plainly appears, when they felt themselves compelled to affirm that the blood made its way from the right to the left ventricle by transuding through the septum of the heart. But this fancy I have already refuted. A new pathway for the blood must therefore be prepared and thrown open, and being once exposed, no further difficulty will, I believe, be experienced by anyone in admitting what I have already proposed in regard to the pulse of the heart and arteries, viz., the passage of the blood from the veins to the arteries, and its distribution to the whole of the body by means of these vessels.

CHAPTER VI.

OF THE COURSE BY WHICH THE BLOOD IS CARRIED FROM THE VENA CAVA INTO THE ARTERIES, OR FROM THE RIGHT INTO THE LEFT VENTRICLE OF THE HEART.

SINCE the intimate connexion of the heart with the lungs, which is apparent in the human subject, has been the probable cause of the errors that have been committed on this point, they plainly do amiss who, pretending to speak of the parts of animals generally, as anatomists for the most part do, confine their researches to the human body

alone, and that when it is dead. They obviously do not act otherwise than he who, having studied the forms of a single commonwealth, should set about the composition of a general system of polity; or who, having taken cognizance of the nature of a single field, should imagine that he had mastered the science of agriculture; or who, upon the ground of one particular proposition, should proceed to draw general conclusions.

Had anatomists only been as conversant with the dissection of the lower animals as they are with that of the human body, the matters that have hitherto kept them in a perplexity of doubt would, in my opinion, have met them freed from every kind of difficulty.

And first, in fishes, in which the heart consists of but a single ventricle, being devoid of lungs, the thing is sufficiently manifest. Here the sac, which is situated at the base of the heart, and is the part analogous to the auricle in man, plainly forces the blood into the heart, and the heart, in its turn, conspicuously transmits it by a pipe or artery, or vessel analogous to an artery; these are facts which are confirmed by simple ocular inspection, as well as by a division of the vessel, when the blood is seen to be projected by each pulsation of the heart.

The same thing is also not difficult of demonstration in those animals that have, as it were, no more than a single ventricle to the heart, such as toads, frogs, serpents, and lizards, which have lungs in a certain sense, as they have a voice. I have many observations by me on the admirable structure of the lungs of these animals, and matters appertaining, which, however, I cannot introduce in this place. Their anatomy plainly shows us that the blood is transferred in them from the veins to the arteries in the same manner as in higher animals, viz., by the action of the heart; the way, in fact, is patent, open, manifest; there is no difficulty, no room for doubt about it; for in them the matter stands precisely as it would in man, were the septum of his heart perforated or removed, or one ventricle made out of two; and this being the case, I imagine that no one will doubt as to the way by which the blood may pass from the veins into the arteries.

But as there are actually more animals which have no

lungs than there are furnished with them, and in like manner a greater number which have only one ventricle than there are with two, it is open to us to conclude, judging from the mass or multitude of living creatures, that for the major part, and generally, there is an open way by which the blood is transmitted from the veins through the sinuses or cavities of the heart into the arteries.

I have, however, cogitating with myself, seen further, that the same thing obtained most obviously in the embryos of those animals that have lungs; for in the fœtus the four vessels belonging to the heart, viz., the vena cava, the pulmonary artery, the pulmonary vein, and the great artery or aorta, are all connected otherwise than in the adult; a fact sufficiently known to every anatomist. The first contact and union of the vena cava with the pulmonary veins, which occurs before the cava opens properly into the right ventricle of the heart, or gives off the coronary vein, a little above its escape from the liver, is by a lateral anastomosis; this is an ample foramen, of an oval form, communicating between the cava and the pulmonary vein, so that the blood is free to flow in the greatest abundance by that foramen from the vena cava into the pulmonary vein, and left auricle, and from thence into the left ventricle. Farther, in this foramen ovale, from that part which regards the pulmonary vein, there is a thin tough membrane, larger than the opening, extended like an operculum or cover; this membrane in the adult blocking up the foramen, and adhering on all sides, finally closes it up, and almost obliterates every trace of it. In the fœtus, however, this membrane is so contrived that falling loosely upon itself, it permits a ready access to the lungs and heart, yielding a passage to the blood which is streaming from the cava, and hindering the tide at the same time from flowing back into that vein. All things, in short, permit us to believe that in the embryo the blood must constantly pass by this foramen from the vena cava into the pulmonary vein, and from thence into the left auricle of the heart; and having once entered there, it can never regurgitate.

Another union is that by the pulmonary artery, and is effected when that vessel divides into two branches after its escape from the right ventricle of the heart. It is as

if to the two trunks already mentioned a third were superadded, a kind of arterial canal, carried obliquely from the pulmonary artery, to perforate and terminate in the great artery or aorta. So that in the dissection of the embryo, as it were, two aortas, or two roots of the great artery, appear springing from the heart. This canal shrinks gradually after birth, and after a time becomes withered, and finally almost removed, like the umbilical vessels.

The arterial canal contains no membrane or valve to direct or impede the flow of blood in this or in that direction: for at the root of the pulmonary artery, of which the arterial canal is the continuation in the fœtus, there are three semilunar valves, which open from within outwards, and oppose no obstacle to the blood flowing in this direction or from the right ventricle into the pulmonary artery and aorta; but they prevent all regurgitation from the aorta or pulmonic vessels back upon the right ventricle; closing with perfect accuracy, they oppose an effectual obstacle to everything of the kind in the embryo. So that there is also reason to believe that when the heart contracts, the blood is regularly propelled by the canal or passage indicated from the right ventricle into the aorta.

What is commonly said in regard to these two great communications, to wit, that they exist for the nutrition of the lungs, is both improbable and inconsistent; seeing that in the adult they are closed up, abolished, and consolidated, although the lungs, by reason of their heat and motion, must then be presumed to require a larger supply of nourishment. The same may be said in regard to the assertion that the heart in the embryo does not pulsate, that it neither acts nor moves, so that nature was forced to make these communications for the nutrition of the lungs. This is plainly false; for simple inspection of the incubated egg, and of embryos just taken out of the uterus, shows that the heart moves in them precisely as in adults, and that nature feels no such necessity.[1] I have myself repeatedly seen these motions, and Aristotle is likewise witness of their reality. "The pulse," he observes,

[1] [The modern stethoscope completely confirms Harvey's views, as by its use the heart of the embryo can be heard to pulsate through the abdominal walls of the mother.—Ed.]

"inheres in the very constitution of the heart, and appears from the beginning, as is learned both from the dissection of living animals and the formation of the chick in the egg."[1] But we further observe, that the passages in question are not only pervious up to the period of birth in man, as well as in other animals, as anatomists in general have described them, but for several months subsequently, in some indeed for several years, not to say for the whole course of life; as, for example, in the goose, snipe, and various birds, and many of the smaller animals. And this circumstance it was, perhaps, that imposed upon Botallus, who thought he had discovered a new passage for the blood from the vena cava into the left ventricle of the heart; and I own that when I met with the same arrangement in one of the larger members of the mouse family, in the adult state, I was myself at first led to something of a like conclusion.

From this it will be understood that in the human embryo, and in the embryos of animals in which the communications are not closed, the same thing happens, namely, that the heart by its motion propels the blood by obvious and open passages from the vena cava into the aorta through the cavities of both the ventricles; the right one receiving the blood from the auricle, and propelling it by the pulmonary artery, and its continuation, named the ductus arteriosus, into the aorta; the left, in like manner, charged by the contraction of its auricle, which has received its supply through the foramen ovale from the vena cava, contracting, and projecting the blood through the root of the aorta into the trunk of that vessel.

In embryos, consequently, whilst the lungs are yet in a state of inaction, performing no function, subject to no motion any more than if they had not been present, nature uses the two ventricles of the heart as if they formed but one, for the transmission of the blood. The condition of the embryos of those animals which have lungs, whilst these organs are yet in abeyance and not employed, is the same as that of those animals which have no lungs.

So it clearly appears in the case of the fœtus, that the

[1] Lib. de Spiritu, cap. v.

heart by its action transfers the blood from the vena cava into the aorta, and that by a route as obvious and open, as if in the adult the two ventricles were made to communicate by the removal of their septum. We therefore find that in the greater number of animals, in all, indeed, at a certain period of their existence, the channels for the transmission of the blood through the heart are conspicuous. But we have to inquire why in some creatures —those, namely, that have warm blood, and that have attained to the adult age, man among the number—we should not conclude that the same thing is accomplished through the substance of the lungs, which in the embryo, and at a time when the function of these organs is in abeyance, nature effects by the direct passages described, and which, indeed, she seems compelled to adopt through want of a passage by the lungs; or why it should be better (for nature always does that which is best) that she should close up the various open routes which she had formerly made use of in the embryo and fœtus, and still uses in all other animals. Not only does she thereby open up no new apparent channels for the passage of the blood, but she even shuts up those which formerly existed.

And now the discussion is brought to this point, that they who inquire into the ways by which the blood reaches the left ventricle of the heart and pulmonary veins from the vena cava, will pursue the wisest course if they seek by dissection to discover the causes why in the larger and more perfect animals of mature age, nature has rather chosen to make the blood percolate the parenchyma of the lungs, than as in other instances chosen a direct and obvious course—for I assume that no other path or mode of transit can be entertained. It must be because the larger and more perfect animals are warmer, and when adult their heat greater—ignited, as I might say, and requiring to be damped or mitigated, that the blood is sent through the lungs, in order that it may be tempered by the air that is inspired, and prevented from boiling up, and so becoming extinguished, or something else of the sort. But to determine these matters, and explain them satisfactorily, were to enter on a speculation in regard to the office of the lungs and the ends for which

they exist. Upon such a subject, as well as upon what pertains to respiration, to the necessity and use of the air, etc., as also to the variety and diversity of organs that exist in the bodies of animals in connexion with these matters, although I have made a vast number of observations, I shall not speak till I can more conveniently set them forth in a treatise apart, lest I should be held as wandering too wide of my present purpose, which is the use and motion of the heart, and be charged with speaking of things beside the question, and rather complicating and quitting than illustrating it. And now, returning to my immediate subject, I go on with what yet remains for demonstration, viz., that in the more perfect and warmer adult animals, and man, the blood passes from the right ventricle of the heart by the pulmonary artery, into the lungs, and thence by the pulmonary veins into the left auricle, and from there into the left ventricle of the heart. And, first, I shall show that this may be so, and then I shall prove that it is so in fact.

CHAPTER VII.

THE BLOOD PASSES THROUGH THE SUBSTANCE OF THE LUNGS FROM THE RIGHT VENTRICLE OF THE HEART INTO THE PULMONARY VEINS AND LEFT VENTRICLE.

That this is possible, and that there is nothing to prevent it from being so, appears when we reflect on the way in which water permeating the earth produces springs and rivulets, or when we speculate on the means by which the sweat passes through the skin, or the urine through the substance of the kidneys. It is well known that persons who use the Spa waters, or those of La Madonna, in the territories of Padua, or others of an acidulous or vitriolated nature, or who simply swallow drinks by the gallon, pass all off again within an hour or two by the bladder. Such a quantity of liquid must take some short time in the concoction: it must pass through the liver; it is allowed by all that the juices of the food we consume pass

twice through this organ in the course of the day;) it must flow through the veins, through the tissue of the kidneys, and through the ureters into the bladder.

To those, therefore, whom I hear denying that the blood, aye the whole mass of the blood may pass through the substance of the lungs, even as the nutritive juices percolate the liver, asserting such a proposition to be impossible, and by no means to be entertained as credible, I reply, with the poet, that they are of that race of men who, when they will, assent full readily, and when they will not, by no manner of means; who, when their assent is wanted, fear, and when it is not, fear not to give it.

The substance of the liver is extremely dense, so is that of the kidney; the lungs, however, are of a much looser texture, and if compared with the kidneys are absolutely spongy. In the liver there is no forcing, no impelling power; in the lungs the blood is forced on by the pulse of the right ventricle, the necessary effect of whose impulse is the distension of the vessels and pores of the lungs. And then the lungs, in respiration, are perpetually rising and falling; motions, the effect of which must needs be to open and shut the pores and vessels, precisely as in the case of a sponge, and of parts having a spongy structure, when they are alternately compressed and again are suffered to expand. The liver, on the contrary, remains at rest, and is never seen to be dilated or constricted. Lastly, if no one denies the possibility in man, oxen, and the larger animals generally, of the whole of the ingested juices passing through the liver, in order to reach the vena cava, for this reason, that if nourishment is to go on, these juices must needs get into the veins, and there is no other way but the one indicated, why should not the same arguments be held of avail for the passage of the blood in adults through the lungs? Why not maintain, with Columbus, that skilful and learned anatomist, that it must be so from the capacity and structure of the pulmonary vessels, and from the fact of the pulmonary veins and ventricle corresponding with them, being always found to contain blood, which must needs have come from the veins, and by no other passage save through the lungs? Columbus, and we also, from what precedes, from dissections, and

other arguments, conceive the thing to be clear. But as there are some who admit nothing unless upon authority, let them learn that the truth I am contending for can be confirmed from Galen's own words, namely, that not only may the blood be transmitted from the pulmonary artery into the pulmonary veins, then into the left ventricle of the heart, and from thence into the arteries of the body, but that this is effected by the ceaseless pulsation of the heart and the motion of the lungs in breathing.

There are, as everyone knows, three sigmoid or semilunar valves situated at the orifice of the pulmonary artery, which effectually prevent the blood sent into the vessel from returning into the cavity of the heart. Now Galen, explaining the uses of these valves, and the necessity for them, employs the following language:[1] "There is everywhere a mutual anastomosis and inosculation of the arteries with the veins, and they severally transmit both blood and spirit, by certain invisible and undoubtedly very narrow passages. Now if the mouth of the pulmonary artery had stood in like manner continually open, and nature had found no contrivance for closing it when requisite, and opening it again, it would have been impossible that the blood could ever have passed by the invisible and delicate mouths, during the contractions of the thorax, into the arteries; for all things are not alike readily attracted or repelled; but that which is light is more readily drawn in, the instrument being dilated, and forced out again when it is contracted, than that which is heavy; and in like manner is anything drawn more rapidly along an ample conduit, and again driven forth, than it is through a narrow tube. But when the thorax is contracted, the pulmonary veins, which are in the lungs, being driven inwardly, and powerfully compressed on every side, immediately force out some of the spirit they contain, and at the same time assume a certain portion of blood by those subtile mouths; a thing that could never come to pass were the blood at liberty to flow back into the heart through the great orifice of the pulmonary artery. But its return through this great opening being prevented, when it is compressed on every

[1] De Usu partium, lib. vi, cap. 10.

side, a certain portion of it distils into the pulmonary veins by the minute orifices mentioned." And shortly afterwards, in the next chapter, he says: "The more the thorax contracts, the more it strives to force out the blood, the more exactly do these membranes (viz., the semilunar valves) close up the mouth of the vessel, and suffer nothing to regurgitate." The same fact he has also alluded to in a preceding part of the tenth chapter: "Were there no valves, a three-fold inconvenience would result, so that the blood would then perform this lengthened course in vain; it would flow inwards during the diastoles of the lungs, and fill all their arteries; but in the systoles, in the manner of the tide, it would ever and anon, like the Euripus, flow backwards and forwards by the same way, with a reciprocating motion, which would nowise suit the blood. This, however, may seem a matter of little moment; but if it meantime appear that the function of respiration suffer, then I think it would be looked upon as no trifle, etc." Shortly afterwards he says: "And then a third inconvenience, by no means to be thought lightly of, would follow, were the blood moved backwards during the expirations, had not our Maker instituted those supplementary membranes." In the eleventh chapter, he concludes: "That they (the valves) have all a common use, and that it is to prevent regurgitation or backward motion; each, however, having a proper function, the one set drawing matters from the heart, and preventing their return, the other drawing matters into the heart, and preventing their escape from it. For nature never intended to distress the heart with needless labour, neither to bring aught into the organ which it had been better to have kept away, nor to take from it again aught which it was requisite should be brought. Since, then, there are four orifices in all, two in either ventricle, one of these induces, the other educes." And again he says: "Farther, since there is one vessel, which consists of a simple covering implanted in the heart, and another, which is double, extending from it, (Galen is here speaking of the right side of the heart, but I extend his observations to the left side also,) a kind of reservoir had to be provided, to which both belonging, the blood should be drawn in by one, and sent out by the other."

Galen adduces this argument for the transit of the blood by the right ventricle from the vena cava into the lungs; but we can use it with still greater propriety, merely changing the terms, for the passage of the blood from the veins through the heart into the arteries. From Galen, however, that great man, that father of physicians, it clearly appears that the blood passes through the lungs from the pulmonary artery into the minute branches of the pulmonary veins, urged to this both by the pulses of the heart and by the motions of the lungs and thorax; that the heart, moreover, is incessantly receiving and expelling the blood by and from its ventricles, as from a magazine or cistern, and for this end it is furnished with four sets of valves, two serving for the induction and two for the eduction of the blood, lest, like the Euripus, it should be incommodiously sent hither and thither, or flow back into the cavity which it should have quitted, or quit the part where its presence was required, and so the heart might be oppressed with labour in vain, and the office of the lungs be interfered with.[1] Finally, our position that the blood is continually permeating from the right to the left ventricle, from the vena cava into the aorta, through the porosities of the lungs, plainly appears from this, that since the blood is incessantly sent from the right ventricle into the lungs by the pulmonary artery, and in like manner is incessantly drawn from the lungs into the left ventricle, as appears from what precedes and the position of the valves, it cannot do otherwise than pass through continuously. And then, as the blood is incessantly flowing into the right ventricle of the heart, and is continually passed out from the left, as appears in like manner, and as is obvious both to sense and reason, it is impossible that the blood can do otherwise than pass continually from the vena cava into the aorta.

Dissection consequently shows distinctly what takes place in the majority of animals, and indeed in all, up to the period of their maturity; and that the same thing occurs in adults is equally certain, both from Galen's words, and what has already been said, only that in the former the

[1] See the Commentary of the learned Hofmann upon the Sixth Book of Galen, "De Usu partium," a work which I first saw after I had written what precedes.

transit is effected by open and obvious passages, in the latter by the hidden porosities of the lungs and the minute inosculations of vessels. It therefore appears that, although one ventricle of the heart, the left to wit, would suffice for the distribution of the blood over the body, and its eduction from the vena cava, as indeed is done in those creatures that have no lungs, nature, nevertheless, when she ordained that the same blood should also percolate the lungs, saw herself obliged to add the right ventricle, the pulse of which should force the blood from the vena cava through the lungs into the cavity of the left ventricle. In this way, it may be said that the right ventricle is made for the sake of the lungs, and for the transmission of the blood through them, not for their nutrition; for it were unreasonable to suppose that the lungs should require so much more copious a supply of nutriment, and that of so much purer and more spirituous a nature as coming immediately from the ventricle of the heart, than either the brain with its peculiarly pure substance, or the eyes with their lustrous and truly admirable structure, or the flesh of the heart itself, which is more suitably nourished by the coronary artery.

CHAPTER VIII.

OF THE QUANTITY OF BLOOD PASSING THROUGH THE HEART FROM THE VEINS TO THE ARTERIES; AND OF THE CIRCULAR MOTION OF THE BLOOD.

Thus far I have spoken of the passage of the blood from the veins into the arteries, and of the manner in which it is transmitted and distributed by the action of the heart; points to which some, moved either by the authority of Galen or Columbus, or the reasonings of others, will give in their adhesion. But what remains to be said upon the quantity and source of the blood which thus passes, is of a character so novel and unheard-of that I not only fear injury to myself from the envy of a few, but I tremble

lest I have mankind at large for my enemies, so much doth wont and custom become a second nature. Doctrine once sown strikes deep its root, and respect for antiquity influences all men. Still the die is cast, and my trust is in my love of truth, and the candour of cultivated minds. And sooth to say, when I surveyed my mass of evidence, whether derived from vivisections, and my various reflections on them, or from the study of the ventricles of the heart and the vessels that enter into and issue from them, the symmetry and size of these conduits,—for nature doing nothing in vain, would never have given them so large a relative size without a purpose,—or from observing the arrangement and intimate structure of the valves in particular, and of the other parts of the heart in general, with many things besides, I frequently and seriously bethought me, and long revolved in my mind, what might be the quantity of blood which was transmitted, in how short a time its passage might be effected, and the like. But not finding it possible that this could be supplied by the juices of the ingested aliment without the veins on the one hand becoming drained, and the arteries on the other getting ruptured through the excessive charge of blood, unless the blood should somehow find its way from the arteries into the veins, and so return to the right side of the heart; I began to think whether there might not be A MOTION, AS IT WERE, IN A CIRCLE. Now this I afterwards found to be true; and I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery, and that it then passed through the veins and along the vena cava, and so round to the left ventricle in the manner already indicated. This motion we may be allowed to call circular, in the same way as Aristotle says that the air and the rain emulate the circular motion of the superior bodies; for the moist earth, warmed by the sun, evaporates; the vapours drawn upwards are condensed, and descending in the form of rain, moisten the earth again. By this arrangement are generations of living things produced; and in like manner are tempests and meteors engen-

dered by the circular motion, and by the approach and recession of the sun.

And similarly does it come to pass in the body, through the motion of the blood, that the various parts are nourished, cherished, quickened by the warmer, more perfect, vaporous, spirituous, and, as I may say, alimentive blood; which, on the other hand, owing to its contact with these parts, becomes cooled, coagulated, and, so to speak, effete. It then returns to its sovereign the heart, as if to its source, or to the inmost home of the body, there to recover its state of excellence or perfection. Here it renews its fluidity, natural heat, and becomes powerful, fervid, a kind of treasury of life, and impregnated with spirits, it might be said with balsam. Thence it is again dispersed. All this depends on the motion and action of the heart.

The heart, consequently, is the beginning of life; the sun of the microcosm, even as the sun in his turn might well be designated the heart of the world; for it is the heart by whose virtue and pulse the blood is moved, perfected, and made nutrient, and is preserved from corruption and coagulation; it is the household divinitv which, discharging its function, nourishes, cherishes, quickens the whole body, and is indeed the foundation of life, the source of all action. But of these things we shall speak more opportunely when we come to speculate upon the final cause of this motion of the heart.

As the blood-vessels, therefore, are the canals and agents that transport the blood, they are of two kinds, the cava and the aorta; and this not by reason of there being two sides of the body, as Aristotle has it, but because of the difference of office, not, as is commonly said, in consequence of any diversity of structure, for in many animals, as I have said, the vein does not differ from the artery in the thickness of its walls, but solely in virtue of their distinct functions and uses. A vein and an artery, both styled veins by the ancients, and that not without reason, as Galen has remarked, for the artery is the vessel which carries the blood from the heart to the body at large, the vein of the present day bringing it back from the general system to the heart; the former is the conduit from, the latter the channel to,

the heart; the latter contains the cruder, effete blood, rendered unfit for nutrition; the former transmits the digested, perfect, peculiarly nutritive fluid.

