

On the Motion of the Heart and Blood in Animals

William Harvey, 1628

[Translation by Robert Willis, 1847]

Letter To The King And Dedication

*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 still 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.

*Dedication 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 skilfull 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 the 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

68 transmitted to us by the ancients, in such a state of forwardness or
69 completeness, that nothing is left for the ingenuity and industry of
70 others. On the contrary, very many maintain that all we know is
71 still infinitely less than all that still remains unknown; nor do
72 philosophers pin their faith to others' precepts in such wise that
73 they lose their liberty, and cease to give credence to the
74 conclusions of their proper senses. Neither do they swear such
75 fealty to their mistress Antiquity, that they openly, and in sight of
76 all, deny and desert their friend Truth. But even as they see that the
77 credulous and vain are disposed at the first blush to accept and
78 believe everything that is proposed to them, so do they observe
79 that the dull and unintellectual are indisposed to see what lies
80 before their eyes, and even deny the light of the noonday sun.
81 They teach us in our course of philosophy to sedulously avoid the
82 fables of the poets and the fancies of the vulgar, as the false
83 conclusions of the sceptics. And then the studious and good and
84 true, never suffer their minds to be warped by the passions of
85 hatred and envy, which unfit men duly to weigh the arguments that
86 are advanced in behalf of truth, or to appreciate the proposition
87 that is even fairly demonstrated. Neither do they think it unworthy
88 of them to change their opinion if truth and undoubted
89 demonstration require them to do so. They do not esteem it
90 discreditable to desert error, though sanctioned by the highest
91 antiquity, for they know full well that to err, to be deceived, is
92 human; that many things are discovered by accident and that many
93 may be learned indifferently from any quarter, by an old man from
94 a youth, by a person of understanding from one of inferior
95 capacity.

96 My dear colleagues, I had no purpose to swell this treatise into
97 a large volume by quoting the names and writings of anatomists,
98 or to make a parade of the strength of my memory, the extent of
99 my reading, and the amount of my pains; because I profess both to
100 learn and to teach anatomy, not from books but from dissections;
101 not from the positions of philosophers but from the fabric of
102 nature; and then because I do not think it right or proper to strive
103 to take from the ancients any honor that is their due, nor yet to
104 dispute with the moderns, and enter into controversy with those
105 who have excelled in anatomy and been my teachers. I would not
106 charge with wilful falsehood any one who was sincerely anxious
107 for truth, nor lay it to any one's door as a crime that he had fallen
108 into error. I avow myself the partisan of truth alone; and I can
109 indeed say that I have used all my endeavours, bestowed all my

110 pains on an attempt to produce something that should be agreeable
111 to the good, profitable to the learned, and useful to letters.

112 Farewell, most worthy Doctors,
113 And think kindly of your Anatomist,
114 William Harvey

115 Prefatory Remarks

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

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

136 But as the structure and movements of the heart differ from
137 those of the lungs, and the motions of the arteries from those of the
138 chest, so it seems likely that other ends and offices will thence
139 arise, and that the pulsations and uses of the heart, likewise of the
140 arteries, will differ in many respects from the heavings and uses of
141 the chest and lungs. For did the arterial pulse and the respiration
142 serve the same ends; did the arteries in their diastole take air into
143 their cavities, as commonly stated, and in their systole emit
144 fuliginous vapours by the same pores of the flesh and skin; and
145 further, did they, in the time intermediate between the diastole and
146 the systole, contain air, and at all times either air or spirits, or
147 fuliginous vapours, what should then be said to Galen, who wrote