CHAPTER IX.

THAT THERE IS A CIRCULATION OF THE BLOOD IS CONFIRMED FROM THE FIRST PROPOSITION.

But lest anyone should say that we give them words only, and make mere specious assertions without any foundation, and desire to innovate without sufficient cause, three points present themselves for confirmation, which being stated, I conceive that the truth I contend for will follow necessarily, and appear as a thing obvious to all. First,—the blood is incessantly transmitted by the action of the heart from the vena cava to the arteries in such quantity that it cannot be supplied from the ingesta, and in such a manner that the whole must very quickly pass through the organ; Second,—the blood under the influence of the arterial pulse enters and is impelled in a continuous, equable, and incessant stream through every part and member of the body, in much larger quantity than were sufficient for nutrition, or than the whole mass of fluids could supply; Third,—the veins in like manner return this blood incessantly to the heart from parts and members of the body. These points proved, I conceive it will be manifest that the blood circulates, revolves, propelled and then returning, from the heart to the extremities, from the extremities to the heart, and thus that it performs a kind of circular motion.

Let us assume either arbitrarily or from experiment, the quantity of blood which the left ventricle of the heart will contain when distended, to be, say two ounces, three ounces, or one ounce and a half—in the dead body I have found it to hold upwards of two ounces. Let us assume further, how much less the heart will hold in the contracted than in the dilated state; and how much blood it

will project into the aorta upon each contraction;—and all the world allows that with the systole something is always projected, a necessary consequence demonstrated in the third chapter, and obvious from the structure of the valves; and let us suppose as approaching the truth that the fourth, or fifth, or sixth, or even but the eighth part of its charge is thrown into the artery at each contraction; this would give either half an ounce, or three drachms, or one drachm of blood as propelled by the heart at each pulse into the aorta; which quantity, by reason of the valves at the root of the vessel, can by no means return into the ventricle. Now in the course of half an hour, the heart will have made more than one thousand beats, in some as many as two, three, and even four thousand. Multiplying the number of drachms propelled by the number of pulses, we shall have either one thousand half ounces, or one thousand times three drachms, or a like proportional quantity of blood, according to the amount which we assume as propelled with each stroke of the heart, sent from this organ into the artery; a larger quantity in every case than is contained in the whole body! In the same way, in the sheep or dog, say that but a single scruple of blood passes with each stroke of the heart, in one half hour we should have one thousand scruples, or about three pounds and a half of blood injected into the aorta; but the body of neither animal contains above four pounds of blood, a fact which I have myself ascertained in the case of the sheep.

Upon this supposition, therefore, assumed merely as a ground for reasoning, we see the whole mass of blood passing through the heart, from the veins to the arteries, and in like manner through the lungs.

But let it be said that this does not take place in half an hour, but in an hour, or even in a day; any way it is still manifest that more blood passes through the heart in consequence of its action, than can either be supplied by the whole of the ingesta, or than can be contained in the veins at the same moment.

Nor can it be allowed that the heart in contracting sometimes propels and sometimes does not propel, or at most propels but very little, a mere nothing, or an imagi-

nary something: all this, indeed, has already been refuted, and is, besides, contrary both to sense and reason. For if it be a necessary effect of the dilatation of the heart that its ventricles become filled with blood, it is equally so that, contracting, these cavities should expel their contents; and this not in any trifling measure. For neither are the conduits small, nor the contractions few in number, but frequent, and always in some certain proportion, whether it be a third or a sixth, or an eighth, to the total capacity of the ventricles, so that a like proportion of blood must be expelled, and a like proportion received with each stroke of the heart, the capacity of the ventricle contracted always bearing a certain relation to the capacity of the ventricle when dilated. And since in dilating, the ventricles cannot be supposed to get filled with nothing, or with an imaginary something, so in contracting they never expel nothing or aught imaginary, but always a certain something, viz., blood, in proportion to the amount of the contraction. Whence it is to be concluded, that if at one stroke the heart in man, the ox or the sheep, ejects but a single drachm of blood, and there are one thousand strokes in half an hour, in this interval there will have been ten pounds five ounces expelled: if with each stroke two drachms are expelled, the quantity would of course amount to twenty pounds and ten ounces; if half an ounce, the quantity would come to forty-one pounds and eight ounces; and were there one ounce it would be as much as eighty-three pounds and four ounces; the whole of which, in the course of one half hour, would have been transfused from the veins to the arteries. The actual quantity of blood expelled at each stroke of the heart, and the circumstances under which it is either greater or less than ordinary, I leave for particular determination afterwards, from numerous observations which I have made on the subject.

Meantime this much I know, and would here proclaim to all, that the blood is transfused at one time in larger, at another in smaller quantity; and that the circuit of the blood is accomplished now more rapidly, now more slowly, according to the temperament, age, etc., of the individual, to external and internal circumstances, to naturals and non-naturals,—sleep, rest, food, exercise, affections of the

mind, and the like. But, supposing even the smallest quantity of blood to be passed through the heart and the lungs with each pulsation, a vastly greater amount would still be thrown into the arteries and whole body, than could by any possibility be supplied by the food consumed. It could be furnished in no other way than by making a circuit and returning.

This truth, indeed, presents itself obviously before us when we consider what happens in the dissection of living animals; the great artery need not be divided, but a very small branch only, (as Galen even proves in regard to man), to have the whole of the blood in the body, as well that of the veins as of the arteries, drained away in the course of no long time—some half hour or less. Butchers are well aware of the fact and can bear witness to it; for, cutting the throat of an ox and so dividing the vessels of the neck, in less than a quarter of an hour they have all the vessels bloodless—the whole mass of blood has escaped. The same thing also occasionally occurs with great rapidity in performing amputations and removing tumours in the human subject.

Nor would this argument lose any of its force, did any one say that in killing animals in the shambles, and performing amputations, the blood escaped in equal, if not perchance in larger quantity by the veins than by the arteries. The contrary of this statement, indeed, is certainly the truth; the veins, in fact, collapsing, and being without any propelling power, and further, because of the impediment of the valves, as I shall show immediately, pour out but very little blood; whilst the arteries spout it forth with force abundantly, impetuously, and as if it were propelled by a syringe. And then the experiment is easily tried of leaving the vein untouched, and only dividing the artery in the neck of a sheep or dog, when it will be seen with what force, in what abundance, and how quickly, the whole blood in the body, of the veins as well as of the arteries, is emptied. But the arteries receive blood from the veins in no other way than by transmission through the heart, as we have already seen; so that if the aorta be tied at the base of the heart, and the carotid or any other artery be opened, no one will now be sur-

prised to find it empty, and the veins only replete with blood.

And now the cause is manifest, why in our dissections we usually find so large a quantity of blood in the veins, so little in the arteries; why there is much in the right ventricle, little in the left, which probably led the ancients to believe that the arteries (as their name implies) contained nothing but spirits during the life of an animal. The true cause of the difference is perhaps this, that as there is no passage to the arteries, save through the lungs and heart, when an animal has ceased to breathe and the lungs to move, the blood in the pulmonary artery is prevented from passing into the pulmonary veins, and from thence into the left ventricle of the heart; just as we have already seen the same transit prevented in the embryo, by the want of movement in the lungs and the alternate opening and shutting of their hidden and invisible porosities and apertures. But the heart not ceasing to act at the same precise moment as the lungs, but surviving them and continuing to pulsate for a time, the left ventricle and arteries go on distributing their blood to the body at large and sending it into the veins; receiving none from the lungs, however, they are soon exhausted, and left, as it were, empty. But even this fact confirms our views, in no trifling manner, seeing that it can be ascribed to no other than the cause we have just assumed.

Moreover it appears from this that the more frequently or forcibly the arteries pulsate, the more speedily will the body be exhausted of its blood during hemorrhage. Hence, also, it happens, that in fainting fits and in states of alarm, when the heart beats more languidly and less forcibly, hemorrhages are diminished and arrested.

Still further, it is from this, that after death, when the heart has ceased to beat, it is impossible by dividing either the jugular or femoral veins and arteries, by any effort to force out more than one half of the whole mass of the blood. Neither could the butcher ever bleed the carcass effectually did he neglect to cut the throat of the ox which he has knocked on the head and stunned, before the heart had ceased beating.

Finally, we are now in a condition to suspect wherefore

it is that no one has yet said anything to the purpose upon the anastomosis of the veins and arteries, either as to where or how it is effected, or for what purpose. I now enter upon the investigation of the subject.

CHAPTER X.

THE FIRST POSITION: OF THE QUANTITY OF BLOOD PASSING FROM THE VEINS TO THE ARTERIES. AND THAT THERE IS A CIRCUIT OF THE BLOOD, FREED FROM OBJECTIONS, AND FARTHER CONFIRMED BY EXPERIMENT.

So far our first position is confirmed, whether the thing be referred to calculation or to experiment and dissection, viz., that the blood is incessantly poured into the arteries in larger quantities than it can be supplied by the food; so that the whole passing over in a short space of time, it is matter of necessity that the blood perform a circuit, that it return to whence it set out.

But if anyone shall here object that a large quantity may pass through and yet no necessity be found for a circulation, that all may come from the meat and drink consumed, and quote as an illustration the abundant supply of milk in the mammæ—for a cow will give three, four, and even seven gallons and more in a day, and a woman two or three pints whilst nursing a child or twins, which must manifestly be derived from the food consumed; it may be answered, that the heart by computation does as much and more in the course of an hour or two.

And if not yet convinced, he shall still insist, that when an artery is divided, a preternatural route is, as it were, opened, and that so the blood escapes in torrents, but that the same thing does not happen in the healthy and uninjured body when no outlet is made; and that in arteries filled, or in their natural state, so large a quantity of blood cannot pass in so short a space of time as to make any return necessary;—to all this it may be answered, that from the calculation already made, and the reasons assigned, it

appears, that by so much as the heart in its dilated state contains in addition to its contents in the state of constriction, so much in a general way must it emit upon each pulsation, and in such quantity must the blood pass, the body being entire and naturally constituted.

But in serpents, and several fishes, by tying the veins some way below the heart, you will perceive a space between the ligature and the heart speedily to become empty; so that, unless you would deny the evidence of your senses, you must needs admit the return of the blood to the heart. The same thing will also plainly appear when we come to discuss our second position.

Let us here conclude with a single example, confirming all that has been said, and from which everyone may obtain conviction through the testimony of his own eyes.

If a live snake be laid open, the heart will be seen pulsating quietly, distinctly, for more than an hour, moving like a worm, contracting in its longitudinal dimensions, (for it is of an oblong shape,) and propelling its contents. It becomes of a paler colour in the systole, of a deeper tint in the diastole; and almost all things else are seen by which I have already said that the truth I contend for is established, only that here everything takes place more slowly, and is more distinct. This point in particular may be observed more clearly than the noon-day sun: the vena cava enters the heart at its lower part, the artery quits it at the superior part; the vein being now seized either with forceps or between the finger and thumb, and the course of the blood for some space below the heart interrupted, you will perceive the part that intervenes between the fingers and the heart almost immediately to become empty, the blood being exhausted by the action of the heart; at the same time the heart will become of a much paler colour, even in its state of dilatation, than it was before; it is also smaller than at first, from wanting blood; and then it begins to beat more slowly, so that it seems at length as if it were about to die. But the impediment to the flow of blood being removed, instantly the colour and the size of the heart are restored.

If, on the contrary, the artery instead of the vein be compressed or tied, you will observe the part between the

obstacle and the heart, and the heart itself, to become inordinately distended, to assume a deep purple or even livid colour, and at length to be so much oppressed with blood that you will believe it about to be choked; but the obstacle removed, all things immediately return to their natural state in colour, size, and impulse.

Here then we have evidence of two kinds of death: extinction from deficiency, and suffocation from excess. Examples of both have now been set before you, and you have had opportunity of viewing the truth contended for with your own eyes in the heart.

CHAPTER XI.

THE SECOND POSITION IS DEMONSTRATED.

That this may the more clearly appear to everyone, I have here to cite certain experiments, from which it seems obvious that the blood enters a limb by the arteries, and returns from it by the veins; that the arteries are the vessels carrying the blood from the heart, and the veins the returning channels of the blood to the heart; that in the limbs and extreme parts of the body the blood passes either immediately by anastomosis from the arteries into the veins, or mediately by the porosities of the flesh, or in both ways, as has already been said in speaking of the passage of the blood through the lungs whence it appears manifest that in the circuit the blood moves from that place to this place, and from that point to this one; from the centre to the extremities, to wit; and from the extreme parts back again to the centre. Finally, upon grounds of calculation, with the same elements as before, it will be obvious that the quantity can neither be accounted for by the ingesta, nor yet be held necessary to nutrition.

The same thing will also appear in regard to ligatures, and wherefore they are said to *draw;* though this is neither from the heat, nor the pain, nor the vacuum they occasion, nor indeed from any other cause yet thought of;

it will also explain the uses and advantages to be derived from ligatures in medicine, the principle upon which they either suppress or occasion hemorrhage; how they induce sloughing and more extensive mortification in extremities; and how they act in the castration of animals and the removal of warts and fleshy tumours. But it has come to pass, from no one having duly weighed and understood the causes and rationale of these various effects, that though almost all, upon the faith of the old writers, recommend ligatures in the treatment of disease, yet very few comprehend their proper employment, or derive any real assistance from them in effecting cures.

Ligatures are either very tight or of medium tightness. A ligature I designate as tight or perfect when it so constricts an extremity that no vessel can be felt pulsating beyond it. Such a ligature we use in amputations to control the flow of blood; and such also are employed in the castration of animals and the ablation of tumours. In the latter instances, all afflux of nutriment and heat being prevented by the ligature, we see the testes and large fleshy tumours dwindle, die, and finally fall off.

Ligatures of medium tightness I regard as those which compress a limb firmly all round, but short of pain, and in such a way as still suffers a certain degree of pulsation to be felt in the artery beyond them. Such a ligature is in use in blood-letting, an operation which the fillet applied above the elbow is not drawn so tight but that the arteries at the wrist may still be felt beating under the finger.

Now let anyone make an experiment upon the arm of a man, either using such a fillet as is employed in blood-letting, or grasping the limb lightly with his hand, the best subject for it being one who is lean, and who has large veins, and the best time after exercise, when the body is warm, the pulse is full, and the blood carried in larger quantity to the extremities, for all then is more conspicuous; under such circumstances let a ligature be thrown about the extremity, and drawn as tightly as can be borne, it will first be perceived that beyond the ligature, neither in the wrist nor anywhere else, do the arteries pulsate, at the same time that immediately above the ligature the artery begins to rise higher at each diastole, to

throb more violently, and to swell in its vicinity with a kind of tide, as if it strove to break through and overcome the obstacle to its current; the artery here, in short, appears as if it were preternaturally full. The hand under such circumstances retains its natural colour and appearance; in the course of time it begins to fall somewhat in temperature, indeed, but nothing is *drawn* into it.

After the bandage has been kept on for some short time in this way, let it be slackened a little, brought to that state or term of medium tightness which is used in bleeding, and it will be seen that the whole hand and arm will instantly become deeply coloured and distended, and the veins show themselves tumid and knotted; after ten or twelve pulses of the artery, the hand will be perceived excessively distended, injected, gorged with blood, *drawn*, as it is said, by this medium ligature, without pain, or heat, or any horror of a vacuum, or any other cause yet indicated.

If the finger be applied over the artery as it is pulsating by the edge of the fillet, at the moment of slackening it, the blood will be felt to glide through, as it were, underneath the finger; and he, too, upon whose arm the experiment is made, when the ligature is slackened, is distinctly conscious of a sensation of warmth, and of something, viz., a stream of blood suddenly making its way along the course of the vessels and diffusing itself through the hand, which at the same time begins to feel hot, and becomes distended.

As we had noted, in connexion with the tight ligature, that the artery above the bandage was distended and pulsated, not below it, so, in the case of the moderately tight bandage, on the contrary, do we find that the veins below, never above, the fillet, swell, and become dilated, whilst the arteries shrink; and such is the degree of distension of the veins here, that it is only very strong pressure that will force the blood beyond the fillet, and cause any of the veins in the upper part of the arm to rise.

From these facts it is easy for every careful observer to learn that the blood enters an extremity by the arteries; for when they are effectually compressed nothing is *drawn* to the member; the hand preserves its colour; nothing

flows into it, neither is it distended; but when the pressure is diminished, as it is with the bleeding fillet, it is manifest that the blood is instantly thrown in with force, for then the hand begins to swell; which is as much as to say, that when the arteries pulsate the blood is flowing through them, as it is when the moderately tight ligature is applied; but where they do not pulsate, as, when a tight ligature is used, they cease from transmitting anything, they are only distended above the part where the ligature is applied. The veins again being compressed, nothing can flow through them; the certain indication of which is, that below the ligature they are much more tumid than above it, and than they usually appear when there is no bandage upon the arm.

It therefore plainly appears that the ligature prevents the return of the blood through the veins to the parts above it, and maintains those beneath it in a state of permanent distension. But the arteries, in spite of its pressure, and under the force and impulse of the heart, send on the blood from the internal parts of the body to the parts beyond the ligature. And herein consists the difference between the tight and the medium ligature, that the former not only prevents the passage of the blood in the veins, but in the arteries also; the latter, however, whilst it does not prevent the force of the pulse from extending beyond it, and so propelling the blood to the extremities of the body, compresses the veins, and greatly or altogether impedes the return of the blood through them.

Seeing, therefore, that the moderately tight ligature renders the veins turgid and distended, and the whole hand full of blood, I ask, whence is this? Does the blood accumulate below the ligature coming through the veins, or through the arteries, or passing by certain hidden porosities? Through the veins it cannot come; still less can it come through invisible channels; it must needs, then, arrive by the arteries, in conformity with all that has been already said. That it cannot flow in by the veins appears plainly enough from the fact that the blood cannot be forced towards the heart unless the ligature be removed; when this is done suddenly all the veins collapse, and disgorge themselves of their contents into the superior parts, the

hand at the same time resumes its natural pale colour, the tumefaction and the stagnating blood having disappeared.

Moreover, he whose arm or wrist has thus been bound for some little time with the medium bandage, so that it has not only got swollen and livid but cold, when the fillet is undone is aware of something cold making its way upwards along with the returning blood, and reaching the elbow or the axilla. And I have myself been inclined to think that this cold blood rising upwards to the heart was the cause of the fainting that often occurs after bloodletting: fainting frequently supervenes even in robust subjects, and mostly at the moment of undoing the fillet, as the vulgar say, from the turning of the blood.

Farther, when we see the veins below the ligature instantly swell up and become gorged, when from extreme tightness it is somewhat relaxed, the arteries meantime continuing unaffected, this is an obvious indication that the blood passes from the arteries into the veins, and not from the veins into the arteries, and that there is either an anastomosis of the two orders of vessels, or porosities in the flesh and solid parts generally that are permeable to the blood. It is farther an indication that the veins have frequent communications with one another, because they all become turgid together, whilst under the medium ligature applied above the elbow; and if any single small vein be pricked with a lancet, they all speedily shrink, and disburthening themselves into this they subside almost simultaneously.

These considerations will enable anyone to understand the nature of the attraction that is exerted by ligatures, and perchance of fluxes generally; how, for example, when the veins are compressed by a bandage of medium tightness applied above the elbow, the blood cannot escape, whilst it still continues to be driven in, by the forcing power of the heart, by which the parts are of necessity filled, gorged with blood. And how should it be otherwise? Heat and pain and a vacuum draw, indeed; but in such wise only that parts are filled, not preternaturally distended or gorged, and not so suddenly and violently overwhelmed with the charge of blood forced in upon them, that the flesh is lacerated and the vessels ruptured.

Nothing of the kind as an effect of heat, or pain, or the vacuum force, is either credible or demonstrable.

Besides, the ligature is competent to occasion the afflux in question without either pain, or heat, or a vacuum. Were pain in any way the cause, how should it happen that, with the arm bound above the elbow, the hand and fingers should swell below the bandage, and their veins become distended? The pressure of the bandage certainly prevents the blood from getting there by the veins. And then, wherefore is there neither swelling nor repletion of the veins, nor any sign or symptom of attraction or afflux, above the ligature? But this is the obvious cause of the preternatural attraction and swelling below the bandage, and in the hand and fingers, that the blood is entering abundantly, and with force, but cannot pass out again.

Now is not this the cause of all tumefaction, as indeed Avicenna has it, and of all oppressive redundancy in parts, that the access to them is open, but the egress from them is closed? Whence it comes that they are gorged and tumefied. And may not the same thing happen in local inflammations, where, so long as the swelling is on the increase, and has not reached its extreme term, a full pulse is felt in the part, especially when the disease is of the more acute kind, and the swelling usually takes place most rapidly. But these are matters for after discussion. Or does this, which occurred in my own case, happen from the same cause. Thrown from a carriage upon one occasion, I struck my forehead a blow upon the place where a twig of the artery advances from the temple, and immediately, within the time in which twenty beats could have been made, I felt a tumour the size of an egg developed, without either heat or any great pain: the near vicinity of the artery had caused the blood to be effused into the bruised part with unusual force and velocity.

And now, too, we understand why in phlebotomy we apply our ligature above the part that is punctured, not below it; did the flow come from above, not from below, the constriction in this case would not only be of no service, but would prove a positive hinderance; it would have to be applied below the orifice, in order to have the flow more free, did the blood descend by the veins from

superior to inferior parts; but as it is elsewhere forced through the extreme arteries into the extreme veins, and the return in these last is opposed by the ligature, so do they fill and swell, and being thus filled and distended, they are made capable of projecting their charge with force, and to a distance, when any one of them is suddenly punctured; but the ligature being slackened, and the returning channels thus left open, the blood forthwith no longer escapes, save by drops; and, as all the world knows, if in performing phlebotomy the bandage be either slackened too much or the limb be bound too tightly, the blood escapes without force, because in the one case the returning channels are not adequately obstructed; in the other the channels of influx, the arteries, are impeded.

CHAPTER XII.

THAT THERE IS A CIRCULATION OF THE BLOOD IS SHOWN FROM THE SECOND POSITION DEMONSTRATED.

If these things be so, another point which I have already referred to, viz., the continual passage of the blood through the heart will also be confirmed. We have seen, that the blood passes from the arteries into the veins, not from the veins into the arteries; we have seen, farther, that almost the whole of the blood may be withdrawn from a puncture made in one of the cutaneous veins of the arm if a bandage properly applied be used; we have seen, still farther, that the blood flows so freely and rapidly that not only is the whole quantity which was contained in the arm beyond the ligature, and before the puncture was made, discharged, but the whole which is contained in the body, both that of the arteries and that of the veins.