148 a book on purpose to show that by nature the arteries contained
149 blood, and nothing but blood, and consequently neither spirits nor
150 air, as may readily be gathered from the experiments and
151 reasonings contained in the same book? Now, if the arteries are
152 filled in the diastole with air then taken into them (a larger quantity
153 of air penetrating when the pulse is large and full), it must come to
154 pass that if you plunge into a bath of water or of oil when the pulse
155 is strong and full, it ought forth-with to become either smaller or
156 much slower, since the circumambient bath will render it either
157 difficult or impossible for the air to penetrate. In like manner, as
158 all the arteries, those that are deep-seated as well as those that are
159 superficial, are dilated at the same instant and with the same
160 rapidity, how is it possible that air should penetrate to the deeper
161 parts as freely and quickly through the skin, flesh, and other
162 structures, as through the cuticle alone? And how should the
163 arteries of the fœtus draw air into their cavities through the
164 abdomen of the mother and the body of the womb? And how
165 should seals, whales, dolphins, and other cetaceans, and fishes of
166 every description, living in the depths of the sea, take in and emit
167 air by the diastole and systole of their arteries through the infinite
168 mass of water? For to say that they absorb the air that is present in
169 the water, and emit their fumes into this medium, were to utter
170 something like a figment. And if the arteries in their systole expel
171 fuliginous vapours from their cavities through the pores of the
172 flesh and skin, why not the spirits, which are said to be contained
173 in those vessels, at the same time, since spirits are much more
174 subtle than fuliginous vapours or smoke? And if the arteries take
175 in and cast out air in the systole and diastole, like the lungs in the
176 process of respiration, why do they not do the same thing when a
177 wound is made in one of them, as in the operation of arteriotomy?
178 When the windpipe is divided, it is sufficiently obvious that the air
179 enters and returns through the wound by two opposite movements;
180 but when an artery is divided, it is equally manifest that blood
181 escapes in one continuous stream, and that no air either enters or
182 issues. If the pulsations of the arteries fan and refrigerate the
183 several parts of the body as the lungs do the heart, how comes it,
184 as is commonly said, that the arteries carry the vital blood into the
185 different parts, abundantly charged with vital spirits, which cherish
186 the heat of these parts, sustain them when asleep, and recruit them
187 when exhausted? How should it happen that, if you tie the arteries,
188 immediately the parts not only become torpid, and frigid, and look
189 pale, but at length cease even to be nourished? This, according to

190 Galen, is because they are deprived of the heat which flowed
191 through all parts from the heart, as its source; whence it would
192 appear that the arteries rather carry warmth to the parts than serve
193 for any fanning or refrigeration. Besides, how can their diastole
194 draw spirits from the heart to warm the body and its parts, and
195 means of cooling them from without? Still further, although some
196 affirm that the lungs, arteries, and heart have all the same offices,
197 they yet maintain that the heart is the workshop of the spirits, and
198 that the arteries contain and transmit them; denying, however, in
199 opposition to the opinion of Columbus, that the lungs can either
200 make or contain spirits. They then assert, with Galen, against
201 Erasistratus, that it is the blood, not spirits, which is contained in
202 the arteries.

203 These opinions are seen to be so incongruous and mutually
204 subversive, that every one of them is justly brought under
205 suspicion. That it is blood and blood alone which is contained in
206 the arteries is made manifest by the experiment of Galen, by
207 arteriotomy, and by wounds; for from a single divided artery, as
208 Galen himself affirms in more than one place, the whole of the
209 blood may be withdrawn in the course of half an hour or less. The
210 experiment of Galen alluded to is this: "If you include a portion of
211 an artery between two ligatures, and slit it open lengthwise you
212 will find nothing but blood"; and thus he proves that the arteries
213 contain only blood. And we too may be permitted to proceed by a
214 like train of reasoning: if we find the same blood in the arteries as
215 in the veins, after having tied them in the same way, as I have
216 myself repeatedly ascertained, both in the dead body and in living
217 animals, we may fairly conclude that the arteries contain the same
218 blood as the veins, and nothing but the same blood. Some, whilst
219 they attempt to lessen the difficulty, affirm that the blood is
220 spirituous and arterious, and virtually concede that the office of the
221 arteries is to carry blood from the heart into the whole of the body,
222 and that they are therefore filled with blood; for spirituous blood is
223 not the less blood on that account. And no one denies the blood as
224 such, even the portion of it which flows in the veins, is imbued
225 with spirits. But if that portion of it which is contained in the
226 arteries be richer in spirits, it is still to be believed that these spirits
227 are inseparable from the blood, like those in the veins; that the
228 blood and spirits constitute one body (like whey and butter in milk,
229 or heat in hot water), with which the arteries are charged, and for
230 the distribution of which from the heart they are provided. This
231 body is nothing else than blood. But if this blood be said to be

232 drawn from the heart into the arteries by the diastole of these
233 vessels, it is then assumed that the arteries by their distension are
234 filled with blood, and not with the surrounding air, as heretofore;
235 for if they be said also to become filled with air from the ambient
236 atmosphere, how and when, I ask, can they receive blood from the
237 heart? If it be answered: during the systole, I take it to be
238 impossible: the arteries would then have to fill while they
239 contracted, to fill, and yet not become distended. But if it be said:
240 during diastole, they would then, and for two opposite purposes,
241 be receiving both blood and air, and heat and cold, which is
242 improbable. Further, when it is affirmed that the diastole of the
243 heart and arteries is simultaneous, and the systole of the two is also
244 concurrent, there is another incongruity. For how can two bodies
245 mutually connected, which are simultaneously distended, attract or
246 draw anything from one another? or being simultaneously
247 contracted, receive anything from each other? And then it seems
248 impossible that one body can thus attract another body into itself,
249 so as to become distended, seeing that to be distended is to be
250 passive, unless, in the manner of a sponge, which has been
251 previously compressed by an external force, it is returning to its
252 natural state. But it is difficult to conceive that there can be
253 anything of this kind in the arteries. The arteries dilate, because
254 they are filled like bladders or leathern bottles; they are not filled
255 because they expand like bellows. This I think easy of
256 demonstration, and indeed conceive that I have already proved it.
257 Nevertheless, in that book of Galen headed "Quod Sanguis
258 continetur in Arteriis," he quotes an experiment to prove the
259 contrary. An artery having been exposed, is opened longitudinally,
260 and a reed or other pervious tube is inserted into the vessel through
261 the opening, by which the blood is prevented from being lost, and
262 the wound is closed. "So long," he says, "as things are thus
263 arranged, the whole artery will pulsate; but if you now throw a
264 ligature about the vessel and tightly compress its wall over the
265 tube, you will no longer see the artery beating beyond the
266 ligature." I have never performed this experiment of Galen's nor
267 do I think that it could very well be performed in the living body,
268 on account of the profuse flow of blood that would take place from
269 the vessel that was operated on; neither would the tube effectually
270 close the wound in the vessel without a ligature; and I cannot
271 doubt but that the blood would be found to flow out between the
272 tube and the vessel. Still Galen appears by this experiment to prove
273 both that the pulsative property extends from the heart by the walls

274 of the arteries, and that the arteries, whilst they dilate, are filled by
275 that pulsific force, because they expand like bellows, and do not
276 dilate as if they are filled like skins. But the contrary is obvious in
277 arteriotomy and in wounds; for the blood spurting from the arteries
278 escapes with force, now farther, now not so far, alternately, or in
279 jets; and the jet always takes place with the diastole of the artery,
280 never with the systole. By which it clearly appears that the artery is
281 dilated with the impulse of the blood; for of itself it would not
282 throw the blood to such a distance and whilst it was dilating; it
283 ought rather to draw air into its cavity through the wound, were
284 those things true that are commonly stated concerning the uses of
285 the arteries. Do not let the thickness of the arterial tunics impose
286 upon us, and lead us to conclude that the pulsative property
287 proceeds along them from the heart. For in several animals the
288 arteries do not apparently differ from the veins; and in extreme
289 parts of the body where the arteries are minutely subdivided, as in
290 the brain, the hand, etc., no one could distinguish the arteries from
291 the veins by the dissimilar characters of their coats: the tunics of
292 both are identical. And then, in the aneurism proceeding from a
293 wounded or eroded artery, the pulsation is precisely the same as in
294 the other arteries, and yet it has no proper arterial covering. To this
295 the learned Riolanus testifies along with me, in his Seventh Book.

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

307 These and other objections of the same kind may be urged
308 against the opinions mentioned. Nor are the views that are
309 entertained of the offices and pulse of the heart, perhaps, less
310 bound up with great and most inextricable difficulties. The heart, it
311 is vulgarly said, is the fountain and workshop of the vital spirits,
312 the centre from which life is dispensed to the several parts of the
313 body. Yet it is denied that the right ventricle makes spirits, which
314 is rather held to supply nourishment to the lungs. For these reasons
315 it is maintained that fishes are without any right ventricle (and

316 indeed every animal wants a right ventricle which is unfurnished
317 with lungs), and that the right ventricle is present solely for the
318 sake of the lungs.

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

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

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

346 4. And as Realdus Columbus says, is it probable that such a
347 quantity of blood should be required for the nutrition of the lungs;
348 the vessel that leads to them, the vena arteriosa or pulmonary
349 artery being of greater capacity than both the iliac veins?

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

355 When it is said that the left ventricle draws materials for the
356 formation of spirits, air and blood, from the lungs and right sinuses
357 of the heart, and in like manner sends spirituous blood into the

358 aorta, drawing fuliginous vapours from there, and sending them by
359 the pulmonary vein into the lungs, whence spirits are at the same
360 time obtained for transmission into the aorta, I ask how, and by
361 what means is the separation effected? And how comes it that
362 spirits and fuliginous vapours can pass hither and thither without
363 admixture or confusion? If the mitral cuspidate valves do not
364 prevent the egress of fuliginous vapours to the lungs, how should
365 they oppose the escape of air? And how should the semilunars
366 hinder the regress of spirits from the aorta upon each supervening
367 diastole of the heart? Above all, how can they say that the
368 spirituous blood is sent from the pulmonary veins by the left
369 ventricle into the lungs without any obstacle to its passage from
370 the mitral valves, when they have previously asserted that the air
371 entered by the same vessel from the lungs into the left ventricle,
372 and have brought forward these same mitral valves as obstacles to
373 its retrogression? Good God! how should the mitral valves prevent
374 the regurgitation of air and not of blood?