Whence we must admit, first, that the blood is sent along with an impulse, and that it is urged with force below the ligature; for it escapes with force, which force it receives from the pulse and power of the heart; for the force and motion of the blood are derived from the heart

alone. Second, that the afflux proceeds from the heart, and through the heart by a course from the great veins; for it gets into the parts below the ligature through the arteries, not through the veins; and the arteries nowhere receive blood from the veins, nowhere receive blood save and except from the left ventricle of the heart. Nor could so large a quantity of blood be drawn from one vein (a ligature having been duly applied), nor with such impetuosity, such readiness, such celerity, unless through the medium of the impelling power of the heart.

But if all things be as they are now represented, we shall feel ourselves at liberty to calculate the quantity of the blood, and to reason on its circular motion. Should anyone, for instance, in performing phlebotomy, suffer the blood to flow in the manner it usually does, with force and freely, for some half hour or so, no question but that the greatest part of the blood being abstracted, faintings and syncopes would ensue, and that not only would the arteries but the great veins also be nearly emptied of their contents. It is only consonant with reason to conclude that in the course of the half hour hinted at, so much as has escaped has also passed from the great veins through the heart into the aorta. And further, if we calculate how many ounces flow through one arm, or how many pass in twenty or thirty pulsations under the medium ligature, we shall have some grounds for estimating how much passes through the other arm in the same space of time: how much through both lower extremities, how much through the neck on either side, and through all the other arteries and veins of the body, all of which have been supplied with fresh blood, and as this blood must have passed through the lungs and ventricles of the heart, and must have come from the great veins,—we shall perceive that a circulation is absolutely necessary, seeing that the quantities hinted at cannot be supplied immediately from the ingesta, and are vastly more than can be requisite for the mere nutrition of the parts.

It is still further to be observed, that in practising phlebotomy the truths contended for are sometimes confirmed in another way; for having tied up the arm properly, and made the puncture duly, still, if from alarm

or any other causes, a state of faintness supervenes, in which the heart always pulsates more languidly, the blood does not flow freely, but distils by drops only. The reason is, that with the somewhat greater than usual resistance offered to the transit of the blood by the bandage, coupled with the weaker action of the heart, and its diminished impelling power, the stream cannot make its way under the ligature; and farther, owing to the weak and languishing state of the heart, the blood is not transferred in such quantity as wont from the veins to the arteries through the sinuses of that organ. So also, and for the same reasons, are the menstrual fluxes of women, and indeed hemorrhages of every kind, controlled. And now, a contrary state of things occurring, the patient getting rid of his fear and recovering his courage, the pulse strength is increased, the arteries begin again to beat with greater force, and to drive the blood even into the part that is bound; so that the blood now springs from the puncture in the vein, and flows in a continuous stream.

CHAPTER XIII.

THE THIRD POSITION IS CONFIRMED: AND THE CIRCULATION OF THE BLOOD IS DEMONSTRATED FROM IT.

Thus far we have spoken of the quantity of blood passing through the heart and the lungs in the centre of the body, and in like manner from the arteries into the veins in the peripheral parts and the body at large. We have yet to explain, however, in what manner the blood finds its way back to the heart from the extremities by the veins, and how and in what way these are the only vessels that convey the blood from the external to the central parts; which done, I conceive that the three fundamental propositions laid down for the circulation of the blood will be so plain, so well established, so obviously true, that they may claim general credence. Now the remaining position will be made sufficiently clear from the valves which are found in

the cavities of the veins themselves, from the uses of these, and from experiments cognizable by the senses.

The celebrated Hieronymus Fabricius of Aquapendente, a most skilful anatomist, and venerable old man, or, as the learned Riolan will have it, Jacobus Silvius, first gave representations of the valves in the veins, which consist of raised or loose portions of the inner membranes of these vessels, of extreme delicacy, and a sigmoid or semilunar shape. They are situated at different distances from one another, and diversely in different individuals; they are connate at the sides of the veins; they are directed upwards or towards the trunks of the veins; the two—for there are for the most part two together—regard each other, mutually touch, and are so ready to come into contact by their edges, that if anything attempt to pass from the trunks into the branches of the veins, or from the greater vessels into the less, they completely prevent it; they are farther so arranged, that the horns of those that succeed are opposite the middle of the convexity of those that precede, and so on alternately.

The discoverer of these valves did not rightly understand their use, nor have succeeding anatomists added anything to our knowledge: 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; the valves, in a word, do not invariably look upwards, but always towards the trunks of the veins, invariably towards the seat of the heart. I, and indeed others, have sometimes found valves in the emulgent veins, and in those of the mesentery, the edges of which were directed towards the vena cava and vena portæ. Let it be added that there are no valves in the arteries, and that dogs, oxen, etc., have invariably valves at the divisions of their crural veins, in the veins that meet towards the top of the os sacrum, and in those branches which come from the haunches, in which no such effect of gravity from the erect position was to be apprehended. Neither are there valves in the jugular veins for the purpose of guarding against apoplexy, as some have said; because in sleep the

head is more apt to be influenced by the contents of the carotid arteries. Neither are the valves present, in order that the blood may be retained in the divarications or smaller trunks and minuter branches, and not be suffered to flow entirely into the more open and capacious channels; for they occur where there are no divarications; although it must be owned that they are most frequent at the points where branches join. Neither do they exist for the purpose of rendering the current of blood more slow from the centre of the body; for it seems likely that the blood would be disposed to flow with sufficient slowness of its own accord, as it would have to pass from larger into continually smaller vessels, being separated from the mass and fountain head, and attaining from warmer into colder places.

But the valves are solely made and instituted lest the blood should pass from the greater into the lesser veins, and either rupture them or cause them to become varicose; lest, instead of advancing from the extreme to the central parts of the body, the blood should rather proceed along the veins from the centre to the extremities; but the delicate valves, while they readily open in the right direction, entirely prevent all such contrary motion, being so situated and arranged, that if anything escapes, or is less perfectly obstructed by the cornua of the one above, the fluid passing, as it were, by the chinks between the cornua, it is immediately received on the convexity of the one beneath, which is placed transversely with reference to the former, and so is effectually hindered from getting any farther.

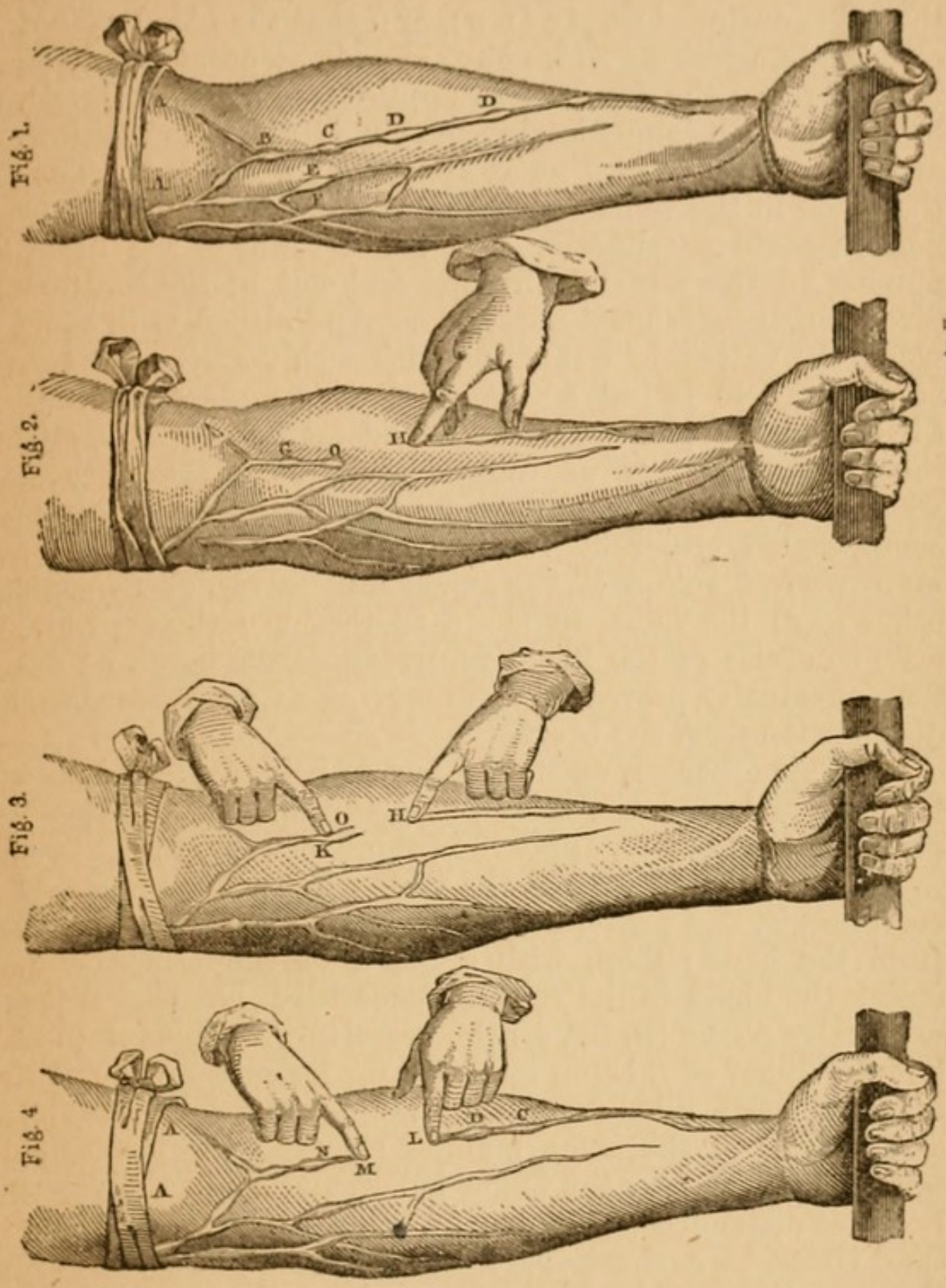
And this I have frequently experienced in my dissections of the veins: if I attempted to pass a probe from the trunk of the veins into one of the smaller branches, whatever care I took I found it impossible to introduce it far any way, by reason of the valves; whilst, on the contrary, it was most easy to push it along in the opposite direction, from without inwards, or from the branches towards the trunks and roots. In many places two valves are so placed and fitted, that when raised they come exactly together in the middle of the vein, and are there united by the contact of their margins; and so accurate is the adaptation, that

neither by the eye nor by any other means of examination, can the slightest chink along the line of contact be perceived. But if the probe be now introduced from the extreme towards the more central parts, the valves, like the floodgates of a river, give way, and are most readily pushed aside. The effect of this arrangement plainly is to prevent all motion of the blood from the heart and vena cava, whether it be upwards towards the head,or downwards towards the feet, or to either side towards the arms, not a drop can pass; all motion of the blood, beginning in the larger and tending towards the smaller veins, is opposed and resisted by them; whilst the motion that proceeds from the lesser to end in the larger branches is favoured, or, at all events, a free and open passage is left for it.

But that this truth may be made the more apparent, let an arm be tied up above the elbow as if for phlebotomy (A, A, fig. 1). At intervals in the course of the veins, especially in labouring people and those whose veins are large, certain knots or elevations (B, C, D, E, F,) will be perceived, and this not only at the places where a branch is received (E, F), but also where none enters (C, D): these knots or risings are all formed by valves, which thus show themselves externally. And now if you press the blood from the space above one of the valves, from H to O, (fig. 2,) and keep the point of a finger upon the vein inferiorly, you will see no influx of blood from above; the portion of the vein between the point of the finger and the valve O will be obliterated; yet will the vessel continue sufficiently distended above that valve (O, G). The blood being thus pressed out, and the vein emptied, if you now apply a finger of the other hand upon the distended part of the vein above the valve O, (fig. 3,) and press downwards, you will find that you cannot force the blood through or beyond the valve; but the greater effort you use, you will only see the portion of vein that is between the finger and the valve become more distended, that portion of the vein which is below the valve remaining all the while empty (H, O, fig. 3).

It would therefore appear that the function of the valves in the veins is the same as that of the three sigmoid valves which we find at the commencement of the aorta and pul-

monary artery, viz., to prevent all reflux of the blood that is passing over them.



Farther, the arm being bound as before, and the veins looking full and distended, if you press at one part in the

course of a vein with the point of a finger (L, fig. 4), and then with another finger streak the blood upwards beyond the next valve (N), you will perceive that this portion of the vein continues empty (L N), and that the blood cannot retrograde, precisely as we have already seen the case to be in fig. 2; but the finger first applied (H, fig. 2, L, fig. 4), being removed, immediately the vein is filled from below, and the arm becomes as it appears at D C, fig. 1. That the blood in the veins therefore proceeds from inferior or more remote to superior parts, and towards the heart, moving in these vessels in this and not in the contrary direction, appears most obviously. 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, or in some other way: the veins, in short, as they are the free and open conduits of the blood returning *to* the heart, so are they effectually prevented from serving as its channels of distribution *from* the heart.

But this other circumstance has to be noted: The arm being bound, and the veins made turgid, and the valves prominent, as before, apply the thumb or finger over a vein in the situation of one of the valves in such a way as to compress it, and prevent any blood from passing upwards from the hand; then, with a finger of the other hand, streak the blood in the vein upwards till it has passed the next valve above (N, fig. 4,) the vessel now remains empty; but the finger at L being removed for an instant, the vein is immediately filled from below; apply the finger again, and having in the same manner streaked the blood upwards, again remove the finger below, and again the vessel becomes distended as before; and this repeat, say a thousand times, in a short space of time. And now compute the quantity of blood which you have thus pressed up beyond the valve, and then multiplying the assumed quantity by one thousand, you will find that so much blood has passed through a certain portion of the vessel; and I do

now believe that you will find yourself convinced of the circulation of the blood, and of its rapid motion. But if in this experiment you say that a violence is done to nature, I do not doubt but that, if you proceed in the same way, only taking as great a length of vein as possible, and merely remark with what rapidity the blood flows upwards, and fills the vessel from below, you will come to the same conclusion.

CHAPTER XIV.

CONCLUSION OF THE DEMONSTRATION OF THE CIRCULATION

And now I may be allowed to give in brief my view of the circulation of the blood, and to propose it for general adoption.

Since all things, both argument and ocular demonstration, show that the blood passes through the lungs and heart by the force of the ventricles, and is sent for distribution to all parts of the body, where it makes its way into the veins and porosities of the flesh, and then flows by the veins from the circumference on every side to the centre, from the lesser to the greater veins, and is by them finally discharged into the vena cava and right auricle of the heart, and this in such a quantity or in such a flux and reflux thither by the arteries, hither by the veins, as cannot possibly be supplied by the ingesta, and is much greater than can be required for mere purposes of nutrition; it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle, and is in a state of ceaseless motion; that this is the act or function which the heart performs by means of its pulse; and that it is the sole and only end of the motion and contraction of the heart.

CHAPTER XV.

THE CIRCULATION OF THE BLOOD IS FURTHER CONFIRMED BY PROBABLE REASONS.

It will not be foreign to the subject if I here show further, from certain familiar reasonings, that the circulation is matter both of convenience and necessity. In the first place, since death is a corruption which takes place through deficiency of heat,[1] and since all living things are warm, all dying things cold, there must be a particular seat and fountain, a kind of home and hearth, where the cherisher of nature, the original of the native fire, is stored and preserved; from which heat and life are dispensed to all parts as from a fountain head; from which sustenance may be derived; and upon which concoction and nutrition, and all vegetative energy may depend. Now, that the heart is this place, that the heart is the principle of life, and that all passes in the manner just mentioned, I trust no one will deny.

The blood, therefore, required to have motion, and indeed such a motion that it should return again to the heart; for sent to the external parts of the body far from its fountain, as Aristotle says, and without motion, it would become congealed. For we see motion generating and keeping up heat and spirits under all circumstances, and rest allowing them to escape and be dissipated. The blood, therefore, becoming thick or congealed by the cold of the extreme and outward parts, and robbed of its spirits, just as it is in the dead, it was imperative that from its fount and origin, it should again receive heat and spirits, and all else requisite to its preservation—that, by returning, it should be renovated and restored.

We frequently see how the extremities are chilled by the external cold, how the nose and cheeks and hands look blue, and how the blood, stagnating in them as in the pendent or lower parts of a corpse, becomes of a dusky hue; the limbs at the same time getting torpid, so that

[1] Aristoteles De Respiratione, lib. ii et iii: De Part. Animal. et alibi.

they can scarcely be moved, and seem almost to have lost their vitality. Now they can by no means be so effectually, and especially so speedily restored to heat and colour and life, as by a new efflux and contact of heat from its source. But how can parts attract in which the heat and life are almost extinct? Or how should they whose passages are filled with condensed and frigid blood, admit fresh aliment—renovated blood—unless they had first got rid of their old contents? Unless the heart were truly that fountain where life and heat are restored to the refrigerated fluid, and whence new blood, warm, imbued with spirits, being sent out by the arteries, that which has become cooled and effete is forced on, and all the particles recover their heat which was failing, and their vital stimulus well-nigh exhausted.

Hence it is that if the heart be unaffected, life and health may be restored to almost all the other parts of the body; but if the heart be chilled, or smitten with any serious disease, it seems matter of necessity that the whole animal fabric should suffer and fall into decay. When the source is corrupted, there is nothing, as Aristotle says,[1] which can be of service either to it or aught that depends on it. And hence, by the way, it may perchance be why grief, and love, and envy, and anxiety, and all affections of the mind of a similar kind are accompanied with emaciation and decay, or with disordered fluids and crudity, which engender all manner of diseases and consume the body of man. For every affection of the mind that is attended with either pain or pleasure, hope or fear, is the cause of an agitation whose influence extends to the heart, and there induces change from the natural constitution, in the temperature, the pulse and the rest, which impairing all nutrition in its source and abating the powers at large, it is no wonder that various forms of incurable disease in the extremities and in the trunk are the consequence, inasmuch as in such circumstances the whole body labours under the effects of vitiated nutrition and a want of native heat.

Moreover, when we see that all animals live through

[1] De Part. Animal. iii.

food digested in their interior, it is imperative that the digestion and distribution be perfect; and, as a consequence, that there be a place and receptacle where the aliment is perfected and whence it is distributed to the several members. Now this place is the heart, for it is the only organ in the body which contains blood for the general use; all the others receive it merely for their peculiar or private advantage, just as the heart also has a supply for its own especial behoof in its coronary veins and arteries. But it is of the store which the heart contains in its auricles and ventricles that I here speak. Then the heart is the only organ which is so situated and constituted that it can distribute the blood in due proportion to the several parts of the body, the quantity sent to each being according to the dimensions of the artery which supplies it, the heart serving as a magazine or fountain ready to meet its demands.

Further, a certain impulse or force, as well as an impeller or forcer, such as the heart, was required to effect this distribution and motion of the blood; both because the blood is disposed from slight causes, such as cold, alarm, horror, and the like, to collect in its source, to concentrate like parts to a whole, or the drops of water spilt upon a table to the mass of liquid; and because it is forced from the capillary veins into the smaller ramifications, and from these into the larger trunks by the motion of the extremities and the compression of the muscles generally. The blood is thus more disposed to move from the circumference to the centre than in the opposite direction, even were there no valves to oppose its motion; wherefore, that it may leave its source and enter more confined and colder channels, and flow against the direction to which it spontaneously inclines, the blood requires both force and an impelling power. Now such is the heart and the heart alone, and that in the way and manner already explained.

CHAPTER XVI.

THE CIRCULATION OF THE BLOOD IS FURTHER PROVED FROM CERTAIN CONSEQUENCES.

THERE are still certain problems, which, taken as consequences of this truth assumed as proven, are not without their use in exciting belief, as it were, *a posteriore;* and which, although they may seem to be involved in much doubt and obscurity, nevertheless readily admit of having reasons and causes assigned for them. Of such a nature are those that present themselves in connexion with contagions, poisoned wounds, the bites of serpents and rabid animals, lues venerea and the like. We sometimes see the whole system contaminated, though the part first infected remains sound; the lues venerea has occasionally made its attack with pains in the shoulders and head, and other symptoms, the genital organs being all the while unaffected; and then we know that the wound made by a rabid dog having healed, fever and a train of disastrous symptoms may nevertheless supervene. Whence it appears that the contagion impressed upon or deposited in a particular part, is by-and-by carried by the returning current of blood to the heart, and by that organ is sent to contaminate the whole body.

In tertian fever, the morbific cause seeking the heart in the first instance, and hanging about the heart and lungs, renders the patient short-winded, disposed to sighing, and indisposed to exertion, because the vital principle is oppressed and the blood forced into the lungs and rendered thick. It does not pass through them, (as I have myself seen in opening the bodies of those who had died in the beginning of the attack,) when the pulse is always frequent, small, and occasionally irregular; but the heat increasing, the matter becoming attenuated, the passages forced, and the transit made, the whole body begins to rise in temperature, and the pulse becomes fuller and stronger. The febrile paroxysm is fully formed, whilst the preternatural

heat kindled in the heart is thence diffused by the arteries through the whole body along with the morbific matter, which is in this way overcome and dissolved by nature.

When we perceive, further, that medicines applied externally exert their influence on the body just as if they had been taken internally, the truth we are contending for is confirmed. Colocynth and aloes in this way move the belly, cantharides excites the urine, garlic applied to the soles of the feet assists expectoration, cordials strengthen, and an infinite number of examples of the same kind might be cited. Perhaps it will not, therefore, be found unreasonable, if we say that the veins, by means of their orifices, absorb some of the things that are applied externally and carry this inwards with the blood, not otherwise, it may be, than those of the mesentery imbibe the chyle from the intestines and carry it mixed with the blood to the liver. For the blood entering the mesentery by the cœliac artery, and the superior and inferior mesenterics, proceeds to the intestines, from which, along with the chyle that has been attracted into the veins, it returns by their numerous ramifications into the vena portæ of the liver, and from this into the vena cava, and this in such wise that the blood in these veins has the same colour and consistency as in other veins, in opposition to what many believe to be the fact. Nor indeed can we imagine two contrary motions in any capillary system—the chyle upwards, the blood downwards. This could scarcely take place, and must be held as altogether improbable. But is not the thing rather arranged as it is by the consummate providence of nature? For were the chyle mingled with the blood, the crude with the digested, in equal proportions, the result would not be concoction, transmutation, and sanguification, but rather, and because they are severally active and passive, a mixture or combination, or medium compound of the two, precisely as happens when wine is mixed with water and syrup. But when a very minute quantity of chyle is mingled with a very large quantity of circulating blood, a quantity of chyle that bears no kind of proportion to the mass of blood, the effect is the same, as Aristotle says, as when a drop of water is added to a cask of wine, or the contrary; the mass does not then

present itself as a mixture, but is still sensibly either wine or water. So in the mesenteric veins of an animal we do not find either chyme or chyle and blood, blended together or distinct, but only blood, the same in colour, consistency, and other sensible properties, as it appears in the veins generally. Still as there is a certain though small and inappreciable proportion of chyle or incompletely digested matter mingled with this blood, nature has interposed the liver, in whose meandering channels it suffers delay and undergoes additional change, lest arriving prematurely and crude at the heart, it should oppress the vital principle. Hence in the embryo, there is almost no use for the liver, but the umbilical vein passes directly through, a foramen or anastomosis existing from the vena portæ. The blood returns from the intestines of the fœtus, not through the liver, but into the umbilical vein mentioned, and flows at once into the heart, mingled with the natural blood which is returning from the placenta; whence also it is that in the development of the fœtus the liver is one of the organs that is last formed. I have observed all the members perfectly marked out in the human fœtus, even the genital organs, whilst there was yet scarcely any trace of the liver. And indeed at the period when all the parts, like the heart itself in the beginning, are still white, and except in the veins there is no appearance of redness, you shall see nothing in the seat of the liver but a shapeless collection, as it were, of extravasated blood, which you might take for the effects of a contusion or ruptured vein.