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

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

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

395 If any one will perform Galen's experiment of dividing the
396 trachea of a living dog, forcibly distending the lungs with a pair of
397 bellows, and then tying the trachea securely, he will find, when he
398 has laid open the thorax, abundance of air in the lungs, even to
399 their extreme investing tunic, but none in either the pulmonary

400 veins or the left ventricle of the heart. But did the heart either
401 attract air from the lungs, or did the lungs transmit any air to the
402 heart, in the living dog, much more ought this to be the case in the
403 experiment just referred to. Who, indeed, doubts that, did he
404 inflate the lungs of a subject in the dissecting-room, he would
405 instantly see the air making its way by this route, were there
406 actually any such passage for it? But this office of the pulmonary
407 veins, namely, the transference of air from the lungs to the heart, is
408 held of such importance, that Hieronymus Fabricius of
409 Aquapendente, contends that the lungs were made for the sake of
410 this vessel, and that it constitutes the principal element in their
411 structure.

412 But I should like to be informed why, if the pulmonary vein
413 were destined for the conveyance of air, it has the structure of a
414 blood-vessel here. Nature had rather need of annular tubes, such as
415 those of the bronchi in order that they might always remain open,
416 and not be liable to collapse; and that they might continue entirely
417 free from blood, lest the liquid should interfere with the passage of
418 the air, as it so obviously does when the lungs labour from being
419 either greatly oppressed or loaded in a less degree with phlegm, as
420 they are when the breathing is performed with a sibilous or rattling
421 noise.

422 Still less is that opinion to be tolerated which, as a two-fold
423 material, one aerial, one sanguineous, is required for the
424 composition of vital spirits, supposes the blood to ooze through the
425 septum of the heart from the right to the left ventricle by certain
426 hidden porosities, and the air to be attracted from the lungs
427 through the great vessel, the pulmonary vein; and which,
428 consequently, will have it, that there are numerous porosities in the
429 septum of the heart adapted for the transmission of the blood. But
430 by Hercules! no such pores can be demonstrated, nor in fact do
431 any such exist. For the septum of the heart is of a denser and more
432 compact structure than any portion of the body, except the bones
433 and sinews. But even supposing that there were foramina or pores
434 in this situation, how could one of the ventricles extract anything
435 from the other—the left, e.g., obtain blood from the right, when we
436 see that both ventricles contract and dilate simultaneously? Why
437 should we not rather believe that the right took spirits from the left,
438 than that the left obtained blood from the right ventricle through
439 these foramina? But it is certainly mysterious and incongruous that
440 blood should be supposed to be most commodiously drawn
441 through a set of obscure or invisible ducts, and air through

442 perfectly open passages, at one and the same moment. And why, I
443 ask, is recourse had to secret and invisible porosities, to uncertain
444 and obscure channels, to explain the passage of the blood into the
445 left ventricle, when there is so open a way through the pulmonary
446 veins? I own it has always appeared extraordinary to me that they
447 should have chosen to make, or rather to imagine, a way through
448 the thick, hard, dense, and most compact septum of the heart,
449 rather than take that by the open pulmonary vein, or even through
450 the lax, soft and spongy substance of the lungs at large. Besides, if
451 the blood could permeate the substance of the septum, or could be
452 imbibed from the ventricles, what use were there for the coronary
453 artery and vein, branches of which proceed to the septum itself, to
454 supply it with nourishment? And what is especially worthy of
455 notice is this: if in the fœtus, where everything is more lax and
456 soft, nature saw herself reduced to the necessity of bringing the
457 blood from the right to the left side of the heart by the foramen
458 ovale, from the vena cava through the pulmonary vein, how should
459 it be likely that in the adult she should pass it so commodiously,
460 and without an effort through the septum of the ventricles which
461 has now become denser by age?

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

481 Since, therefore, from the foregoing considerations and many
482 others to the same effect, it is plain that what has heretofore been
483 said concerning the motion and function of the heart and arteries

484 must appear obscure, inconsistent, or even impossible to him who
485 carefully considers the entire subject, it would be proper to look
486 more narrowly into the matter to contemplate the motion of the
487 heart and arteries, not only in man, but in all animals that have
488 hearts; and also, by frequent appeals to vivisection, and much
489 ocular inspection, to investigate and discern the truth.
490

491 **Chapter I: The Author's Motives For Writing**

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

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

519 These views as usual, pleased some more, others less; some
520 chid and calumniated me, and laid it to me as a crime that I had
521 dared to depart from the precepts and opinions of all anatomists;
522 others desired further explanations of the novelties, which they

523 said were both worthy of consideration, and might perchance be
524 found of signal use. At length, yielding to the requests of my
525 friends, that all might be made participators in my labors, and
526 partly moved by the envy of others, who, receiving my views with
527 uncandid minds and understanding them indifferently, have
528 essayed to traduce me publicly, I have moved to commit these
529 things to the press, in order that all may be enabled to form an
530 opinion both of me and my labors. This step I take all the more
531 willingly, seeing that Hieronymus Fabricius of Aquapendente,
532 although he has accurately and learnedly delineated almost every
533 one of the several parts of animals in a special work, has left the
534 heart alone untouched. Finally, if any use or benefit to this
535 department of the republic of letters should accrue from my
536 labors, it will, perhaps, be allowed that I have not lived idly, and
537 as the old man in the comedy says:

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

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

550 **Chapter II: On the Motions of the Heart, as Seen in the** 551 **Dissection of Living Animals**

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

557 These things are more obvious in the colder animals, such as
558 toads, frogs, serpents, small fishes, crabs, shrimps, snails, and

559 shellfish. They also become more distinct in warm-blooded
560 animals, such as the dog and hog, if they be attentively noted when
561 the heart begins to flag, to move more slowly, and, as it were, to
562 die: the movements then become slower and rarer, the pauses
563 longer, by which it is made much more easy to perceive and
564 unravel what the motions really are, and how they are performed.
565 In the pause, as in death, the heart is soft, flaccid, exhausted, lying,
566 as it were, at rest.

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

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

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

579 3. The heart being grasped in the hand, is felt to become
580 harder during its action. Now this hardness proceeds from tension,
581 precisely as when the forearm is grasped, its tendons are perceived
582 to become tense and resilient when the fingers are moved.

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

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

595 We are therefore authorized to conclude that the heart, at the
596 moment of its action, is at once constricted on all sides, rendered
597 thicker in its parietes and smaller in its ventricles, and so made apt
598 to project or expel its charge of blood. This, indeed, is made
599 sufficiently manifest by the preceding fourth observation in which
600 we have seen that the heart, by squeezing out the blood that it

601 contains, becomes paler, and then when it sinks into repose and the
602 ventricle is filled anew with blood, that the deeper crimson colour
603 returns. But no one need remain in doubt of the fact, for if the
604 ventricle be pierced the blood will be seen to be forcibly projected
605 outwards upon each motion or pulsation when the heart is tense.

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

611 Hence the very opposite of the opinions commonly received
612 appears to be true; inasmuch as it is generally believed that when
613 the heart strikes the breast and the pulse is felt without, the heart is
614 dilated in its ventricles and is filled with blood; but the contrary of
615 this is the fact, and the heart, when it contracts (and the impulse of
616 the apex is conveyed through the chest wall), is emptied. Whence
617 the motion which is generally regarded as the diastole of the heart,
618 is in truth its systole. And in like manner the intrinsic motion of the
619 heart is not the diastole but the systole; neither is it in the diastole
620 that the heart grows firm and tense, but in the systole, for then
621 only, when tense, is it moved and made vigorous.

622 Neither is it by any means to be allowed that the heart only
623 moves in the lines of its straight fibres, although the great Vesalius
624 giving this notion countenance, quotes a bundle of osiers bound in
625 a pyramidal heap in illustration; meaning, that as the apex is
626 approached to the base, so are the sides made to bulge out in the
627 fashion of arches, the cavities to dilate, the ventricles to acquire the
628 form of a cupping-glass and so to suck in the blood. But the true
629 effect of every one of its fibres is to constrict the heart at the
630 same time they render it tense; and this rather with the effect of
631 thickening and amplifying the walls and substance of the organ
632 than enlarging its ventricles. And, again, as the fibres run from the
633 apex to the base, and draw the apex towards the base, they do not
634 tend to make the walls of the heart bulge out in circles, but rather
635 the contrary; inasmuch as every fibre that is circularly disposed,
636 tends to become straight when it contracts; and is distended
637 laterally and thickened, as in the case of muscular fibres in general,
638 when they contract, that is, when they are shortened longitudinally,
639 as we see them in the bellies of the muscles of the body at large.
640 To all this let it be added, that not only are the ventricles
641 contracted in virtue of the direction and condensation of their
642 walls, but farther, that those fibres, or bands, styled nerves by

643 Aristotle, which are so conspicuous in the ventricles of the larger
644 animals, and contain all the straight fibres (the parietes of the heart
645 containing only circular ones), when they contract simultaneously
646 by an admirable adjustment all the internal surfaces are drawn
647 together as if with cords, and so is the charge of blood expelled
648 with force.