But in the incubated egg there are, as it were, two umbilical vessels, one from the albumen passing entire through the liver, and going straight to the heart; another from the yelk, ending in the vena portæ; for it appears that the chick, in the first instance, is entirely formed and nourished by the white; but by the yelk after it has come to perfection and is excluded from the shell; for this part may still be found in the abdomen of the chick many days after its exclusion, and is a substitute for the milk to other animals.

But these matters will be better spoken of in my observations on the formation of the fœtus, where many propositions, the following among the number, will be discussed:

Wherefore is this part formed or perfected first, that last, and of the several members, what part is the cause of another? And there are many points having special reference to the heart, such as wherefore does it first acquire consistency, and appear to possess life, motion, sense, before any other part of the body is perfected, as Aristotle says in his third book, "De partibus Animalium"? And so also of the blood, wherefore does it precede all the rest? And in what way does it possess the vital and animal principle, and show a tendency to motion, and to be impelled hither and thither, the end for which the heart appears to be made? In the same way, in considering the pulse, why should one kind of pulse indicate death, another recovery? And so of all the other kinds of pulse, what may be the cause and indication of each? Likewise we must consider the reason of crises and natural critical discharges; of nutrition, and especially the distribution of the nutriment; and of defluxions of every description. Finally, reflecting on every part of medicine, physiology, pathology, semeiotics, and therapeutics, when I see how many questions can be answered, how many doubts resolved, how much obscurity illustrated by the truth we have declared, the light we have made to shine, I see a field of such vast extent in which I might proceed so far, and expatiate so widely, that this my tractate would not only swell out into a volume, which was beyond my purpose, but my whole life, perchance, would not suffice for its completion.

In this place, therefore, and that indeed in a single chapter, I shall only endeavour to refer the various particulars that present themselves in the dissection of the heart and arteries to their several uses and causes; for so I shall meet with many things which receive light from the truth I have been contending for, and which, in their turn, render it more obvious. And indeed I would have it confirmed and illustrated by anatomical arguments above all others.

There is but a single point which indeed would be more correctly placed among our observations on the use of the spleen, but which it will not be altogether impertinent to notice in this place incidentally. From the splenic branch which passes into the pancreas, and from the upper part,

arise the posterior coronary, gastric, and gastroepiploic veins, all of which are distributed upon the stomach in numerous branches and twigs, just as the mesenteric vessels are upon the intestines. In a similar way, from the inferior part of the same splenic branch, and along the back of the colon and rectum proceed the hemorrhoidal veins. The blood returning by these veins, and bringing the cruder juices along with it, on the one hand from the stomach, where they are thin, watery, and not yet perfectly chylified; on the other thick and more earthy, as derived from the fæces, but all poured into this splenic branch, are duly tempered by the admixture of contraries; and nature mingling together these two kinds of juices, difficult of coction by reason of most opposite defects, and then diluting them with a large quantity of warm blood, (for we see that the quantity returned from the spleen must be very large when we contemplate the size of its arteries,) they are brought to the porta of the liver in a state of higher preparation. The defects of either extreme are supplied and compensated by this arrangement of the veins.

CHAPTER XVII.

THE MOTION AND CIRCULATION OF THE BLOOD ARE CONFIRMED FROM THE PARTICULARS APPARENT IN THE STRUCTURE OF THE HEART, AND FROM THOSE THINGS WHICH DISSECTION UNFOLDS.

I DO not find the heart as a distinct and separate part in all animals; some, indeed, such as the zoophytes, have no heart; this is because these animals are coldest, of no great bulk, of soft texture or of a certain uniform sameness or simplicity of structure; among the number I may instance grubs and earth-worms, and those that are engendered of putrefaction and do not preserve their species. These have no heart, as not requiring any impeller of nourishment into the extreme parts; for they have bodies

which are connate and homogeneous, and without limbs; so that by the contraction and relaxation of the whole body they assume and expel, move and remove the aliment. Oysters,[1] mussels, sponges, and the whole genus of zoophytes or plant-animals have no heart; for the whole body is used as a heart, or the whole animal is a heart. In a great number of animals, almost the whole tribe of insects,[2] we cannot see distinctly by reason of the smallness of the body; still in bees, flies, hornets, and the like, we can perceive something pulsating with the help of a magnifying-glass; in pediculi, also, the same thing may be seen, and as the body is transparent, the passage of the food through the intestines, like a black spot or stain, may be perceived by the aid of the same magnifying-glass.

But in some of the pale blooded and colder animals, as in snails, whelks, shrimps, and shell-fish, there is a part which pulsates—a kind of vesicle or auricle without a heart—slowly indeed, and not to be perceived except in the warmer season of the year. In these creatures this part is so contrived that it shall pulsate, as there is here a necessity for some impulse to distribute the nutritive fluid, by reason of the variety of organic parts, or of the density of the substance; but the pulsations occur unfrequently, and sometimes in consequence of the cold not at all, an arrangement the best adapted to them as being of a doubtful nature, so that sometimes they appear to live, sometimes to die; sometimes they show the vitality of an animal, sometimes of a vegetable. This seems also to be the case with the insects which conceal themselves in winter, and lie, as it were, defunct, or merely manifesting a kind of vegetative existence. But whether the same thing happens in the case of certain animals that have red blood, such as frogs, tortoises, serpents, swallows, may be very properly doubted.

[1] [Oysters and mussels are structurally much more complex than Harvey believed. In both a distinct heart is to be found.—Ed.]

[2] [It is now known that insects have a rudimentary heart in the form of a long contractile cavity, styled the "dorsal vessel." It is usually composed of eight sacs which open into one another by means of valvular apertures allowing the current of blood to flow in one direction only, towards the head.—Ed.]

In all the larger and warmer animals which have red blood, there was need of an impeller of the nutritive fluid, and that perchance possessing a considerable amount of power. In fishes, serpents, lizards, tortoises, frogs, and others of the same kind there is a heart present, furnished with both an auricle and a ventricle, whence it is perfectly true, as Aristotle has observed,[1] that no sanguineous animal is without a heart, by the impelling power of which the nutritive fluid is forced, both with greater vigour and rapidity to a greater distance; and not merely agitated by an auricle as it is in lower forms. And then in regard to animals that are yet larger, warmer, and more perfect, as they abound in blood, which is always hotter and more spirituous, and which possess bodies of greater size and consistency, these require a larger, stronger, and more fleshy heart, in order that the nutritive fluid may be propelled with yet greater force and celerity. And further, inasmuch as the more perfect animals require a still more perfect nutrition, and a larger supply of native heat, in order that the aliment may be thoroughly concocted and acquire the last degree of perfection, they required both lungs and a second ventricle, which should force the nutritive fluid through them.

Every animal that has lungs has therefore two ventricles to its heart, one right, the other left; and wherever there is a right, there also is there a left ventricle; but the contrary of this does not hold good: where there is a left there is not always a right ventricle. The left ventricle I call that which is distinct in office, not in place from the other, that one namely which distributes the blood to the body at large, not to the lungs only. Hence the left ventricle seems to form the principle part of the heart; situated in the middle, more strongly marked, and constructed with greater care, the heart seems formed for the sake of the left ventricle, and the right but to minister to it. The right neither reaches to the apex of the heart, nor is it nearly of such strength, being three times thinner in its walls, and in some sort jointed on to the left, (as Aristotle says;) though indeed it is of greater capacity, inasmuch as

[1] De Part. Animal. lib. iii.

it has not only to supply material to the left ventricle, but likewise to furnish aliment to the lungs.

It is to be observed, however, that all this is otherwise in the embryo, where there is not such a difference between the two ventricles. There, as in a double nut, they are nearly equal in all respects, the apex of the right reaching to the apex of the left, so that the heart presents itself as a sort of double-pointed cone. And this is so, because in the fœtus, as already said, whilst the blood is not passing through the lungs from the right to the left cavities of the heart, it flows by the foramen ovale and ductus arteriosus, directly from the vena cava into the aorta, whence it is distributed to the whole body. Both ventricles have therefore the same office to perform, whence their equality of constitution. It is only when the lungs come to be used, and it is requisite that the passages indicated should be blocked up, that the difference in point of strength and other things between the two ventricles begins to be apparent. In the altered circumstances the right has only to drive the blood through the lungs, whilst the left has to propel it through the whole body.

There are moreover within the heart numerous braces, in the form of fleshy columns and fibrous bands, which Aristotle, in his third book on Respiration, and the Parts of Animals, entitles nerves. These are variously extended, and are either distinct or contained in grooves in the walls and partition, where they occasion numerous pits or depressions. They constitute a kind of small muscles, which are superadded and supplementary to the heart, assisting it to execute a more powerful and perfect contraction, and so proving subservient to the complete expulsion of the blood. They are in some sort like the elaborate and artful arrangement of ropes in a ship, bracing the heart on every side as it contracts, and so enabling it more effectually and forcibly to expel the charge of blood from its ventricles. This much is plain, at all events, that in some animals they are less strongly marked than in others; and, in all that have them, they are more numerous and stronger in the left than in the right ventricle; and while some have them present in the left, yet they are absent in the right ventricle. In man they are more numerous in the left than in the

right ventricle, more abundant in the ventricles than in the auricles; and occasionally, there appear to be none present in the auricles. They are numerous in the large, more muscular and hardier bodies of countrymen, but fewer in more slender frames and in females.

In those animals in which the ventricles of the heart are smooth within, and entirely without fibres or muscular bands, or anything like hollow pits, as in almost all the smaller birds, the partridge and the common fowl, serpents, frogs, tortoises, and most fishes, there are no chordæ tendineæ, nor bundles of fibres, neither are there any tricuspid valves in the ventricles.

Some animals have the right ventricle smooth internally, but the left provided with fibrous bands, such as the goose, swan, and larger birds; and the reason is the same here as elsewhere. As the lungs are spongy, and loose, and soft, no great amount of force is required to force the blood through them, therefore the right ventricle is either without the bundles in question, or they are fewer and weaker, and not so fleshy or like muscles. Those of the left ventricle, however, are both stronger and more numerous, more fleshy and muscular, because the left ventricle requires to be stronger, inasmuch as the blood which it propels has to be driven through the whole body. And this, too, is the reason why the left ventricle occupies the middle of the heart, and has parieties three times thicker and stronger than those of the right. Hence all animals—and among men it is similar—that are endowed with particularly strong frames, and with large and fleshy limbs at a great distance from the heart, have this central organ of greater thickness, strength, and muscularity. This is manifest and necessary. Those, on the contrary, that are of softer and more slender make have the heart more flaccid, softer, and internally either less or not at all fibrous. Consider farther the use of the several valves, which are all so arranged, that the blood once received into the ventricles of the heart shall never regurgitate, once forced into the pulmonary artery and aorta shall not flow back upon the ventricles. When the valves are raised and brought together they form a three-cornered line, such as is left by the bite of a leech; and the more they are forced, the more firmly

do they oppose the passage of the blood. The tricuspid valves are placed, like gate-keepers, at the entrance into the ventricles from the venæ cavæ and pulmonary veins, lest the blood when most forcibly impelled should flow back. It is for this reason that they are not found in all animals, nor do they appear to have been constructed with equal care in all the animals in which they are found. In some they are more accurately fitted, in others more remissly or carelessly contrived, and always with a view to their being closed under a greater or a slighter force of the ventricle. In the left ventricle, therefore, in order that the occlusion may be the more perfect against the greater impulse, there are only two valves, like a mitre, and produced into an elongated cone, so that they come together and touch to their middle; a circumstance which perhaps led Aristotle into the error of supposing this ventricle to be double, the division taking place transversely. For the same reason, and that the blood may not regurgitate upon the pulmonary veins, and thus the force of the ventricle in propelling the blood through the system at large come to be neutralized, it is that these mitral valves excel those of the right ventricle in size and strength, and exactness of closing. Hence, it is essential that there can be no heart without a ventricle, since this must be the source and storehouse of the blood. The same law does not hold good in reference to the brain. For almost no genus of birds has a ventricle in the brain, as is obvious in the goose and swan, the brains of which nearly equal that of a rabbit in size; now rabbits have ventricles in the brain, whilst the goose has none. In like manner, wherever the heart has a single ventricle, there is an auricle appended, flaccid, membranous, hollow, filled with blood; and where there are two ventricles, there are likewise two auricles. On the other hand, some animals have an auricle without any ventricle; or at all events they have a sac analogous to an auricle; or the vein itself, dilated at a particular part, performs pulsations, as is seen in hornets, bees, and other insects, which certain experiments of my own enable me to demonstrate have not only a pulse, but a respiration in that part which is called the tail, whence it is that this part is elongated and contracted now more

rarely, now more frequently, as the creature appears to be blown and to require a larger quantity of air. But of these things, more in our Treatise on Respiration.

It is in like manner evident that the auricles pulsate, contract, as I have said before, and throw the blood into the ventricles; so that wherever there is a ventricle an auricle is necessary, not merely that it may serve, according to the general belief, as a source and magazine for the blood: for what were the use of its pulsations had it only to contain? The auricles are prime movers of the blood, especially the right auricle, which, as already said, is "the first to live, the last to die;" whence they are subservient to sending the blood into the ventricles, which, contracting continuously, more readily and forcibly expel the blood already in motion; just as the ball-player can strike the ball more forcibly and further if he takes it on the rebound than if he simply threw it. Moreover, and contrary to the general opinion, neither the heart nor anything else can dilate or distend itself so as to draw anything into its cavity during the diastole, unless, like a sponge, it has been first compressed, and is returning to its primary condition. But in animals all local motion proceeds from, and has its origin in the contraction of some part: consequently it is by the contraction of the auricles that the blood is thrown into the ventricles, as I have already shown, and from there, by the contraction of the ventricles, it is propelled and distributed. Concerning local motions, it is true that the immediate moving organ in every motion of an animal primarily endowed with a motive spirit (as Aristotle has it,[1]) is contractile; in which way the word *νεῦρον* is derived from *νεύω*, nuto, contraho; and if I am permitted to proceed in my purpose of making a particular demonstration of the organs of motion in animals from observations in my possession, I trust I shall be able to make sufficiently plain how Aristotle was acquainted with the muscles, and advisedly referred all motion in animals to the nerves, or to the contractile element, and therefore called those little bands in the heart nerves.

But that we may proceed with the subject which we have

[1] In the book, de Spiritu, and elsewhere.

in hand, viz., the use of the auricles in filling the ventricles, we should expect that the more dense and compact the heart, the thicker its parieties, the stronger and more muscular must be the auricle to force and fill it, and *vice versa*. Now this is actually so: in some the auricle presents itself as a sanguinolent vesicle, as a thin membrane containing blood, as in fishes, in which the sac that stands in lieu of the auricle, is of such delicacy and ample capacity, that it seems to be suspended or to float above the heart. In those fishes in which the sac is somewhat more fleshy, as in the carp, barbel, tench, and others, it bears a wonderful and strong resemblance to the lungs.

In some men of sturdier frame and stouter make, the right auricle is so strong, and so curiously constructed on its inner surface of bands and variously interlacing fibres, that it seems to equal in strength the ventricle of the heart in other subjects; and I must say that I am astonished to find such diversity in this particular in different individuals. It is to be observed, however, that in the fœtus the auricles are out of all proportion large, which is because they are present before the heart[1] makes its appearance or suffices for its office even when it has appeared, and they therefore have, as it were, the duty of the whole heart committed to them, as has already been demonstrated. But what I have observed in the formation of the fœtus as before remarked (and Aristotle had already confirmed all in studying the incubated egg,) throws the greatest light and likelihood upon the point. Whilst the fœtus is yet in the form of a soft worm, or, as is commonly said, in the milk, there is a mere bloody point or pulsating vesicle, a portion apparently of the umbilical vein, dilated at its commencement or base. Afterwards, when the outline of the fœtus is distinctly indicated, and it begins to have greater bodily consistence, the vesicle in question becomes more fleshy and stronger, changes its position, and passes into the auricles, above which the body of the heart begins to sprout, though as yet it apparently performs no office. When the fœtus is farther advanced, when the bones can be distinguished from the fleshy parts,

[1] [The ventricles.—Ed.]

and movements take place, then it also has a heart which pulsates, and, as I have said, throws blood by either ventricle from the vena cava into the arteries.

Thus nature, ever perfect and divine, doing nothing in vain, has neither given a heart where it was not required, nor produced it before its office had become necessary; but by the same stages in the development of every animal, passing through the forms of all, as I may say (ovum, worm, fœtus), it acquires perfection in each. These points will be found elsewhere confirmed by numerous observations on the formation of the fœtus.

Finally, it is not without good grounds that Hippocrates, in his book, De Corde, entitles it a muscle; its action is the same, so is its function, viz., to contract and move something else, in this case, the charge of blood.

Farther, we can infer the action and use of the heart from the arrangement of its fibres and its general structure as in muscles generally. All anatomists admit with Galen that the body of the heart is made up of various courses of fibres running straight, obliquely, and transversely, with reference to one another; but in a heart which has been boiled the arrangement of the fibres is seen to be different. All the fibres in the parietes and septum are circular, as in the sphincters; those, again, which are in the columns extend lengthwise, and are oblique longitudinally; and so it comes to pass, that when all the fibres contract simultaneously, the apex of the cone is pulled towards its base by the columns, the walls are drawn circularly together into a globe, the whole heart in short is contracted, and the ventricles narrowed. It is therefore impossible not to perceive that, as the action of the organ is so plainly contraction, its function is to propel the blood into the arteries.

Nor are we the less to agree with Aristotle in regard to the importance of the heart, or to question if it receives sense and motion from the brain, blood from the liver, or whether it be the origin of the veins and of the blood, and such like. They who affirm these propositions, overlook, or do not rightly understand the principal argument, to the effect that the heart is the first part which exists, and that it contains within itself blood, life, sensation, and motion,

before either the brain or the liver were created or had appeared distinctly, or, at all events, before they could perform any function. The heart, ready furnished with its proper organs of motion, like a kind of internal creature, existed before the body. The first to be formed, nature willed that it should afterwards fashion, nourish, preserve, complete the entire animal, as its work and dwelling-place: and as the prince in a kingdom, in whose hands lie the chief and highest authority, rules over all, the heart is the source and foundation from which all power is derived, on which all power depends in the animal body.

Many things having reference to the arteries farther illustrate and confirm this truth. Why does not the pulmonary vein pulsate, seeing that it is numbered among the arteries? Or wherefore is there a pulse in the pulmonary artery? Because the pulse of the arteries is derived from the impulse of the blood. Why does an artery differ so much from a vein in the thickness and strength of its coats? Because it sustains the shock of the impelling heart and streaming blood. Hence, as perfect nature does nothing in vain, and suffices under all circumstances, we find that the nearer the arteries are to the heart, the more do they differ from the veins in structure; here they are both stronger and more ligamentous, whilst in extreme parts of the body, such as the feet and hands, the brain, the mesentery, and the testicles, the two orders of vessels are so much alike that it is impossible to distinguish between them with the eye. Now this is for the following very sufficient reasons: the more remote the vessels are from the heart, with so much the less force are they distended by the stroke of the heart, which is broken by the great distance at which it is given. Add to this, that the impulse of the heart exerted upon the mass of blood, which must needs fill the trunks and branches of the arteries, is diverted, divided, as it were, and diminished at every subdivision, so that the ultimate capillary divisions of the arteries look like veins, and this not merely in constitution but in function. They have either no perceptible pulse, or they rarely exhibit one, and never except where the heart beats more violently than usual, or at a part where

the minute vessel is more dilated or open than elsewhere. It therefore happens that at times we are aware of a pulse in the teeth, in inflammatory tumours, and in the fingers; at another time we feel nothing of the sort. By this single symptom I have ascertained for certain that young persons, whose pulses are naturally rapid, were labouring under fever; and in like manner, on compressing the fingers in youthful and delicate subjects during a febrile paroxysm, I have readily perceived the pulse there. On the other hand, when the heart pulsates more languidly, it is often impossible to feel the pulse not merely in the fingers, but the wrist, and even at the temple, as in persons afflicted with lipothymiæ asphyxia, or hysterical symptoms, and in the debilitated and moribund.

Here surgeons are to be advised that, when the blood escapes with force in the amputation of limbs, in the removal of tumours, and in wounds, it constantly comes from an artery; not always indeed per saltum, because the smaller arteries do not pulsate, especially if a tourniquet has been applied.

For the same reason the pulmonary artery not only has the structure of an artery, but it does not differ so widely from the veins in the thickness of its walls as does the aorta. The aorta sustains a more powerful shock from the left than the pulmonary artery does from the right ventricle, and the walls of this last vessel are thinner and softer than those of the aorta in the same proportion as the walls of the right ventricle of the heart are weaker and thinner than those of the left ventricle. In like manner, the lungs are softer and laxer in structure than the flesh and other constituents of the body, and in a similar way the walls of the branches of the pulmonary artery differ from those of the vessels derived from the aorta. And the same proportion in these particulars is universally preserved. The more muscular and powerful men are, the firmer their flesh; the stronger, thicker, denser, and more fibrous their hearts, the thicker, closer, and stronger are the auricles and arteries. Again, in those animals the ventricles of whose hearts are smooth on their inner surface, without villi or valves, and the walls of which are thin, as in fishes, serpents, birds, and very many genera of animals, the

arteries differ little or nothing in the thickness of their coats from the veins.