649 Neither is it true, as vulgarly believed, that the heart by any
650 dilatation or motion of its own, has the power of drawing the blood
651 into the ventricles; for when it acts and becomes tense, the blood is
652 expelled; when it relaxes and sinks together it receives the blood in
653 the manner and wise which will by-and-by be explained.

654 **Chapter III. Of the Motions of the Arteries, as seen in the** 655 **Dissection of Living Animals**

656 In connexion with the motions of the heart these things are
657 further to be observed having reference to the motions and pulses
658 of the arteries.

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

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

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

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

679 In the same way, when we see the blood in arteriotomy

680 projected now to a greater, now to a less distance, and that the
681 greater jet corresponds to the diastole of the artery and to the time
682 when the heart contracts and strikes the ribs, and is in its state of
683 systole, we understand that the blood is expelled by the same
684 movement.

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

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696 **Chapter IV. Of the Motion of the Heart and Its Auricles, as** 697 **Seen in the Bodies of Living Animals**

698 **Chapter V. Of the Motion, Action and Office of the Heart**

699 From these and other observations of a similar nature, I am
700 persuaded it will be found that the motion of the heart is as
701 follows:
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703 First of all, the auricle contracts, and in the course of its
704 contraction forces the blood (which it contains in ample quantity
705 as the head of the veins, the store-house and cistern of the blood)
706 into the ventricle, which, being filled, the heart raises itself
707 straightway, makes all its fibres tense, contracts the ventricles, and
708 performs a beat, by which beat it immediately sends the blood
709 supplied to it by the auricle into the arteries. The right ventricle
710 sends its charge into the lungs by the vessel which is called vena
711 arteriosa, but which in structure and function, and all other
712 respects, is an artery. The left ventricle sends its charge into the
713 aorta, and through this by the arteries to the body at large.

714 These two motions, one of the ventricles, the other of the
715 auricles, take place consecutively, but in such a manner that there

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

739 Even so does it come to pass with the motions and action of
740 the heart, which constitute a kind of deglutition, a transfusion of
741 the blood from the veins to the arteries. And if anyone, bearing
742 these things in mind, will carefully watch the motions of the heart
743 in the body of a living animal, he will perceive not only all the
744 particulars I have mentioned, viz., the heart becoming erect, and
745 making one continuous motion with its auricles; but farther, a
746 certain obscure undulation and lateral inclination in the direction
747 of the axis of the right ventricle, as if twisting itself slightly in
748 performing its work. And indeed everyone may see, when a horse
749 drinks, that the water is drawn in and transmitted to the stomach at
750 each movement of the throat, which movement produces a sound
751 and yields a pulse both to the ear and the touch; in the same way it
752 is with each motion of the heart, when there is the delivery of a
753 quantity of blood from the veins to the arteries a pulse takes place,
754 and can be heard within the chest.

755 The motion of the heart, then, is entirely of this description,
756 and the one action of the heart is the transmission of the blood and
757 its distribution, by means of the arteries, to the very extremities of

758 the body; so that the pulse which we feel in the arteries is nothing
759 more than the impulse of the blood derived from the heart.

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

767 The above, indeed, is admitted by all, both from the structure
768 of the heart and the arrangement and action of its valves. But still
769 they are like persons purblind or groping about in the dark, for
770 they give utterance to various, contradictory, and incoherent
771 sentiments, delivering many things upon conjecture, as we have
772 already shown. The grand cause of doubt and error in this subject
773 appears to me to have been the intimate connexion between the
774 heart and the lungs. When men saw both the pulmonary artery and
775 the pulmonary veins losing themselves in the lungs, of course it
776 became a puzzle to them to know how or by what means the right
777 ventricle should distribute the blood to the body, or the left draw it
778 from the venæ cavæ. This fact is borne witness to by Galen, whose
779 words, when writing against Erasistratus in regard to the origin and
780 use of the veins and the coction of the blood, are the following:
781 “You will reply,” he says, “that the effect is so; that the blood is
782 prepared in the liver, and is thence transferred to the heart to
783 receive its proper form and last perfection; a statement which does
784 not appear devoid of reason; for no great and perfect work is ever
785 accomplished at a single effort, or receives its final polish from
786 one instrument. But if this be actually so, then show us another
787 vessel which draws the absolutely perfect blood from the heart,
788 and distributes it as the arteries do the spirits over the whole
789 body.” Here then is a reasonable opinion not allowed, because,
790 forsooth, besides not seeing the true means of transit, he could not
791 discover the vessel which should transmit the blood from the heart
792 to the body at large!