Moreover, the reason why the lungs have such ample vessels, both arteries and veins, (for the capacity of the pulmonary veins exceeds that of both the crural and jugular vessels,) and why they contain so large a quantity of blood, as by experience and ocular inspection we know they do, admonished of the fact indeed by Aristotle, and not led into error by the appearances found in animals which have been bled to death,—is, because the blood has its fountain, and storehouse, and the workshop of its last perfection in the heart and lungs. Why, in the same way we find in the course of our anatomical dissections the pulmonary vein and left ventricle so full of blood, of the same black colour and clotted character as that with which the right ventricle and pulmonary artery are filled, is because the blood is incessantly passing from one side of the heart to the other through the lungs. Wherefore, in fine, the pulmonary artery has the structure of an artery, and the pulmonary veins have the structure of veins. In function and constitution, and everything else, the first is an artery, the others are veins, contrary to what is commonly believed; and the reason why the pulmonary artery has so large an orifice, is because it transports much more blood than is requisite for the nutrition of the lungs.

All these appearances, and many others, to be noted in the course of dissection, if rightly weighed, seem clearly to illustrate and fully to confirm the truth contended for throughout these pages, and at the same time to oppose the vulgar opinion; for it would be very difficult to explain in any other way to what purpose all is constructed and arranged as we have seen it to be.

AN ANATOMICAL DISQUISITION

ON THE

CIRCULATION OF THE BLOOD.

TO

JOHN RIOLAN, JUN., OF PARIS;

A MOST SKILFUL PHYSICIAN; THE CORYPHÆUS OF ANATOMISTS; REGIUS PROFESSOR OF ANATOMY AND BOTANY IN THE UNIVERSITY OF PARIS; DEAN OF THE SAME UNIVERSITY; AND FIRST PHYSICIAN TO THE QUEEN, MOTHER OF LOUIS XIII.

BY WILLIAM HARVEY, AN ENGLISHMAN,

PROFESSOR OF ANATOMY AND SURGERY IN THE ROYAL COLLEGE OF PHYSICIANS OF LONDON; AND PRINCIPAL PHYSICIAN TO HIS MOST SERENE MAJESTY THE KING.

CAMBRIDGE, 1649.

THE FIRST ANATOMICAL DISQUISITION ON THE CIRCULATION OF THE BLOOD, ADDRESSED TO JO. RIOLAN.

Some few months ago there appeared a small anatomical and pathological work from the pen of the celebrated Riolanus, for which, as sent to me by the author himself, I return him my grateful thanks.[1] I also congratulate this author on the highly laudable undertaking in which he has engaged. To demonstrate the seats of all diseases is a task that can only be achieved under favour of the highest abilities; for surely he enters on a difficult province who proposes to bring under the cognizance of the eyes those diseases which almost escape the keenest understanding. But such efforts become the prince of anatomists; for there is no science which does not spring from pre-existing knowledge, and no certain and definite idea which has not derived its origin from the senses. Induced, therefore, by the subject itself, and the example of so distinguished an individual, which makes me think lightly of the labour, I also intend putting to press my Medical Anatomy, or Anatomy in its Application to Medicine. Not with the purpose, like Riolanus, of indicating the seats of diseases from the bodies of healthy subjects, and discussing the several diseases that make their appearance there, according to the views which others have entertained of them; but that I may relate from the many dissections I have made of the bodies of persons diseased, worn out by serious and strange affections, how and in what way the internal organs were changed in their situation, size, structure, figure, consistency, and other sensible qualities, from their natural forms and appearances, such as they are usually described by anatomists; and in what

[1] Encheiridium Anatomicum et Pathologicum. 12mo. Parisiis, 1648.

various and remarkable ways they were affected. For even as the dissection of healthy and well-constituted bodies contributes essentially to the advancement of philosophy and sound physiology, so does the inspection of diseased and cachectic subjects powerfully assist philosophical pathology. And, indeed, the physiological consideration of the things which are according to nature is to be first undertaken by medical men; since that which is in conformity with nature is right, and serves as a rule both to itself and to that which is amiss, and by the light it sheds, errors and preternatural affections are defined. Pathology then stands out more clearly, and from pathology the use and art of healing, as well as occasions for the discovery of many new remedies, occur. Nor could anyone readily imagine how extensively internal organs are altered in diseases, especially chronic diseases, and what monstrosities among internal parts these diseases engender. So that I venture to say that the examination of a single body of one who has died of tabes or some other disease of long standing, or of a poisonous nature, is of more service to medicine than the dissection of the bodies of ten men who have been hanged.

I would not have it supposed by this that I in any way disapprove of the purpose of Riolanus, that learned and skilful anatomist. On the contrary, I think it deserving of the highest praise, as likely to be extremely useful to medicine, inasmuch as it illustrates the physiological branch of this science. But I have thought that it would scarcely turn out less profitable to the art of healing, did I place before the eyes of my readers not only the places, but the affections of these places, illustrating them as I proceed with observations, and recording the results of my experience derived from my numerous dissections.

But it is imperative on me first to dispose of those observations contained in the work referred to, which bear upon the circulation of the blood as discovered by me, and which seem to require especial notice at my hands. For the judgment of such a man, who is indeed the prince and leader of all the anatomists of the present age, is not to be lightly esteemed in this matter, but is rather to be held of greater weight and authority, either for praise or

blame, than the commendations or censure of all the world besides.

Riolanus, then, in Enchiridion, book iii. chapter 8, admits our motion of the blood in animals, and falls in with our conclusions in regard to the circulation; yet not entirely and avowedly; for he says, in the second book, chapter twenty-one, that the blood contained in the vena portæ does not circulate like that in the vena cava; and in the third book, chapter eight, he states that there is some blood which circulates, and that the circulatory vessels are the aorta and vena cava; but then he denies that the continuations of these trunks have any circulation, "because the blood is effused into all the parts of the second and third regions, where it remains for purposes of nutrition, nor does it return to any greater vessels, unless forcibly drawn back when there is a great lack of blood in the greater vessels, or driven by a fit of passion when it flows to the greater circulatory vessels;" and shortly afterwards: "thus, as the blood of the veins naturally ascends incessantly or returns to the heart, the blood of the arteries descends or departs from the heart. Still, if the smaller veins of the arms and legs be empty, the blood filling the empty channels in succession, may descend in the veins, as I have clearly shown," he says, "against Harvey and Walæus." And as the authority of Galen and daily experience confirm the anastomoses of the veins and arteries, and the necessity of the circulation of the blood, "you perceive," he continues, "the manner in which the circulation is effected, without perturbation or confusion of fluids and the destruction of the ancient system of medicine."

These words explain the motives by which this illustrious anatomist was actuated when he was led partly to admit, partly to deny the circulation of the blood; and why he only ventures on an undecided and inconclusive opinion of the subject. His fear is lest it destroy the ancient medicine. He does not yield implicitly to the truth, which it appears he could not help seeing, but rather guided by caution, he fears speaking plainly out, lest he offend the ancient physic, or perhaps seem to retract the physiological doctrines he supports in his Anthropology. The circulation of the blood does not shake, but

much rather confirms the ancient medicine; though it runs counter to the physiology of physicians, and their speculations upon natural subjects, and opposes the anatomical doctrine of the use and action of the heart and lungs, and rest of the viscera. That this is so shall readily be made to appear, both from his own words and avowal, and partly also from what I shall supply; viz., that the whole of the blood, wherever it be in the living body, moves and changes its place, not merely that which is in the larger vessels and their continuations, but that also which is in their minute subdivisions, and which is contained in the porosities of every part; that it flows from and back to the heart ceaselessly and without pause, and could not pause for ever so short a time without detriment, although I admit that occasionally, and in some places, its motion is quicker or slower.[1]

In the first place, then, our learned anatomist only denies that the contents of the branches in continuation of the vena portæ circulate; but he could neither oppose nor deny this, did he not conceal from himself the force of his own arguments; for he says in his Third Book, chap. viii., "If the heart at each pulsation admits a drop of blood which it throws into the aorta, and in the course of an hour makes two thousand beats, it is a necessary consequence that the quantity of blood transmitted must be great." He is farther forced to admit as much in reference to the mesentery, when he sees that far more than single drops of blood are sent into the cœliac and mesenteric arteries at each pulsation; so that there must either be some outlet for the fluid, of magnitude commensurate with its quantity, or the branches of the vena portæ must give way. Nor can the explanation that is had recourse to with a view of meeting the difficulty, viz., that the blood of the mesentery ebbs and flows by the same channels, after the manner of Euripus, be received as either probable or possible. Neither can the reflux from the mesentery be effected by those ways and that system of translation, by which he will have it to disgorge itself into the aorta; this were against the force of the existing cur-

[1] Vide chapter iii.

rent, by a contrary motion; nor can anything like pause or alternation be admitted, where there is very certainly an incessant influx: the blood sent into the mesentery must as inevitably go elsewhere as that which is poured into the heart. This is obvious; were it otherwise, indeed, everything like a circulation might be overturned upon the same argument and by the same subterfuge; it might just as well be said that the blood contained in the left ventricle of the heart is propelled into the aorta during the systole, and flows back to it during the diastole, the aorta disgorging itself into the ventricle, precisely as the ventricle has disgorged itself into the aorta. There would thus be circulation neither in the heart nor in the mesentery, but an alternate flux and reflux,—a useless labour, as it seems. If, therefore, and for the reason assigned and approved by him, a circulation through the heart be argued for as a thing necessary, the argument has precisely the same force when applied to the mesentery: if there be no circulation in the mesentery, neither is there any in the heart; for both affirmations, this in reference to the heart, that in reference to the mesentery, merely changing the words, stand or fall together, by force of the very same arguments.

He says: "The sigmoid valves prevent regurgitation into the heart; but there are no valves in the mesentery." To this I reply, that this is not true; for there is a valve in the splenic vein, and sometimes also in other veins. And besides, valves are not met with universally in veins; there are few or none in the deep-seated veins of the extremities, but many in the subcutaneous branches. For where the blood is flowing naturally from smaller into greater branches, into which it is disposed to enter, the pressure of the surrounding muscles is enough, and more than enough to prevent all retrograde movement, and it is forced on where the way lies open; in such circumstances, what use were there for valves? But the quantity of blood that is forced into the mesentery by each stroke of the heart, may be estimated in the same way as you estimate the quantity impelled into the hand when you bind a ligature with medium tightness about the wrist: if in so many beats the vessels of the hand become distended,

and the whole extremity swells, you will find, that much more than a single drop of blood has entered with each pulse, and which cannot return, but must remain to fill the hand and increase its size. Analogy permits us to say, that the same thing takes place in reference to the mesentery and its vessels, in an equal degree at least, if not in a greater degree, seeing that the vessels of the mesentery are considerably larger than those of the wrist. And if anyone will but think on the difficulty that is experienced with all the aid supplied by compresses, ligatures, and a multiplied apparatus, in restraining the flow of blood from the smallest artery when wounded, with what force it overcomes all obstacles and soaks through the whole apparatus, he will scarcely, I imagine, think it likely that there can be any retrograde motion against such an impulse and influx of blood, any retrograde force to meet and overcome a direct force of such power. Turning over these things in his mind, I say, no one will ever be brought to believe that the blood from the branches of the vena portæ can possibly make its way by the same channels against an influx by the artery of such impetuosity and force, and so unload the mesentery.

Moreover, if the learned anatomist does not think that the blood is moved and changed by a circular motion, but that the same fluid always stagnates in the channels of the mesentery, he appears to suppose that there are two descriptions of blood, serving different uses and ends; that the blood of the vena portæ, and that of the vena cava are dissimilar in constitution, seeing that the one requires a circulation for its preservation, the other requires nothing of the kind; which neither appears on the face of the thing, nor is its truth demonstrated by him. Our author then refers to Enchiridion, book ii. chapter 18, where "A fourth order of mesenteric vessels, the lacteal vessels, discovered by Asellius," is mentioned, and seems to infer that they extract all the nutriment from the intestines, and transfer this to the liver, the workshop of the blood, whence, having been concocted and changed into blood, (so he says in his third book, chapter the 8th), "the blood is transferred from the liver to the right ventricle of the heart." "Which things premised," he con-

tinues,[1] "all the difficulties which were formerly experienced in regard to the distribution of the chyle and blood by the same channel cease; for the lacteal véins carry the chyle to the liver, and as these canals are distinct, so may they be severally obstructed." But truly I would here ask: how this milky fluid can be poured into and pass through the liver, and how from thence gain the vena cava and the ventricle of the heart? when our author denies that the blood of the vena portæ passes through the liver, and that so a circulation is established. I pause for a reply. I would fain know how such a thing can be shown to be probable; especially when the blood appears to be both more spirituous or subtile and penetrating than the chyle or milk contained in these lacteal vessels, and is further impelled by the pulsations of the arteries that it may find a passage by other channels.

Our learned author mentions a certain tract of his on the Circulation of the Blood: I wish I could obtain a sight of it; perhaps I might retract. But had the learned writer been so disposed, I do not see but that having admitted the circular motion of the blood,[2] all the difficulties which were formerly felt in connexion with the distribution of the chyle and the blood by the same channels are brought to an equally satisfactory solution; so much so indeed that there would be no necessity for inquiring after or laying down any separate vessels for the chyle. Even as the umbilical veins absorb the nutritive juices from the fluids of the egg and transport them for the nutrition and growth of the chick, in its embryo state, so do the mesenteric veins suck up the chyle from the intestines and transfer it to the liver; and why should we not maintain that they perform the same office in the adult? For all the mooted difficulties vanish when we cease to suppose two contrary motions in the same vessels, and admit but one and the same continuous motion in the mesenteric vessels from the intestines to the liver.

I shall elsewhere state my views of the lacteal veins

[1] Enchiridion, lib. ii. cap. 18.

[2] Enchiridion, lib. iii. cap. 8: "The blood incessantly and naturally ascends or flows back to the heart in the veins, as in the arteries it descends or departs from the heart."

when I treat of the milk found in different parts of new-born animals, especially of the human subject; for it is met with in the mesentery and all its glands, and in those of the thymus, the axillæ, and the breasts of infants. The latter the midwives are in the habit of pressing out, for the health, as they believe, of the infants. But it has pleased the learned Riolanus, not only to take away circulation from the blood contained in the mesentery; he affirms that neither do the vessels in continuation of the vena cava, nor the arteries, nor any of the parts of the second and third regions, admit of circulation, so that he entitles and enumerates as circulating vessels the vena cava and aorta only. For this he appears to me to give a very unstable reason. "The blood," he says, in Book iii., chapter 8, "is effused into all the parts of the second and third regions, and remains there for their nutrition; nor does it return to the great vessels, unless forcibly drawn back by an extreme dearth of blood in the great vessels, nor, unless carried by an impulse, does it flow to the circulatory vessels."

That so much of the blood must remain as is appropriated to the nutrition of the tissues, is necessary; for it cannot nourish unless it be assimilated and become coherent, and form substance in place of that which is lost; but that the whole of the blood which flows into a part should there remain, in order that so small a portion should undergo transformation, is not necessary, for no part uses so much blood for its nutrition as is contained in its arteries, veins, and interstices. Nor because the blood is continually coming and going is it necessary to suppose that it leaves nothing for nutriment behind it. Consequently it is by no means necessary that the whole remain in order that nutrition be effected. But our learned author, in the same book, where he affirms this, appears almost everywhere else to assert the contrary. In that paragraph especially where he describes the circulation in the brain, he says: "And the brain by means of the circulation sends back blood to the heart, and thus refrigerates the organ." And in the same way are all the more remote parts said to refrigerate the heart; thus in fevers, when the præcordia are scorched and burn with febrile heat,

patients baring their limbs and casting off the bed-clothes, seek to cool the heart; and the blood generally, tempered and cooled down, as our learned author states it to be with reference to the brain in particular, returns by the veins and refrigerates the heart. Our author, therefore, appears to insinuate a certain necessity for a circulation from every part, as well as from the brain, contrary to what he had before said in very precise terms. But then he cautiously and ambiguously asserts, that the blood does not return from the parts composing the second and third regions, unless, as he says, it is drawn by force, and through a marked deficiency of blood in the larger vessels. Which is most true if these words be rightly understood; for by the larger vessels, in which the deficiency is said to cause the reflux, I think he must be understood to mean the veins not the arteries; for the arteries are never emptied, except into the veins or porosities of the parts, but are incessantly filled by the strokes of the heart; but in the vena cava and other returning channels, in which the blood glides rapidly on, hastening to the heart, there would speedily be a great deficiency of blood did not every part incessantly restore the blood that is incessantly poured into it. Add to this, that by the impulse of the blood which is forced with each stroke into every part of the second and third regions, that which is contained in the porosities is urged into the small veins, from which it passes into larger vessels, its motion assisted besides by the motion and compression of circumjacent parts. From every containing thing when compressed and constringed, contained matters are forced out. Thus it is that by the motions of the muscles and extremities, the blood contained in the minor vessels is forced onwards and delivered into the larger trunks. That the blood is incessantly driven from the arteries into every part of the body, that it there gives a pulse and never flows back in these channels, cannot be doubted, if it be admitted that with each pulse of the heart all the arteries are simultaneously distended by the blood sent into them. Our learned author himself allows that the diastole of the arteries is produced by the systole of the heart, and that the blood once out of the heart cannot regurgitate into the ventricles

by reason of the opposing valves; if I say, our learned author believes that these things are so, it will be as manifestly true with regard to the force and impulse by which the blood contained in the vessels is propelled into every part of every region of the body. For wheresoever the arteries pulsate, so far must the impulse and influx extend, and therefore is the impulse felt in every part of each several region; for there is a pulse everywhere, to the very points of the fingers and under the nails, nor is there any part of the body where the shooting pain that accompanies each pulse of the artery, and the effort made to effect a solution of the continuity is not experienced when it is the seat of a phlegmon or furuncle.

Moreover, that the blood contained in the porosities of the parts returns to the heart, is manifest from what we observe in the hands and feet. For we frequently see the hands and feet, in young persons especially, during severe weather, become so cold that to the touch they feel like ice, and they are so benumbed and stiffened that they seem scarcely to retain a trace of sensibility or to be capable of any motion; still are they all the while saturated with blood, and look red or livid. These parts can be warmed in no way, save by the circulation; the chilled blood, which has lost its spirit and heat, being driven out, and fresh, warm, and vivified blood flowing in by the arteries in its stead, which fresh blood cherishes and warms the parts, and restores to them sense and motion; nor could the extremities be restored by the warmth of a fire or other external heat, any more than those of a dead body could be so recovered. They are only brought to life again, as it were, by an influx of internal warmth. And this indeed is the principal use and end of the circulation; it is that for which the blood is sent on its ceaseless course, to exert its influence continually in its circuit, that all parts dependent on the primary innate heat may be retained alive, in their state of vital and vegetative being, and able to perform their functions; whilst, to use the language of physiologists, they are sustained and actuated by the inflowing heat and vital spirits. Thus, by the aid of two extremes, viz., cold and heat, is the temperature of the animal body retained at its mean. For as

the air inspired tempers the too great heat of the blood in the lungs and centre of the body, and effects the expulsion of suffocating fumes, so in its turn does the hot blood, thrown by the arteries into all parts of the body, cherish and nourish and keep them in life, defending them from extinction through the power of external cold.

It would, therefore, be unfair and extraordinary did not every particle composing the body enjoy the advantages of the circulation and transmutation of the blood; the ends for which the circulation was mainly established by nature would no longer be effected. To conclude then: you see how the circulation may be accomplished through the whole body, and each of its individual parts, in the smaller as well as in the larger vessels, without confusion and disturbance of humours; and all as matter of necessity and for the general advantage. Without circulation, indeed, there would be no restoration of chilled and exhausted parts, no continuance of these in life, since it is apparent enough that the whole influence of the preservative heat comes by the arteries, and is the work of the circulation.

It, therefore, appears to me that the learned Riolanus speaks rather expediently than truly, when in his Enchiridion he denies a circulation to certain parts; it would seem as though he had wished to please the many, and oppose none; to have written with such a bias rather than rigidly and in behalf of the simple truth. This is also apparent when he would have the blood to make its way into the left ventricle through the septum of the heart, by certain invisible and obscure passages, rather than through those ample and abundantly pervious channels, the pulmonary vessels, furnished as they are with valves, and opposing all reflux or regurgitation. He informs us that he has elsewhere discussed the reasons of the impossibility or inconvenience of this: I much desire to see it. It would be extraordinary, indeed, were the aorta and pulmonary artery, with the same dimensions, properties, and structure, not to have the same functions. But it would be more wonderful still were the whole tide of the blood to reach the left ventricle by a set of inscrutable passages of the septum, a tide which, in quantity must correspond, first

to the influx from the vena cava into the right side of the heart, and next to the efflux from the left, both of which require such ample conduits. But our author has adduced these matters inconsistently, for he has established the lungs as an emunctory or passage from the heart;[1] and he says: "The lung is affected by the blood which passes through it, the sordes flowing along with the blood." And again: "The lungs receive injury from distempered and ill-conditioned viscera; these deliver an impure blood to the heart, which it cannot correct except by multiplied circulations." In the same place, he further proceeds, whilst speaking against Galen of bloodletting in peripneumonia and the communication of the veins: "Were it true that the blood naturally passed from the right ventricle of the heart to the lungs, that it might be carried into the left ventricle and from thence into the aorta; and were the circulation of the blood admitted, who does not see that in affections of the lungs the blood would flow to them in larger quantity and would oppress them, unless it were taken away, first, freely, and then in repeated smaller quantities in order to relieve them, which indeed was the advice of Hippocrates, who in affections of the lungs takes away blood from every part—the head, nose, tongue, arms and feet, in order that its quantity may be diminished and a diversion effected from the lungs; he takes away blood till the body is almost bloodless. Now admitting the circulation, the lungs are most readily depleted by opening a vein; but rejecting it, I do not see how any revulsion of the blood can be accomplished by this means; for did it flow back by the pulmonary artery upon the right ventricle, the sigmoid valves would oppose its entrance, and any escape from the right ventricle into the vena cava is prevented by the tricuspid valves. The blood, therefore, is soon exhausted when a vein is opened in the arm or foot, if we admit the circulation; and the opinion of Fernelius is at the same time upset by this admission, viz., that in affections of the lungs it is better to bleed from the right than the left arm; because the blood cannot flow backwards into the vena cava unless the two barriers situated in the heart be first broken down."

[1] Lib. iii. cap. 6.

He adds yet further in the same place:[1] "If the circulation of the blood be admitted, and it be acknowledged that this fluid generally passes through the lungs, not through the middle partition of the heart, a double circulation becomes requisite; one effected through the lungs, in the course of which the blood quitting the right ventricle of the heart passes through the lungs in order that it may arrive at the left ventricle; leaving the heart on the one hand, therefore, the blood speedily returns to it again; another and longer circulation proceeding from the left ventricle of the heart performs the circuit of the whole body by the arteries, and by the veins returns to the right side of the heart."

The learned anatomist might here have added a third and extremely short circulation, viz.—from the left to the right ventricle of the heart, with that blood which courses through the coronary arteries and veins, and by their ramifications is distributed to the body, walls, and septum of the heart.

"He who admits one circulation," proceeds our author, "cannot repudiate the other;" and he might, as it appears, have added, "the third." For why should the coronary arteries of the heart pulsate, if it were not to force on the blood by their pulsations? and why should there be coronary veins, the end and office of all veins being to receive the blood brought by the arteries, were it not to deliver and discharge the blood sent into the substance of the heart? In this consideration let it be remembered that a valve is very commonly found at the orifice of the coronary vein, as our learned author himself admits,[2] preventing all ingress, but offering no obstacle to the egress of the blood. It therefore seems that he cannot do otherwise than admit this third circulation, who acknowledges a general circulation through the body, and that the blood also passes through the lungs and the brain.[3] Nor, indeed, can he deny a similar circulation to every other part of every other region. The blood flowing under the influence of the arterial pulse, and returning by the veins, every particle of the body has its circulation.

[1] Lib. iii. cap. 6. [2] Lib. iii. cap. 9. [3] Lib. iv. cap. 2.

From the words of our learned writer quoted above, his opinion may be gathered both of the general circulation, and then of the circulation through the lungs and the several parts of the body; for he who admits the first, manifestly cannot refuse to acknowledge the others. How indeed could he who has repeatedly asserted a circulation through the general system and the greater vessels, deny a circulation in the branches continuous with these vessels, or in the several parts of the second and third regions? as if all the veins, and those he calls greater circulatory vessels, were not enumerated by every anatomist, and by himself, as being within the second region of the body. Is it possible that there can be a circulation which is universal, and which yet does not extend through every part? Where he denies it, then, he does so hesitatingly, and vacillates between negations, giving us mere words. Where, on the contrary, he asserts the circulation, he speaks out heartily, and gives sufficient reasons, as becomes a philosopher; and when he relies on this opinion in a particular instance, he delivers himself like an experienced physician and honest man, and, in opposition to Galen and his favourite Fernelius, advises bloodletting as the chief remedy in dangerous diseases of the lungs.

No learned man and Christian, having doubts in such a case, would have recommended his experience to posterity, to the imminent risk, and even loss of human life; neither would he without very sufficient reasons, have repudiated the authority of Galen and Fernelius, which has usually such weight with him. Whatever he has denied in the circulation of the blood, therefore, whether with reference to the mesentery or other parts, and in favour of the lacteal veins or the ancient system of physic, or in any other respect, must be ascribed to his courtesy and modesty, and is to be excused.

Thus far, I think, it appears plain enough, from the very words and arguments of our author, that there is a circulation everywhere; that the blood, wherever it is, changes its place, and by the veins returns to the heart; so that our learned author seems to be of the same opinion as myself. It would therefore be labour in vain, did I here quote at greater length the various reasons which I have

given in my work on the Motion of the Blood, in confirmation of my opinions, and which are derived from the structure of the vessels, the position of the valves, and other matters of experience and observation; moreover, I have not yet seen the treatise on the Circulation of the Blood of the learned writer; nor, indeed, have I yet met with a single argument of his, beyond his bare negation, which could lead him to repudiate a circulation which he admits as universal, in very many parts, regions, and vessels.

It is true that by way of subterfuge he has recourse to an anastomosis of the vessels on the authority of Galen, and the evidence of daily experience. But so distinguished a personage, an anatomist so expert, so inquisitive, and careful, should first have shown anastomoses between the larger arteries and larger veins, and these, both obvious and ample, with mouths in relation with such a torrent as is constituted by the whole mass of the blood, and larger than the capacity of the continuous branches, (from which he takes away all circulation,) before he rejected those that are familiarly known, that are more likely and more open. He ought to have clearly shown us where these anastomoses are, and how they are fashioned, whether they be adapted only to permit the access of the blood into the veins, and not to allow of its regurgitation, in the same way as we see the ureters connected with the urinary bladder, or in what other manner things are contrived. But—and here I speak over boldly perhaps—neither our learned author himself, nor Galen, nor any experience, has ever succeeded in making such anastomoses as he imagines, sensible to the eye.

I have myself pursued this subject of the anastomosis with all the diligence I could command, and have given not a little both of time and labour to the inquiry; but I have never succeeded in tracing any connexion between arteries and veins by a direct anastomosis of their orifices. I would gladly learn of those who give so much to Galen, how they dare swear to what he says. Neither in the liver, spleen, lungs, kidneys, nor any other viscus, is there such an anastomosis; and by boiling, I have rendered the whole parenchyma of these organs so friable that it could be shaken like dust from the fibres, or picked away with a needle, until I could trace the fibres of every subdivision, and see

every capillary filament distinctly. I can therefore boldly affirm, that there is neither any anastomosis of the vena portæ with the cava, of the arteries with the veins, or of the capillary ramifications of the biliary ducts, which can be traced through the entire liver, with the veins. This alone may be observed in the recent liver: all the branches of the vena cava ramifying through the convexity of the liver, have their tunics pierced with an infinity of minute holes, as is a sieve, and are fashioned to receive the blood in its descent. The branches of the porta are not so constituted, but simply spread out in subdivisions; and the distribution of these two vessels is such, that whilst the one runs upon the convexity, the other proceeds along the concavity of the liver to its outer margin, without anastomosing.

In three places only do I find anything that can be held equivalent to an anastomosis. From the carotids, as they are creeping over the base of the brain, numerous and interlaced fibres arise, which afterwards form the choroid plexus, and passing through the lateral ventricles, finally unite and terminate in the third sinus, which performs the office of a vein. In the spermatic vessels, commonly called vasa præparantia, certain minute arteries proceeding from the great artery adhere to the venæ præparantes, which they accompany, and are at length taken in and included within their coats, in such a way that they seem to have a common ending, so that where they terminate on the upper portion of the testis, on that cone-shaped process called the corpus varicosum et pampiniforme, it is altogether uncertain whether we are to regard their terminations as veins, or as arteries, or as both. In the same way are the ultimate ramifications of the arteries which run to the umbilical vein, lost in the tunics of this vessel.

What doubt can there be, if by such channels the great arteries, distended by the stream of blood sent into them, are relieved of so great and obvious a torrent, but that nature would not have denied distinct and visible passages, vortices, and estuaries, had she intended to divert the whole current of the blood, and had wished in this way to deprive the lesser branches and the solid parts of all the benefit of the influx of that fluid?

Finally, I shall quote this single experiment, which appears to me sufficient to clear up all doubts about the anastomoses, and their uses, if any exist, and to set at rest the question of a passage of the blood from the veins to the arteries, by any special channels, or by regurgitation.

Having laid open the thorax of an animal, and tied the vena cava near the heart, so that nothing shall pass from that vessel into its cavities, and immediately afterwards, having divided the carotid arteries on both sides, the jugular veins being left untouched; if the arteries be now perceived to become empty but not the veins, I think it will be manifest that the blood does nowhere pass from the veins into the arteries except through the ventricles of the heart. Were it not so, as observed by Galen, we should see the veins as well as the arteries emptied in a very short time, by the efflux from their corresponding arteries.

For what further remains, oh, Riolanus! I congratulate both myself and you: myself, for the opinion with which you have graced my circulation; and you, for your learned, polished, and terse production, than which nothing more elegant can be imagined. For the favour you have done me in sending me this work, I feel most grateful, and I would gladly, as in duty bound, proclaim my sense of its merits, but I confess myself unequal to the task; for I know that the Enchiridion bearing the name of Riolanus inscribed upon it, has thereby more of honour conferred upon it than it can derive from any praise of mine, which nevertheless I would yield without reserve. The famous book will live for ever; and when marble shall have mouldered, will proclaim to posterity the glory that belongs to your name. You have most happily conjoined anatomy with pathology, and have greatly enriched the subject with a new and most useful osteology. Proceed in your worthy career, most illustrious Riolanus, and love him who wishes that you may enjoy both happiness and length of days, and that all your admirable works may conduce to your eternal fame.

WILLIAM HARVEY.

A

SECOND DISQUISITION TO JOHN RIOLAN, JUN.,

IN WHICH

MANY OBJECTIONS

TO THE

CIRCULATION OF THE BLOOD

ARE REFUTED.

A SECOND DISQUISITION TO JOHN RIOLAN.

It is now many years, most learned Riolanus, since, with the aid of the press, I published a portion of my work. But scarcely a day, scarcely an hour, has passed since the birthday of the Circulation of the Blood, that I have not heard something for good or for evil said of this my discovery. Some abuse it as a feeble infant, and yet unworthy to have seen the light; others, again, think the bantling deserves to be cherished and cared for; some oppose it with much ado, others patronize it with abundant commendation; one party holds that I have completely demonstrated the circulation of the blood by experiment, observation, and ocular inspection, against all force and array of argument; another thinks it scarcely yet sufficiently illustrated—not yet cleared of all objections. There are some, too, who say that I have shown a vainglorious love of vivisections, and who deride the introduction of frogs and serpents, flies, and others of the lower animals upon the scene, as a piece of puerile levity, not even refraining from opprobrious epithets.

To return evil speaking with evil speaking, however, I hold to be unworthy in a philosopher and searcher after truth; I believe that I shall do better and more advisedly if I meet so many indications of ill breeding with the light of faithful and conclusive observation. It cannot be helped that dogs bark and vomit their foul stomachs, or that cynics should be numbered among philosophers; but care can be taken that they do not bite or inoculate their mad humours, or with their dogs' teeth gnaw the bones and foundations of truth.

Detractors, mummers, and writers defiled with abuse, as I resolved with myself never to read them, satisfied that nothing solid or excellent, nothing but foul terms, was to be expected from them, so have I held them still less worthy of an answer. Let them consume on their own ill

nature; they will scarcely find many well-disposed readers, I imagine, nor does God give that which is most excellent and chiefly to be desired—wisdom, to the wicked; let them go on railing, I say, until they are weary, if not ashamed.

If for the sake of studying the meaner animals you should even enter the bakehouse with Heraclitus, as related in Aristotle, I bid you approach; for not only are the immortal Gods not absent here, but the great and almighty Father is sometimes most visible in His lesser, and to the eye least considerable works.[1]

In my book on the Motion of the Heart and Blood in Animals, I have only adduced those facts from among many other observations, by which either errors were best refuted, or truth was most strongly supported; I have left many proofs, won by dissection and appreciable to sense, as redundant and unnecessary; some of these, however, I now supply in brief terms, for the sake of the studious, and those who have expressed their desire to have them.

The authority of Galen is of such weight with all, that I have seen several hesitate greatly with that experiment before them, in which the artery is tied upon a tube placed within its cavity, by which it is proposed to prove that the arterial pulse is produced by a power communicated from the heart through the coats of the arteries, and not from the shock of the blood contained within them; and in like manner, that the arteries dilate as bellows, and are not filled as sacs. This experiment is spoken of by Vesalius, the celebrated anatomist; but neither Vesalius nor Galen says that he had tried the experiment, which, however, I did. Vesalius only prescribes, and Galen advises it, to those anxious to discover the truth, and for their better assurance, not thinking of the difficulties that attend its performance, nor of its futility when done, for indeed, although executed with the greatest skill, it supplies nothing in support of the opinion which maintains that the coats of the vessel are the cause of the pulse. It rather proclaims that this is owing to the impulse of the blood.

[1] [To those who hesitated to visit him in his kiln or bakehouse, Heraclitus addressed the words in the text. Aristotle, who quotes them, has been defending the study of the lower animals.—Ed.]

For the moment you have thrown your ligature around the artery upon the reed or tube, immediately, by the force of the blood thrown in from above, it is dilated beyond the circle of the tube, by which the flow is impeded, and the shock is broken. The artery which is tied only pulsates obscurely, being now cut off from the full force of the blood that flows through it, the shock being reverberated, as it were, from that part of the vessel which is above the ligature. But if the artery below the ligature be now divided, the contrary of what has been maintained will be apparent, from the spurting of the blood impelled through the tube, just as happens in the cases of aneurism, referred to in my book on the Motion of the Blood, which arise from an erosion of the coats of the vessel, and when the blood is contained in a membranous sac, formed not by the coats of the vessel dilated, but preternaturally produced from the surrounding tissues and flesh. The arteries beyond an aneurism of this kind will be felt beating very feebly, whilst in those above it and in the swelling itself the pulse will be perceived of great strength and fulness. Here we cannot imagine that the pulsation and dilatation take place by the coats of the arteries, or any power communicated to the walls of the sac; they are plainly due to the shock of the blood.

But that the error of Vesalius, and the inexperience of those who assert their belief that the part below the tube does not pulsate when the ligature is tied, may be made the more apparent, I can state, after having made the trial, that the inferior part will continue to pulsate if the experiment be properly performed; and whilst they say that when you have undone the ligature the inferior arteries begin again to pulsate, I maintain that the part below beats less forcibly when the ligature is untied than it did when the thread was still tight. But the effusion of blood from the wound confuses everything, and renders the whole experiment unsatisfactory and misleading, so that nothing certain can be shown, as I have said, on account of the hemorrhage. But if, as I know by experience, you lay bare an artery, and control the divided portion by the pressure of your fingers, you may try many things at pleasure by which the truth will be made to

appear. In the first place, you will feel the blood coming down in the artery at each pulsation, and visibly dilating the vessel. You may also at will suffer the blood to escape, by relaxing the pressure, and leaving a small outlet; and you will see that it jets out with each stroke, with each contraction of the heart, and with each dilatation of the artery, as I have said in speaking of arteriotomy, and the experiment of perforating the heart. If you allow the efflux to go on uninterruptedly, either from the simple divided artery or from a tube inserted into it, you will be able to perceive by the sight, and if you apply your hand, by the touch likewise, every character of the stroke of the heart in the jet; the rhythm, order, intermission, force, etc., of its pulsations, all becoming sensible there, just as the jets from a syringe would be obvious to sight and touch, if pushed in succession and with different degrees of force upon the palm of the hand. I have occasionally observed the jet from a divided carotid artery to be so forcible, that, when received on the hand, the blood rebounded to the distance of four or five feet.

But that that may be made clearer which is in doubt, viz. —that the pulsific power does not proceed from the heart by the coats of the arteries, I beg here to refer to a portion of the descending aorta, about a span in length, with its division into the two crural trunks, which I removed from the body of a nobleman, and which is converted into a bony tube. By this hollow tube, nevertheless, did the arterial blood reach the lower extremities of this nobleman during his life, and cause the arteries in these to beat; and yet the main trunk was precisely in the same condition as is the artery in the experiment of Galen, when it was tied upon a hollow tube. Where it was converted into bone it could neither dilate nor contract like bellows, nor transmit the pulsific power from the heart to the inferior vessels; it could not convey a force which it was incapable of receiving through the solid matter of the bone. In spite of all, however, I well remember to have frequently noted the pulse in the legs and feet of this patient whilst he lived, for I was myself his most attentive physician, and he my very particular friend. The arteries in the inferior extremities of this nobleman must therefore and of necessity have been

dilated by the impulse of the blood like flaccid sacs, and not have expanded in the manner of bellows through the action of their tunics. It is obvious, that whether an artery be tied over a hollow tube, or its tunics be converted into a bony and unyielding canal, the interruption to the pulsific power in the inferior part of the vessel must be the same.

I have known another instance in which a portion of the aorta near the heart was converted into bone, in the body of a nobleman, a man of great muscular strength. The experiment of Galen, therefore, or, at all events, a state analogous to it, not effected on purpose but encountered by accident, makes it sufficiently appear, that compression or ligature of the coats of an artery does not interfere with the pulsative properties of its derivative branches; and indeed, if the experiment which Galen recommends were properly performed by anyone, its results would be found in opposition to the views which Vesalius believed they would support.

But we do not, therefore, deny everything like motion to the walls of the arteries; on the contrary, we allow them the same motions which we concede to the heart, viz., a diastole, and a systole or return from the distended to the natural state. This much we believe to be effected by a power inherent in the coats themselves. But it is to be observed, that they are not both dilated and contracted by the same, but by different causes and means, as may be observed of the motions of all parts, and of the ventricle of the heart itself, which is distended by the auricle, and contracted by its own inherent power. Thus the arteries are dilated by the heart, but they subside of themselves.[1]

You may also perform another experiment at the same time: if you fill one of two basins of the same size with blood issuing *per saltum* from an artery, the other with venous blood from a vein of the same animal, you will have an opportunity of perceiving by the eye, both immediately and by-and-by, when the blood in either vessel has become cold, what differences there are between them.

[1] Vide Chapter III. of the Disquisition on the Motion of the Heart and Blood.

You will find that it is not as they believe who fancy that there is one kind of blood in the arteries and another in the veins, that in the arteries being of a more florid colour, more frothy, and imbued with an abundance of I know not what spirits, effervescing, swelling, and occupying a greater space, like milk or honey set upon the fire. For were the blood which is thrown from the left ventricle of the heart into the arteries, fermented into any such frothy and flatulent fluid, so that a drop or two distended the whole cavity of the aorta, unquestionably, upon the subsidence of this fermentation, the blood would return to its original quantity of a few drops; (and this, indeed, is the reason that some assign for the usually empty state of the arteries in the dead body). The same thing would happen to arterial blood in the cup, as we discover with milk and honey when they come to cool. But if in either basin you find blood nearly of the same colour, not of very different consistency in the coagulated state, forcing out serum in the same manner, and filling the cups to the same height when cold that it did when hot, this will be enough for anyone to rest his faith upon, and afford argument enough, I think, for rejecting the dreams that have been put forward on the subject. Sense and reason alike assure us that the blood contained in the left ventricle is not of a different nature from that in the right. Moreover, when we see that the mouth of the pulmonary artery is of the same size as the aorta, and in other respects equal to that vessel, it would be imperative on us to affirm that the pulmonary artery was distended by a single drop of frothy blood, as well as the aorta, so that the right as well as the left side of the heart was filled with an effervescing or fermenting blood.

The causes which especially dispose men's minds to admit diversity in the arterial and venous blood are three in number: one, because in arteriotomy the blood that flows is of a more florid hue than that which escapes from a vein; a second, because in the dissection of dead bodies the left ventricle of the heart, and the arteries in general, are mostly found empty; a third, because the arterial blood is believed to be more spirituous, and being replete with spirit is made to occupy a much larger space. The

causes and reasons, however, of all these things present themselves to us when we seek after them.

1st. With reference to the colour it is to be observed, that wherever the blood issues by a very small orifice, it is in some measure strained, and the thinner and lighter part, which usually swims on the top and is the most penetrating, is emitted.[1] Thus, in phlebotomy, when the blood escapes forcibly and to a distance, in a full stream, and from a large orifice, it is thicker, has more body, and a darker colour; but, if it flows from a small orifice, and only drop by drop, as it usually does when the bleeding fillet is untied, it is of a brighter hue; for then it is strained, as it were, and the thinner, and more penetrating portion only escapes; in the same way, in the bleeding from the nose, in that which takes place from a leech-bite, or from scarifications, or in any other way by diapedesis or transudation, the blood is always seen to have a brighter cast, because the thickness and firmness of the coats of the arteries render the outlet or outlets smaller, and less disposed to yield a ready passage to the out-pouring blood. It happens also, that when fat persons are bled, the orifice of the vein is apt to be compressed by the subcutaneous fat, by which the blood is made to appear thinner, more florid, and in some sort arterious. On the other hand, the blood that flows into a basin from a large artery freely divided, will look venous. The blood in the lungs is of a much more florid colour than it is in the arteries, and we know how it is strained through the pulmonary tissue.

2nd. The emptiness of the arteries in the dead body, which probably misled Erasistratus in supposing that they only contained aereal spirits, happens from this, that when respiration ceases the lungs collapse, and then the passages

[1] [Harvey was in error in making this statement. The blood can in no sense be strained as suggested. The brighter colour of slowly transuded blood is owing to its greater exposure to the air, the brightness or darkness of its hue being dependent upon the amount of oxygen in combination with the hæmoglobin of the red corpuscles. When insufficient oxygen is present, the hæmoglobin is reduced and gives rise to the purple colour of venous blood. The hæmoglobin of arterial blood is saturated with oxygen gas.—Ed.]

through them are closed; the heart, however, continues for a time to contract upon the blood, whence we find the left auricle more contracted, and the corresponding ventricle, as well as the arteries at large, appearing empty, simply because there is no supply of blood flowing round to fill them. In cases, however, in which the heart has ceased to pulsate and the lungs to afford a passage to the blood simultaneously, as in those who have died from drowning or syncope, or who die suddenly, you will find the arteries, as well as the veins, full of blood.

3rd. With reference to the third point, or that of the spirits, it may be said that, as it is still a question what they are, how they exist in the body, of what consistency, whether separate and distinct from the blood and solids, or mingled with these,—upon each and all of these points there are so many and such conflicting opinions, that it is not wonderful that the spirits, whose nature is thus left so wholly ambiguous, should serve as the common subterfuge of ignorance. Persons of limited information, when they are at a loss to assign a cause for anything, very commonly reply that it is done by the spirits; and so they introduce the spirits upon all occasions, even as indifferent poets are always thrusting the gods upon the stage as a means of unravelling the plot, and bringing about the catastrophe.

Fernelius, and many others, suppose that there are aereal spirits and invisible substances. Fernelius proves that there are animal spirits, by saying that the cells in the brain are apparently unoccupied, and as nature abhors a vacuum, he concludes that in the living body they are filled with spirits, just as Erasistratus had held that, because the arteries were empty of blood, therefore they must be filled with spirits. But Medical Schools admit three kinds of spirits: the natural spirits flowing through the veins, the vital spirits through the arteries, and the animal spirits through the nerves; whence physicians say, after Galen, that sometimes the parts of the brain are oppressed by sympathy, because the faculty with the essence, *i.e.*, the spirit, is overwhelmed; and sometimes this happens independently of the essence. Farther, besides the three orders of influxive spirits adverted to, a like number of implanted or stationary spirits seem to be

acknowledged; but we have found none of all these spirits by dissection, neither in the veins, nerves, arteries, nor other parts of living animals. Some speak of corporeal, others of incorporeal spirits; and they who advocate the corporeal spirits will have the blood, or the thinner portion of the blood, to be the bond of union with the soul, the spirit being contained in the blood as the flame is in the smoke of a lamp or candle, and held admixed by the incessant motion of the fluid. Others, again, distinguish between the spirits and the blood. They who advocate incorporeal spirits have no ground of experience to stand upon; their spirits indeed are synonymous with powers or faculties, such as a concoctive spirit, a chylopoietic spirit, a procreative spirit, etc.—they admit as many spirits, in short, as there are faculties or organs.

But then the schoolmen speak of a spirit of fortitude, prudence, patience, and the other virtues, and also of a most holy spirit of wisdom, and of every divine gift; and they besides suppose that there are good and evil spirits that roam about or possess the body, that assist or cast obstacles in the way. They hold some diseases to be owing to a Cacodæmon or evil spirit, as there are others that are due to a cacochemy or defective assimilation.