793 But had anyone been there in behalf of Erasistratus, and of
794 that opinion which we now espouse, and which Galen himself
795 acknowledges in other respects consonant with reason, to have
796 pointed to the aorta as the vessel which distributes the blood from
797 the heart to the rest of the body, I wonder what would have been
798 the answer of that most ingenious and learned man? Had he said
799 that the artery transmits spirits and not blood, he would indeed

800 sufficiently have answered Erasistratus, who imagined that the
801 arteries contained nothing but spirits; but then he would have
802 contradicted himself, and given a foul denial to that for which he
803 had keenly contended in his writings against this very Erasistratus,
804 to wit, that blood in substance is contained in the arteries, and not
805 spirits; a fact which he demonstrated not only by many powerful
806 arguments, but by experiments.

807 But if the divine Galen will here allow, as in other places he
808 does, “that all the arteries of the body arise from the great artery,
809 and that this takes its origin from the heart; that all these vessels
810 naturally contain and carry blood; that the three semilunar valves
811 situated at the orifice of the aorta prevent the return of the blood
812 into the heart, and that nature never connected them with this, the
813 most noble viscus of the body, unless for some important end”; if,
814 I say, this father of physicians concedes all these things,—and I
815 quote his own words,—I do not see how he can deny that the great
816 artery is the very vessel to carry the blood, when it has attained its
817 highest term of perfection, from the heart for distribution to all
818 parts of the body. Or would he perchance still hesitate, like all who
819 have come after him, even to the present hour, because he did not
820 perceive the route by which the blood was transferred from the
821 veins to the arteries, in consequence, as I have already said, of the
822 intimate connexion between the heart and the lungs? And that this
823 difficulty puzzled anatomists not a little, when in their dissections
824 they found the pulmonary artery and left ventricle full of thick,
825 black, and clotted blood, plainly appears, when they felt
826 themselves compelled to affirm that the blood made its way from
827 the right to the left ventricle by transuding through the septum of
828 the heart. But this fancy I have already refuted. A new pathway for
829 the blood must therefore be prepared and thrown open, and being
830 once exposed, no further difficulty will, I believe, be experienced
831 by anyone in admitting what I have already proposed in regard to
832 the pulse of the heart and arteries, viz., the passage of the blood
833 from the veins to the arteries, and its distribution to the whole of
834 the body by means of these vessels.

835 **Chapter VI. Of the Course by Which the Blood Is Carried**
836 **from the Vena Cava into the Arteries, or from the Right**
837 **into the Left Ventricle of the Heart**

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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

880 the veins into the arteries.

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882 **Chapter VII. The Blood Passes Through the Substance of the**
883 **Lungs from the Right Ventricle of the Heart into the**
884 **Pulmonary Veins and Left Ventricle**

885 **Chapter VIII. Of the Quantity of Blood Passing Through the**
886 **Heart from the Veins to the Arteries; And of the Circular**
887 **Motion of the Blood**

888 Thus far I have spoken of the passage of the blood from the
889 veins into the arteries, and of the manner in which it is transmitted
890 and distributed by the action of the heart; points to which some,
891 moved either by the authority of Galen or Columbus, or the
892 reasonings of others, will give in their adhesion. But what remains
893 to be said upon the quantity and source of the blood which thus
894 passes is of a character so novel and unheard-of that I not only fear
895 injury to myself from the envy of a few, but I tremble lest I have
896 mankind at large for my enemies, so much doth wont and custom
897 become a second nature. Doctrine once sown strikes deep its root,
898 and respect for antiquity influences all men. Still the die is cast,
899 and my trust is in my love of truth and the candour of cultivated
900 minds. And sooth to say, when I surveyed my mass of evidence,
901 whether derived from vivisections, and my various reflections on
902 them, or from the study of the ventricles of the heart and the
903 vessels that enter into and issue from them, the symmetry and size
904 of these conduits,-for nature doing nothing in vain, would never
905 have given them so large a relative size without a purpose,-or from
906 observing the arrangement and intimate structure of the valves in
907 particular, and of the other parts of the heart in general, with many
908 things besides, I frequently and seriously bethought me, and long
909 revolved in my mind, what might be the quantity of blood which
910 was transmitted, in how short a time its passage might be effected,
911 and the like. But not finding it possible that this could be supplied
912 by the juices of the ingested aliment without the veins on the one
913 hand becoming drained, and the arteries on the other getting
914 ruptured through the excessive charge of blood, unless the blood