Although there is nothing more uncertain and questionable, then, than the doctrine of spirits that is proposed to us, nevertheless physicians seem for the major part to conclude, with Hippocrates, that our body is composed or made up of three elements: containing parts, contained part, and causes of action, spirits being understood by the latter term. But if spirits are to be taken as synonymous with causes of activity, whatever has power in the living body and a faculty of action must be included under the denomination. It would appear, therefore, that all spirits were neither aereal substances, nor powers, nor habits; and that all were not incorporeal.

But keeping in view the propositions that especially interest us, and omitting others, as leading to tediousness, it seems that the spirits which flow by the veins or the arteries are not distinct from the blood, any more than the flame of a lamp is distinct from the inflammable vapour that is on fire, but the blood and these spirits

signify one and the same thing, though different,—like generous wine and its spirit. For as wine, when it has lost all its spirit, is no longer wine, but a vapid liquor or vinegar, so blood without spirit is not blood, but something else—clot or cruor. In like manner a hand of stone, or of a dead body, is no hand in the most complete sense, neither is blood, void of the vital principle, proper blood. It is immediately to be held as corrupt when deprived of its spirit. The spirit, therefore, which inheres in the arteries, and especially in the blood which fills them, is to be regarded either as its act or its agent, in the same way as the spirit of wine in wine, and the spirit of aqua vitæ in brandy, or as a flame kindled in alcohol, which, as it were, lives and feeds on, or is nourished by itself. The blood consequently, though richly imbued with spirits, does not swell, nor ferment, nor rise to a head through them, so as to require and occupy a larger space,—which may be ascertained beyond the possibility of question by the two cups of equal size. It is to be regarded as wine, possessed of a large amount of spirits, or, in the Hippocratic sense, of signal powers of acting and effecting.

It is therefore the same blood in the arteries that is in the veins, although it may be admitted to be more spirituous, and possessed of higher vital force. But it is not changed into anything more vaporous, or more aereal, as if there were no spirits but such as are aereal, and no cause of action or activity that is not of the nature of flatus or wind. But neither the animal, natural, nor vital spirits which inhere in the solids, such as the ligaments and nerves (especially if they be of so many different species), and are contained within the hidden interstices of the tissues, are to be regarded as so many different aereal forms, or kinds of vapour.

Here I would gladly be informed by those who admit corporeal spirits in the bodies of animals, of a gaseous or vaporous consistency, whether or not they have the power of passing hither and thither, like distinct bodies independently of the blood? Or whether the spirits follow the blood in its motions, either as integral parts of the fluid or as indissolubly connected with it, so that they can

neither quit the tissues nor pass hither nor thither without the influx and reflux, and motion of the blood? If the spirits exhaling from the blood, like the vapour of water attenuated by heat, exist in a state of constant flow and succession as the pabulum of the tissues, it necessarily follows that they are not distinct from this pabulum, but are incessantly disappearing. It therefore seems that they can neither have influx nor reflux, nor passage, nor yet remain at rest without the influx, the reflux, the passage of the blood which is the fluid that serves as their vehicle or pabulum.

And next I desire to know of those who tell us that the spirits are formed in the heart, being compounded of the vapours or exhalations of the blood (excited either by the heat of the heart or the concussion) and the inspired air, whether such spirits are not to be accounted much colder than the blood, seeing that both the elements of their composition, namely, air and vapour, are much colder? For the vapour of boiling water is much more bearable than the water itself; the flame of a candle is less burning than the red-hot snuff, and burning charcoal than incandescent iron or brass. Whence it would seem that spirits of this nature rather receive their heat from the blood, than that the blood is warmed by these spirits. Such spirits are rather to be regarded as fumes and excrementitious effluvia proceeding from the body in the manner of odours, than in any way as natural artificers of the tissues, a conclusion which we are the more disposed to admit, when we see that they so speedily lose any virtue they may possess, and which they had derived from the blood as their source. They are at best of a very frail and evanescent nature. Whence also it becomes probable that the expiration of the lungs is a means by which these vapours being cast off, the blood is fanned and purified; whilst inspiration is a means by which the blood in its passage between the two ventricles of the heart is tempered by the cold of the surrounding atmosphere, lest, getting heated, and blown up with a kind of fermentation, like milk or honey set over the fire, it should so distend the lungs that the animal got suffocated, as we often see in those with dangerous asthma, which Galen himself seems to refer to its proper cause when he says it is owing to an obstruction

of the smaller arteries, viz., the vasa venosa et arteriosa. I have found by experience that patients affected with asthma might be brought out of states of very imminent danger by having cupping-glasses applied, and a plentiful and sudden affusion of cold water. Thus much—and perhaps it is more than was necessary—have I said on the subject of spirits in this place, for I felt it proper to define them, and to say something of their nature in a physiological disquisition.

I shall only further add, that they who descant on the *calidum innatum* or innate heat, as an instrument of nature available for every purpose, and who speak of the necessity of heat as the cherisher and retainer in life of the several parts of the body, who at the same time admit that this heat cannot exist unless connected with something, and because they find no substance of anything like commensurate mobility, or which might keep pace with the rapid influx and reflux of this heat (in affections of the mind especially), take refuge in spirits as most subtile substances, possessed of the most penetrating qualities, and highest mobility—these persons see nothing less than the wonderful and almost divine character of the natural operations as proceeding from the instrumentality of this common agent, viz., the *calidum innatum*. They farther regard these spirits as of a sublime, lucid, ethereal, celestial, or divine nature, and the bond of the soul, even as the vulgar and unlettered, when they do not comprehend the causes of various effects, refer them to the immediate interposition of the Deity. They therefore declare that the heat perpetually flowing into the several parts is in virtue of the influx of spirits through the channels of the arteries; as if the blood could neither move so swiftly, nor penetrate so intimately, nor cherish so effectually. Such faith do they put in this opinion, to such lengths are they carried by their belief, that they deny the contents of the arteries to be blood! And then they proceed with trivial reasonings to maintain that the arterial blood is of a peculiar kind, or that the arteries are filled with such aereal spirits, and not with blood, all the while, in opposition to everything which Galen has advanced against Erasistratus, both on grounds of experiment and of reason, But that arterial blood

differs in nothing essential from venous blood has been already sufficiently demonstrated; and our senses likewise assure us that the blood and spirits do not flow in the arteries separately and disjoined, but as one body.

We have occasion to observe so often as our hands, feet, or ears have become stiff and cold, that as they recover again by the warmth that flows into them, they acquire their natural colour and heat simultaneously; that the veins which had become small and shrunken, swell visibly and enlarge, so that when they regain their heat suddenly they become painful; from which it appears, that that which by its influx brings heat is the same which causes repletion and colour. Now this can be and is nothing but the blood.

When an artery and a vein are divided, anyone may clearly see that the part of the vein towards the heart pours out no blood, whilst that beyond the wound gives a torrent; the divided artery, on the contrary, (as in my experiment on the carotids,) pours out a flood of pure blood from the orifice next the heart, and in jets as if it were forced from a syringe, whilst from the further orifice of the divided artery little or no blood escapes. This experiment plainly proves in what direction the current sets in either order of vessels. It also shows with what velocity the current moves, not gradually and by drops, but even with violence. And lest anyone, by way of subterfuge, should take shelter in the notion of invisible spirits, let the orifice of the divided vessel be plunged under water or oil, when, if there be any air contained in it, the fact will be proclaimed by a succession of visible bubbles. Hornets, wasps, and other insects of the same description plunged in oil, and so suffocated, emit bubbles of air from their tails whilst they are dying. For which reason it is not improbable that they thus respire when alive, for all other animals if submerged and drowned, when they finally sink to the bottom and die, emit bubbles of air from the mouth and lungs. It is also demonstrated by the same experiment, that the valves of the veins act with such accuracy, that air blown into them does not penetrate. Much less then can blood make its way through them, so that it is certain that neither sensibly nor insensibly, nor gradually

and drop by drop, can any blood pass from the heart by the veins.

And that no one may seek shelter in asserting that these things are so when nature is disturbed and put into a preternatural state, but not when she is left to herself and at liberty to act, that the same things do not come to pass in morbid and unusual states as in the healthy and natural condition, they are to be met by saying, that if it were so, that so much blood was lost from the farther orifice of a divided vein because nature was disturbed, still the incision does not close the nearer orifice, from which nothing either escapes or can be expressed, whether nature be disturbed or not. Others argue in the same way, maintaining that, although the blood immediately spurts out in such profusion with every beat when an artery is divided near the heart, it does not therefore follow that the blood is propelled by the pulse when the heart and artery are entire. It is most probable, however, that every stroke impels something; and it seems certain that there would be no pulse of the container, without an impulse being communicated to the thing contained. Yet some, that they may seize upon a farther means of defence, and escape the necessity of admitting the circulation, do not fear to affirm that the arteries in the living body and in the natural state are already so full of blood, that they are incapable of receiving another drop; and so also of the ventricles of the heart. But it is indubitable that, whatever the degree of distension and the extent of contraction of the heart and arteries, they are still in a condition to receive an additional quantity of blood forced into them, and that this is far more than is usually reckoned in grains or drops, seems also certain. For if the ventricles become so excessively distended that they will admit no more blood, the heart ceases to beat, (as we sometimes see in our vivisections,) and, if it continues tense and resisting, death by asphyxia ensues.

In the work on the Motion of the Heart and Blood, I have already sufficiently discussed the question as to whether the blood in its motion was attracted, or impelled, or moved by its own inherent nature. I have there also spoken of the action and office, of the dilatation and contraction of the heart, and have shown what these truly are,

and how the heart contracts during the diastole of the arteries; so that I must hold those who take points for dispute from among them as either not understanding the subject, or as unwilling to look at things for themselves, and to investigate them with their own senses,[1]

I do not believe that any kind of attraction can be demonstrated in the living body except that of the nutriment, which gradually and incessantly passes on to supply the waste that takes place in the tissues, in the same way as the oil rises in the wick of a lamp to be consumed by the flame. Whence I conclude that the primary and common organ of all sensible attraction and impulsion is of the nature of sinew, or fibre, or muscle, in order that it may be contractile, that contracting it may be shortened, and so either stretch out, draw towards, or propel. But these topics will be better discussed elsewhere, when we speak of the organs of motion in the animal body.

To those who repudiate the circulation because they neither see the efficient nor final cause of it, and who exclaim, *cui bono?* I have yet to reply, having hitherto taken no note of the ground of objection which they take up. And first I own I am of opinion that our first duty is to inquire whether the thing exists, before asking why it exists? For from the facts and circumstances which meet us in the circulation, its uses and objects are to be sought. Meantime I would only ask, how many things we admit in physiology, pathology, and therapeutics, the causes of which are unknown to us? That there are many, no one doubts, such as the causes of putrid fevers, of revulsions, and of the purgation of excrementitious matters.

Whoever, therefore, sets himself in opposition to the circulation, because, if it be acknowledged, he cannot account for a variety of medical problems, nor in the treatment of diseases and the administration of medicines, give satisfactory reasons for the phenomena that appear; or who will not see that the precepts he has received from his teachers are false; or who thinks it unseemly to give up accredited opinions; or who regards it as in some sort criminal to call in question doctrines that have descended through a long

[1] Vide Chapter XIV.

succession of ages, and carry the authority of the ancients; —to all of these I reply, that the facts cognizable by the senses wait upon no opinions, and that the works of nature bow to no antiquity. For indeed there is nothing either more ancient or of higher authority than nature.

To those who object to the circulation as throwing obstacles in the way of their explanations of the phenomena that occur in medical cases (and there are persons who will not be content to take up with a new system, unless it explains everything, as in astronomy), and who oppose it with their own erroneous assumptions, such as that, if it be true, phlebotomy cannot cause revulsion, as the blood will still continue to be forced into the affected part; that the passage of excrementitious matters and foul humours through the heart, that most noble and important viscus, is to be apprehended; that an efflux and excretion, occasionally of foul and corrupt blood, takes place from the same body, from different parts, even from the same part and at the same time, which, were the blood agitated by a continuous current, would be shaken and effectually mixed in passing through the heart, and many points of the like kind admitted in our medical schools, which are seen to be repugnant to the doctrine of the circulation,—to them I shall not answer farther here, than that the circulation is not always the same in every place, and at every time, but is contingent upon many circumstances, as the more rapid or slower motion of the blood, the strength or weakness of the heart as the propelling organ, the quantity and quality or constitution of the blood, the rigidity or laxity of the tissues, and the like. A thicker blood moves more slowly through narrower channels; it is more effectually strained in its passage through the substance of the liver than through that of the lungs. It has not the same velocity through flesh and the softer parenchymatous structures and through sinewy parts of greater compactness and consistency: for the thinner and purer and more spirituous part permeates more quickly, the thicker more earthy and indifferently concocted portion moves more slowly, or is refused admission. The nutritive portion, or ultimate aliment of the tissues, the dew or cambium, is of a more penetrating nature, inasmuch as it has to be added everywhere, and to

everything that grows and is nourished in its length and thickness, even to the horns, nails, hair and feathers; and then the excrementitious matters have to be secreted in some places, where they accumulate, and either prove a burthen or are concocted. But I do not believe that the excrementitious fluids or bad humours when once separated, nor the milk, the phlegm, and the spermatic fluid, nor the ultimate nutritive part, the dew or cambium, necessarily circulate with the blood. That which nourishes every part adheres and becomes agglutinated to it. Upon each of these topics and various others besides, to be discussed and demonstrated in their several places, viz., in the physiology and other parts of the art of medicine, as well as of the consequences, advantages or disadvantages of the circulation of the blood, I do not mean to touch here; it were fruitless indeed to do so until the circulation has been established and conceded as a fact. And here the example of astronomy is by no means to be followed, in which from mere appearances or phenomena that which is in fact, and the reason wherefore it is so, are investigated. But as he who inquires into the cause of an eclipse must be placed beyond the moon if he would ascertain it by sense, and not by reason, so with regard to things sensible, for things that come under the cognizance of the senses, no more certain demonstration or means of gaining faith can be adduced than examination by the senses, and ocular inspection.

There is one remarkable experiment which I would have everyone try who is anxious for truth, and by which it is clearly shown that the arterial pulse is owing to the impulse of the blood. Let a portion of the dried intestine of a dog or wolf, or any other animal, such as we see in the druggists' shops, be taken and filled with water, and then secured at both ends like a sausage. By tapping with the finger at one extremity, you will immediately feel a pulse and vibration in any other part to which you apply the fingers, as you do when you feel the pulse at the wrist. In this way, indeed, and also by means of a distended vein, you may accurately either in the dead or living body, imitate and show every variety of the pulse, whether as to force, frequency, volume, rhythm, etc. Just as in a long bladder full of fluid, or in an oblong drum, every stroke

upon one end is immediately felt at the other, so also in a dropsy of the belly and in abscesses under the skin, we are accustomed to distinguish between collections of fluid and of air, between anasarca and tympanites in particular. If every impulse and vibration given on one side is clearly felt by a hand placed on the other side, we judge the case to be tympanites, not, as falsely asserted, because we hear a sound like that of a drum, and this produced by flatus, which never happens, but because, as in a drum, even the slightest tap passes through and produces a certain vibration on the opposite side, for it indicates that there is a serous and ichorous substance present, of such a consistency as urine, and not any sluggish or viscid matter as in anasarca, which when struck retains the impress of the blow or pressure, and does not transmit the impulse.[1]

Having brought forward this experiment I may observe, that a most formidable objection to the circulation of the blood rises out of it, which, however, has neither been observed nor adduced by anyone who has written against me. When we see by the experiment just described, that the systole and diastole of the pulse can be accurately imitated without any escape of fluid, it is obvious that the same thing may take place in the arteries from the stroke of the heart, without the necessity for a circulation, but like Euripus, with a mere motion of the blood alternately backwards and forwards. But we have already satisfactorily replied to this difficulty; and now we venture to say that the thing could not be possible in the arteries of a living animal. To be assured of this it is enough to see that the right auricle is incessantly injecting the right ventricle of the heart with blood, the return of which is prevented by the tricuspid valves; the left auricle in like manner filling the left ventricle, the return of the blood there being opposed by the mitral valves. The ventricles in their turn are propelling the blood into either great artery, the reflux

[1] [Harvey here makes several mistakes, due to the imperfect medical knowledge of his time. The distension of a cavity by gas is not discovered by the presence of vibrations as suggested, fluid being a much better conductor of such impulses. Nor does the distinction drawn between serum ichor and anasarca hold good in the light of modern experience.—Ed.]

in each being prevented by the sigmoid valves in its orifice. Either, therefore, the blood must move on incessantly through the lungs, and in like manner within the arteries of the body, or stagnating and pent up, it must rupture the containing vessels, or choke the heart by over distension, as I have shown it to do in the vivisection of a snake, described in my book on the Motion of the Blood. To resolve this doubt I shall relate two experiments among many others, the first of which, indeed, I have already adduced, and which show with singular clearness that the blood flows incessantly and with great force and in ample abundance in the veins towards the heart. The internal jugular vein of of a live fallow deer was exposed, and divided (many of the nobility and his most serene majesty the king, my master, being present); a few drops only of blood were observed to escape from the lower orifice rising up from under the clavicle; whilst from the superior orifice of the vein and coming down from the head, a round torrent of blood gushed forth. You may observe the same fact any day in practising phlebotomy: if with a finger you compress the vein a little below the orifice, the flow of blood is immediately arrested; but the pressure being removed, forthwith the flow returns as before.

From any long vein of the forearm get rid of the blood as much as possible by holding the hand aloft and pressing the blood towards the trunk, you will perceive the vein collapsed and leaving, as it were, a depression in the skin; but now compress the vein with the point of a finger, and you will immediately perceive all that part of it which is towards the hand, to enlarge and to become distended with the blood that is coming from the hand. How comes it when the breath is held and the lungs thereby compressed, a large quantity of air having been taken in, that the vessels of the chest are at the same time obstructed, the blood driven into the face, and the eyes rendered red and suffused? Why is it, as Aristotle asks in his problems, that all the actions are more energetically performed when the breath is held than when it is given? In like manner, when the frontal and lingual veins are incised, the blood is made to flow more freely by compressing the neck and holding the breath. I have several times opened the breast

and pericardium of a man within two hours after his execution by hanging, and before the colour had totally left the face, and in presence of many witnesses, have demonstrated the right auricle of the heart and the lungs distended with blood; the auricle in particular of the size of a large man's fist, and so full of blood that it looked as if it would burst. This great distension, however, had disappeared next day, the body having stiffened and become cold, and the blood having made its escape through various channels. These and other similar facts, therefore, make it sufficiently certain that the blood flows through the whole of the veins of the body towards the base of the heart, and that unless there was a further passage afforded it, it would be pent up in these channels, or would oppress and overwhelm the heart; as on the other hand, did it not flow outwards by the arteries, but was found regurgitating, it would soon be seen how much it would oppress.

I add another observation. A noble knight, Sir Robert Darcy, an ancestor of that celebrated physician and most learned man, my very dear friend Dr. Argent, when he had reached to about the middle period of life, made frequent complaint of a certain distressing pain in the chest, especially in the night season; so that dreading at one time syncope, at another suffocation in his attacks he led an unquiet and anxious life. He tried many remedies in vain, having had the advice of almost every medical man. The disease going on from bad to worse, he by-and-by became cachectic and dropsical, and finally, grievously distressed, he died in one of his paroxysms. In the body of this gentleman, at the inspection of which there were present Dr. Argent, then president of the College of Physicians, and Dr. Gorge, a distinguished theologian and preacher, who was pastor of the parish, we found the wall of the left ventricle of the heart ruptured, having a rent in it of size sufficient to admit any of my fingers, although the wall itself appeared sufficiently thick and strong. This laceration had apparently been caused by an impediment to the passage of the blood from the left ventricle into the arteries.

I was acquainted with another strong man, who having received an injury and affront from one more powerful

than himself, and upon whom he could not have his revenge, was so overcome with anger and indignation, which he yet communicated to no one, that at last he fell into a strange distemper, suffering from extreme oppression and pain of the heart and breast, and the prescriptions of none of the very best physicians proving of any avail, he fell in the course of a few years into a scorbutic and cachectic state, pined away and died. This patient only received some little relief when the whole of his chest was compressed, stroked and kneaded by a strong man, as a baker kneads dough. His friends thought him poisoned by some maleficent influence, or possessed with an evil spirit. The arteries of his throat, enlarged to the size of the thumb, looked like the aorta itself, for they were as large as the descending aorta. They pulsated violently, and appeared like two long aneurisms. These symptoms had led to trying the effects of arteriotomy in the temples, but with no relief. In the dead body I found the heart and aorta so much gorged and distended with blood, that the cavities of the ventricles equalled those of a bullock's heart in size. Such is the force of the blood pent up, and such are the effects of its impulse.

We may therefore conclude, that although there may be impulse without any exit, as illustrated in the experiment lately spoken of, still that this could not take place in the vessels of living creatures without most serious dangers and impediments. From this, however, it is manifest that the blood in its course does not everywhere pass with the same celerity, neither with the same force in all places and at all times, but that it varies greatly according to age, sex, temperament, habit of body, and other contingent circumstances, external as well as internal, natural or non-natural. For it does not course through occluded intricate and obstructed passages with the same readiness that it does through straight, unimpeded, and pervious channels. Neither does it run through close, hard, and crowded parts, with the same velocity as through spongy, soft, and permeable tissues. Neither does it flow and penetrate with such swiftness when the impulse is slow and weak, as when this is forcible and frequent, in which case the blood is driven onwards with vigour and in large quantity. Nor is the

same blood, when it has become more consistent or earthy, so penetrative as when it is more serous and attenuated or liquid. And then it seems only reasonable to think that the blood in its circuit passes more slowly through the kidneys than through the substance of the heart; more swiftly through the liver than through the kidneys; through the spleen more quickly than through the lungs, and through the lungs more speedily than through any of the other viscera or the muscles, in proportion always to the denseness or sponginess of the tissue of each.

We may be permitted to take the same view of the influence of age, sex, temperament, and habit of body, whether this be hard or soft; of that of the ambient cold which condenses bodies, and makes the veins in the extremities to shrink and almost to disappear, and deprives the surface both of colour and heat; and also of that of meat and drink which render the blood more watery, by supplying fresh nutritive matter. From the veins, therefore, the blood flows more freely in phlebotomy when the body is warm than when it is cold. We also observe the signal influence of the affections of the mind when a timid person is bled and happens to faint: immediately the flow of blood is arrested, a deadly pallor overspreads the surface, the limbs stiffen, the ears sing, the eyes are dazzled or blinded, and, as it were, convulsed. But here I come upon a field where I might roam freely and give myself up to speculation. But, indeed, so great a light of truth breaks in upon me here; occasion offers of explaining so many problems, of resolving so many doubts, of discovering the causes of so many slighter and more serious diseases, and of suggesting remedies for their cure, that the subject seems almost to demand a separate treatise. And it will be my business in my "Medical Observations," to lay before my reader matter upon all these topics which shall be worthy of the gravest consideration.

What, indeed, is more deserving of attention than the fact that in almost every affection, appetite, hope, or fear, our body suffers, the countenance changes, and the blood appears to course hither and thither? In anger the eyes are fiery and the pupils contracted; in modesty the cheeks are suffused with blushes; in fear, infamy and shame, the

face is pale, but the ears burn as if for the evil they were to hear; in lust how quickly is the member distended with blood and erected! But, above all, and this is of the highest importance to the medical practitioner,—how speedily is pain relieved or removed by the detraction of blood, the application of cupping-glasses, or the compression of the artery which leads to a part? It sometimes vanishes as if by magic. But these are topics that I must refer to my "Medical Observations," where they will be found referred to and explained.

Some weak and inexperienced persons vainly seek by dialectics and far-fetched arguments, either to upset or establish things that are only to be founded on anatomical dissection, and believed on the evidence of the senses. He who truly desires to be informed of the question in hand, and whether the facts alleged be sensible, visible, or not, must be held bound either to look for himself, or to believe the conclusions held by those who have tested the matter. Indeed, there is no higher method of attaining to assurance and certainty. Who would attempt to persuade those who had never tasted wine that it was a drink much pleasanter to the palate than water? How should we prove to the blind from birth that the sun was luminous, and far surpassed the stars in brightness? So it is with the circulation of the blood, which has now for so many years been before all, confirmed by facts recognizable by the senses, by autopsies and by various experiments. No one has yet been found to dispute the sensible facts, the motion, efflux and afflux of the blood, by like observations based on the evidence of sense, or to oppose the experiments adduced, by other experiments of the same character; nay, no one has yet attempted an opposition on the ground of ocular testimony.

There have not been wanting many who, inexperienced and ignorant of anatomy, and making no appeal to the senses in their opposition, have, on the contrary, met it with empty assertions, and mere suppositions, with assertions derived from the lessons of teachers and captious cavillings. Many, too, have vainly sought refuge in words, and these not always very nicely chosen, but reproachful and contumelious, which, however, have no farther effect

than to expose their utterer's vanity and weakness, and ill breeding, and lack of the arguments that are to be sought in the conclusions of the senses, and false sophistical reasonings that seem utterly opposed to sense. Even as the waves of the Sicilian sea, excited by the blast, dash against the rocks around Charybdis, and then hiss and foam, and are tossed hither and thither; so do they who reason against the evidence of their senses.

If nothing were to be admitted by the senses without evidence derived from reason, or occasionally even contrary to the previously received conclusions of reason, there would now be no problem left for discussion. Had we not our most perfect assurances by the senses, and were not their perceptions confirmed by reasoning, in the same way as geometricians proceed with their figures, we should admit no science of any kind; for it is the province of geometry to make rational demonstration of things that are not sensible from things sensible, to discover things abstruse and beyond the senses from things more manifest and better known. Aristotle counsels us better when, in in treating of the generation of bees, he says:[1] "Faith is to be given to reason, if the matters demonstrated agree with those that are perceived by the senses; when the things have been thoroughly scrutinized, then are the senses to be trusted rather than the reason." Whence we ought to approve or disapprove, to receive or reject everything only after the most careful examination; but to examine, to test whether anything have been well or ill advanced, to ascertain whether some falsehood does not lurk under a proposition, it is imperative on us to bring it to the proof of sense, and to admit or reject it on the decision of sense. Whence Plato in his Critias says, that the explanation of those things is not difficult of which we can have experience. They are not of apt scientific apprehension who have no experience.

How arduous and difficult is it to teach those who have no experience, the things of which they have not any knowledge by their senses! And how useless and intractable to true science are such auditors! They show the judg-

[1] De Generat. Animal. lib. iii. cap. x.

ment of the blind in regard to colours, of the deaf in reference to concords. Who ever pretended to teach the ebb and flow of the tide, or from a diagram to demonstate the measurements of the angles and the proportions of the sides of a triangle to a blind man, or to one who had never seen the sea nor a diagram? He who is not conversant with anatomy, inasmuch as he forms no conception of the subject from the evidence of his own eyes, is virtually blind to all that concerns anatomy, and unfit to appreciate what is founded thereon. He knows nothing of that which occupies the attention of the anatomist, nor of the principles inherent in the nature of the things which guide him in his reasonings; facts and inferences as well as their sources are alike unknown to such a one. But no kind of science can possibly flow, save from some pre-existing knowledge of more obvious things; and this is one main reason why our science in regard to the nature of celestial bodies is so uncertain and conjectural. I would ask of those who profess a knowledge of the causes of all things, why the two eyes keep constantly moving together, up or down, to this side or to that, and not independently, one looking this way another that; why the two auricles of the heart contract simultaneously, and the like? Are fevers, pestilence, and the wonderful properties of various medicines to be denied because their causes are unknown? Who can tell us why the fœtus in utero, breathing no air up to the tenth month of its existence, is yet not suffocated? why, if born in the course of the seventh or eighth month, and having once breathed, it is nevertheless suffocated if its respiration be prevented?[1] Why can the fœtus still contained within the uterus, or enveloped in the membranes, live without respiration; whilst once exposed to the air, unless it breathes it cannot retain life?[2]

[1] Vide Chapter VI. of the Disq. on the Motion of the Heart and Blood.

[2] [It may be here stated that the above questions relating to intra-uterine and early aërial life have been satisfactorily explained by later study. Harvey had only a vague idea of the uses of the Respiration, although in the main it was right, and far in advance of contemporary knowledge. It remained for Chemistry to unlock the secrets of that function, upon which the hitherto inexplicable transition depended. Chemistry can scarcely be said to have existed until long after Harvey wrote the above.—Ed.]

Observing that many hesitate to acknowledge the circulation, and others oppose it, because, as I conceive, they have not rightly understood me, I shall here recapitulate briefly what I have said in my work on the Motion of the Heart and Blood. The blood contained in the veins, as it were in its base, and where it is visibly in largest quantity, viz., in the vena cava, close to the base of the heart and right auricle, gradually increasing in temperature by its internal heat, and becoming attenuated, it swells and rises in the manner of fermentation, whereby the auricle being dilated, and then contracting, in virtue of its pulsative power, forthwith delivers its charge into the right ventricle. This being filled, and the systole ensuing, the charge, hindered from returning into the auricle by the tricuspid valves, is forced into the pulmonary artery, which stands with open door to receive it, and is immediately distended with it. Once in the pulmonary artery, the blood cannot return, by reason of the sigmoid valves. Then the lungs, alternately expanded and contracted during inspiration and expiration, afford it passage by the proper vessels into the pulmonary veins, from which the left auricle, acting equally and at the same time with the right auricle, in motion, rhythm, order, and function, drives the blood into the left ventricle, as the right auricle does into the right ventricle. Then the left ventricle, acting harmoniously with the right ventricle, and all regress being prevented by the mitral valves, the blood is projected into the aorta, and consequently impelled into every branch of the arteries. The arteries, filled by this sudden impulse, as they cannot discharge themselves so speedily, are distended; they receive a shock, or undergo their diastole. But as this process goes on incessantly, I infer that the arteries both of the lungs and of the body at large, under the influence of such a multitude of strokes of the heart and injections of blood, would finally become so over-gorged and distended, that any further injection must cease, or the vessels would burst, or the whole blood in the body would accumulate within them, were there not some exit provided.

The same reasoning is applicable to the ventricles of the heart, distended with blood by the ceaseless action of the

auricles. Did they not empty themselves by the arteries, they would become over-gorged, and be fixed and made incapable of all motion. Now this, my conclusion, is true and necessary, if my premises be true; but that these are either true or false, our senses must inform us, not our reason—ocular inspection, not any process of the mind.

I maintain further, that the blood in the veins always and everywhere flows from less to greater branches, and from every part towards the heart; whence I gather that the whole charge which the arteries receive, and which is incessantly thrown into them, is delivered to the veins, and flows back by them to the source whence it came. In this way, indeed, is the circulation of the blood set in motion by an impelled flow from and a reflux to the heart; the fluid being forcibly projected into the arterial system, and then absorbed and imbibed from every part by the veins, it returns through these in a continuous stream. Sense assures us that all this is so, and necessary inference from the perceptions of sense takes away all occasion for doubt. Lastly, this is what I have striven, by my observations and experiments, to illustrate and make known; I have not endeavoured from causes and probable principles to demonstrate my propositions, but, as of higher authority, to establish them by appeals to sense and experiment, after the manner of anatomists.

And here I would refer to the amount of force, even of violence, which sight and touch make us aware of in the heart and greater arteries; and to the systole and diastole constituting the pulse in the large warm-blooded animals, which I do not say is equal in all the vessels containing blood, nor in all animals that have blood; but which is of such a nature and amount in all, that a flow and rapid passage of the blood through the smaller arteries, the porosities of the parts, and all the branches of the veins, must of necessity take place; and therefore there is a circulation.

For neither do the minute arteries,[1] nor the veins, pulsate;

[1] [It would almost seem as if Harvey had confused what we now designate capillaries with the minute arteries. Pulsations synchronous with the heart's action are occasionally observed even in such minute arteries as those of the web of the frog's foot, while in man they are

but the larger arteries and those near the heart pulsate, because they do not transmit the blood so quickly as they receive it.[1] Having exposed an artery, and divided it so that the blood shall flow out as fast and freely as it is received, you will scarcely perceive any pulse in that vessel; and for the simple reason, that an open passage being afforded, the blood escapes, merely passing through the vessel, not distending it. In fishes, serpents, and the colder animals, the heart beats so slowly and feebly, that a pulse can scarcely be perceived in the arteries; the blood in them is transmitted gradually. Whence in them, as also in the smaller branches of the arteries in man, there is no distinction between the coats of the arteries and veins, because the arteries have to sustain no shock from the impulse of the blood.[2]

An artery denuded and divided in the way I have indicated sustains no shock, neither does it pulsate; whence it clearly appears that the arteries have no inherent pulsative power, and that neither do they derive any from the heart; but that they undergo their diastole solely from the impulse of the blood. In the full stream, flowing to a distance, you may see the systole and diastole, and by touch perceive, as I before stated, all the motions of the heart—their order, force, rhythm, etc.,[3] as it were in a mirror. Precisely as in the water that is forced aloft, through a leaden pipe, by working the piston of a forcing-pump, each stroke of which, though the jet be many feet distant, is nevertheless distinctly perceptible,—the beginning, increasing strength, and end of the impulse, as well as its amount, and the regularity or irregularity with which it is given, being indicated, the same precisely is the case from the orifice of a divided artery. Wherefore, as in the instance of the forcing engine quoted, you will perceive that the

more marked. As a general statement it may be asserted that the pulse is absent from capillaries and veins.—Ed.]

[1] Vide Chapter III, on the Motion of the Heart and Blood.

[2] [While the above is approximately, it is not absolutely, the case. The coats of the arteries are highly elastic throughout, with a circular muscular envelopment which increases in relative importance as the vessels diminish in size. The veins are less elastic than the arteries, and have a very variable muscular element present.—Ed.]

[3] Vide Chapter III, on the Motion of the Heart and Blood.

efflux is uninterrupted, although the jet is alternately greater and less. So in the arteries, besides the concussion or impulse of the blood, the pulse or beat of the artery, which is not equally exhibited in all, there is a perpetual flow and motion of the blood, which returns in an unbroken stream to the point from whence it commenced—the right auricle of the heart.

All these points you may satisfy yourself upon, by exposing one of the longer arteries, as those in the neck, and having taken it between your finger and thumb, dividing it on the side remote from the heart. By the greater or less pressure of your fingers, you can have the vessel pulsating less or more, or losing the pulse entirely, and recovering it at will. And as these things proceed thus when the chest is uninjured, so also do they go on for a short time when the thorax is laid open, and the lungs having collapsed, all the respiratory motions have ceased. Here, nevertheless, for a little while you may perceive the left auricle contracting and emptying itself, and becoming whiter. At length, by growing weaker and weaker, it begins to intermit, as does the left ventricle also, and then it ceases to beat altogether, and becomes quiescent. In like manner does the stream of blood from the divided artery grow less and less, the pulse of the vessel smaller and weaker, until finally, the supply of blood and the impulse of the left ventricle failing, nothing escapes from it. You may perform the same experiment, tying the pulmonary veins, and so taking away the pulse of the left auricle, or relaxing the ligature, and restoring it at pleasure. In this experiment, too, you will observe what happens in moribund animals, viz., that the left auricle first ceases from pulsation and motion, then the left ventricle, next the right ventricle, finally the right auricle. So that where the vital force and pulse first begin, there do they also last fail.

These particulars having been recognized by the senses, it is manifest that the blood passes through the lungs, and not through the septum of the heart, and only through them when they are moved in the act of respiration, not when they are collapsed and quiescent. We therefore see the probable reason why nature has instituted the foramen

ovale in the embryo, as it does not breathe, instead of sending the blood by the way of the pulmonary artery into the left auricle and ventricle, which foramen she closes when the new-born creature begins to breathe freely. We can also now understand why, when the vessels of the lungs become congested and oppressed, and in those who are affected with serious diseases, it should be so dangerous and fatal a symptom when the respiratory organs become implicated.

We perceive none the less why the blood is so florid in the lungs. It is because it is there thinner, having to undergo filtration.

Moreover, it is to be observed from the summary which precedes, and by way of satisfying those who demand the causes of the circulation, and incline to regard the power of the heart as the source of everything—that it is not only the seat and source of the pulse which propels the blood, but also, as Aristotle thinks, of the power which attracts and produces it. Besides, they believe that the spirits are engendered by the heart, and by the influxive vital heat, in virtue of the innate heat of the heart, as the immediate instrument of the soul, or common bond and prime organ in the performance of every act of vitality; in a word, that the motion, perfection, heat, and every property besides of the blood and spirits are derived from the heart, as their fountain or original, and that it is the primary cause of pulsation and life. This doctrine is as old as Aristotle, who maintained all these qualities to inhere in the blood, as heat inheres in hot water or in boiling pottage. To those persons, were I to speak openly, I should say that I do not agree with the common opinion. There are many points to be noted in the production of the parts of the body which incline me this way, but which it does not seem expedient to enter upon here. Before long, perhaps, I shall have occasion to lay before the world things that are more wonderful than these, and which will throw still greater light upon natural philosophy.

Meantime I shall only say, and set forth without demonstration—with the good leave of our learned men, and with all respect for antiquity—that the heart, with the veins and arteries and the blood they contain, is to be

regarded as the beginning and author, the fountain and origin of all things in the body, the primary cause of life, in the same way as the brain with all its nerves, organs of sense and spinal marrow inclusive, is spoken of as the one and general organ of sensation. But if by the word heart the mere body of the heart, made up of its auricles and ventricles, be understood, then I do not believe that the heart is the fashioner of the blood; neither do I imagine that the blood has powers, properties, motion, or heat, as the gift of the heart. Lastly, I do not admit that the cause of the systole and contraction is the same as that of the diastole or dilatation, whether in the arteries, or in the auricles, or ventricles of the heart; for I hold that that part of the pulse which is designated the diastole depends on another cause different from the systole, and that it must always and everywhere precede any systole. I hold that the innate heat is the first cause of dilatation, and that the primary dilatation is in the blood itself, after the manner of bodies in a state of fermentation, gradually attenuated and swelling, and that in the blood this is ultimately extinguished. I assent to Aristotle's example of boiling gruel or milk thus far, that the rising and falling of the blood does not depend upon vapours or exhalations, or spirits, or anything rising in a vaporous or aëreal shape, nor upon any external agency, but upon an internal principle regulated by nature.

Nor is the heart, as some imagine, anything like a chauffer or fireplace or heated kettle, and so the source of the heat of the blood. The blood, instead of receiving, rather gives heat to the heart, as it does to all the other parts, for the blood is the hottest element in the body. It is on this account that the heart is furnished with coronary arteries and veins; it is for the same reason that other parts have vessels, viz., to secure the access of warmth for their due conservation and stimulation; so that the warmer any part is, the greater is its supply of blood, or otherwise; where the blood is in largest quantity, there also is the heat highest. For this reason the heart, remarkable through its cavities, is to be viewed as the laboratory, fountain, and perennial focus of heat, and as comparable to a hot kettle, not because of its proper sub-

stance, but because of its contained blood. For the same reason the liver, spleen, lungs, etc., are reputed hot parts, because they have numerous veins or vessels containing blood. In this way do I view the native or innate heat as the common instrument of every function, the prime cause of the pulse among the rest. This, however, I do not mean to state absolutely, but only propose it by way of thesis. Whatever objections may be brought against it by good and learned men, without scurrilous or contemptuous language, I shall be ready to consider, I shall even be most grateful to anyone who will take up and discuss the subject.

These then, are, as it were, the very elements and indications of the passage and circulation of the blood, viz., from the right auricle into the right ventricle; from the right ventricle by the way of the lungs into the left auricle; thence into the left ventricle and aorta; then by all the arteries flowing from the heart through the porosities of the parts into the veins, and by the veins back again with great rapidity to the base of the heart.

There is an experiment on the veins by which anyone that chooses may convince himself of this truth: Let the arm be bound with a moderately tight bandage, and then, by opening and shutting the hand, make all the veins to swell as much as possible, and the integuments below the fillet to become red. Now let the arm and hand be plunged into very cold water, or snow, until the blood pent up in the veins shall have become cooled down; then let the fillet be undone suddenly, and you will perceive, by the cold blood returning to the heart, with what celerity the current flows, and what an effect it produces when it has reached the heart. You will no longer be surprised that some should faint when the fillet is undone after venesection.[1] This experiment shows that the veins swell below the ligature not with attenuated blood, or with blood raised by spirits or vapours, for the immersion in the cold water would repress their ebullition, but with blood only, and such as could never make its way back into the arteries, either by anastomoses or by devious passages. It

[1] Vide Chapter XI. of the Motion of the Heart, etc.

shows, moreover, how and in what way those who are travelling over snowy mountains are sometimes stricken suddenly with death, and other things of the same kind.

Lest it should seem difficult for the blood to make its way through the pores of the various structures of the body, I shall add one illustration: The same thing happens in the bodies of those that are hanged or strangled, as in the arm that is bound with a ligature: all the parts beyond the noose,—the face, lips, tongue, eyes, and every part of the head appear gorged with blood, swollen and of a deep red or livid colour. If the noose be relaxed, in whatever position you have the body, before many hours have passed you will perceive the whole of the blood to have left the head and face, and gravitated through the pores of the skin, flesh, and other structures, from the superior parts towards those that are inferior and dependent, until they become tumid and of a dark colour. But if this happens in the dead body, with the blood dead and coagulated, the frame stiffened with the chill of death, the passages all compressed or blocked up, it is easy to perceive how much more apt it will be to occur in the living subject, when the blood is alive and replete with spirits, when the pores are all open and penetrable, and the passage in every way made easy.

When the ingenious, able, and acute Descartes, (whose honourable mention of my name demands my acknowledgments,) and others, having taken out the heart of a fish, and put it on a plate before them, see the pulse continue and the heart contract, and when it raises or erects itself and becomes firm to the touch, they think it enlarges, expands, and that its ventricles thence become more capacious. But, in my opinion, they do not observe correctly; for, at the time that the heart gathers itself up, and becomes erect, it is certain that it is rather lessened in every one of its dimensions; that it is in its systole, not in its diastole. Neither, on the contrary, when it collapses and sinks down, is it then properly in its state of diastole and distension, by which the ventricles become more capacious. But we do not say that the heart is in the state of diastole in the dead body, as having sunk relaxed after the systole,

but it is then collapsed, and destitute of all motion, it is in a state of rest, not distension. It is only truly distended, and in the proper state of diastole, when it is filled by the charge of blood projected into it by the contraction of the auricles, which appears evident enough in the course of vivisections. Descartes, therefore, does not perceive how much the relaxation and subsidence of the heart and arteries differ from their distension or diastole; and that the cause of the distension, relaxation, and constriction, is not one and the same. As contrary effects so must they acknowledge contrary causes; as different movements they must have different motors; just as all anatomists know that the flexion and extension of an extremity are accomplished by opposite and antagonistic muscles, so contrary or diverse motions are necessarily performed by contrary and diverse organs instituted by nature for the purpose. Nor do I find the efficient cause of the pulse aptly explained by this philosopher, when with Aristotle he assumes the cause of the systole to be the same as that of the diastole, namely, an effervescence of the blood due to a kind of ebullition. The pulse is a succession of sudden strokes and quick percussions; but we know of no kind of fermentation or ebullition in which the matter rises and falls in the twinkling of an eye; the heaving is always gradual where the subsidence is notable. Besides, in the dissection of a living animal, we can perceive the ventricles of the heart both charged and distended by the contraction of the auricles, and more or less increased in size according to the charge; and farther, we can see that the distension of the heart is rather a violent motion, the effect of an impulse, and not performed by any kind of attraction.

There are others who consider that, as no kind of impulse of the nutritive juices is required in vegetables, but that these are attracted by the parts which require them, and flow in to take the place of what has been lost, so neither is there any necessity for an impulse in animals, the vegetative faculty in both working alike. But there is a difference between plants and animals. In animals, a constant supply of warmth is required to cherish the members, to maintain them in life by the vivifying heat,

and to restore parts injured from without. It is not merely nutrition that has to be provided for.

So much for the circulation, which if impeded, perverted, or too much excited, is followed by a host of dangerous diseases and remarkable symptoms: in connexion with the veins by varices, abscesses, pains, hemorrhoids, hemorrhages; in connexion with the arteries by enlargements, phlegmons, severe and lancinating pains, aneurisms, sarcoses, fluxions, sudden attacks of suffocation, asthmas, stupors, apoplexies, and innumerable other affections. But this is not the place to enter on the consideration of these; neither may I say under what circumstances and how speedily some of these diseases, that are even reputed incurable, are remedied and dispelled, as if by enchantment. I shall have much to put forth in my Medical Observations and Pathology, which, so far as I know, has as yet been observed by no one.

That I may afford you still more ample satisfaction, most learned Riolanus, as you do not think there is a circulation in the vessels of the mesentery, I shall conclude by proposing the following experiment: ligature the porta close to the liver, in a living animal, which is easily done. You will perceive the veins below the ligature swelling in the same way as those of the arm when the ligature is bound above the elbow, which will proclaim the course of the blood there. And as you still seem to think that the blood can regurgitate from the veins into the arteries by anastomoses, let the vena cava be tied in a living animal near the bifurcation of the crural veins, and immediately afterwards let an artery be opened to give issue to the blood; you will soon observe the whole of the blood discharged from all the veins, even in the ascending cava, beyond the ligature the crural veins and the parts below them remaining full. This certainly could not happen were there any retrograde passage for the blood from the veins to the arteries by anastomoses.

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