915 should somehow find its way from the arteries into the veins, and
916 so return to the right side of the heart, I began to think whether
917 there might not be a MOTION, AS IT WERE, IN A CIRCLE. Now, this I
918 afterwards found to be true; and I finally saw that the blood, forced
919 by the action of the left ventricle into the arteries, was distributed
920 to the body at large, and its several parts, in the same manner as it
921 is sent through the lungs, impelled by the right ventricle into the
922 pulmonary artery, and that it then passed through the veins and
923 along the vena cava, and so round to the left ventricle in the
924 manner already indicated. This motion we may be allowed to call
925 circular, in the same way as Aristotle says that the air and the rain
926 emulate the circular motion of the superior bodies; for the moist
927 earth, warmed by the sun, evaporates; the vapours drawn upwards
928 are condensed, and descending in the form of rain, moisten the
929 earth again. By this arrangement are generations of living things
930 produced; and in like manner are tempests and meteors engendered
931 by the circular motion, and by the approach and recession of the
932 sun.

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

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

955 As the blood-vessels, therefore, are the canals and agents that
956 transport the blood, they are of two kinds, the cava and the aorta;

957 and this not by reason of there being two sides of the body, as
958 Aristotle has it, but because of the difference of office, not, as is
959 commonly said, in consequence of any diversity of structure, for in
960 many animals, as I have said, the vein does not differ from the
961 artery in the thickness of its walls, but solely in virtue of their
962 distinct functions and uses. A vein and an artery, both styled veins
963 by the ancients, and that not without reason, as Galen has
964 remarked, for the artery is the vessel which carries the blood from
965 the heart to the body at large, the vein of the present day bringing
966 it back from the general system to the heart; the former is the
967 conduit from, the latter the channel to, the heart; the latter contains
968 the cruder, effete blood, rendered unfit for nutrition; the former
969 transmits the digested, perfect, peculiarly nutritive fluid.

970 **Chapter IX. That There Is a Circulation of the Blood Is**
971 **Confirmed from the First Proposition**

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

991 Let us assume, either arbitrarily or from experiment, the
992 quantity of blood which the left ventricle of the heart will contain
993 when distended, to be, say, two ounces, three ounces, or one ounce

994 and a half—in the dead body I have found it to hold upwards of
995 two ounces. Let us assume further how much less the heart will
996 hold in the contracted than in the dilated state; and how much
997 blood it will project into the aorta upon each contraction; and all
998 the world allows that with the systole something is always
999 projected, a necessary consequence demonstrated in the third
1000 chapter, and obvious from the structure of the valves; and let us
1001 suppose as approaching the truth that the fourth, or fifth, or sixth,
1002 or even but the eighth part of its charge is thrown into the artery at
1003 each contraction; this would give either half an ounce, or three
1004 drachms, or one drachm of blood as propelled by the heart at each
1005 pulse into the aorta; which quantity, by reason of the valves at the
1006 root of the vessel, can by no means return into the ventricle. Now,
1007 in the course of half an hour, the heart will have made more than
1008 one thousand beats, in some as many as two, three, and even four
1009 thousand. Multiplying the number of drachms propelled by the
1010 number of pulses, we shall have either one thousand half ounces,
1011 or one thousand times three drachms, or a like proportional
1012 quantity of blood, according to the amount which we assume as
1013 propelled with each stroke of the heart, sent from this organ into
1014 the artery—a larger quantity in every case than is contained in the
1015 whole body! In the same way, in the sheep or dog, say but a single
1016 scruple of blood passes with each stroke of the heart, in one
1017 half-hour we should have one thousand scruples, or about three
1018 pounds and a half, of blood injected into the aorta; but the body of
1019 neither animal contains above four pounds of blood, a fact which I
1020 have myself ascertained in the case of the sheep.

1021 Upon this supposition, therefore, assumed merely as a ground
1022 for reasoning, we see the whole mass of blood passing through the
1023 heart, from the veins to the arteries, and in like manner through the
1024 lungs.

1025 But let it be said that this does not take place in half an hour,
1026 but in an hour, or even in a day; any way, it is still manifest that
1027 more blood passes through the heart in consequence of its action,
1028 than can either be supplied by the whole of the ingesta, or than can
1029 be contained in the veins at the same moment.

1030 Nor can it be allowed that the heart in contracting sometimes
1031 propels and sometimes does not propel, or at most propels but very
1032 little, a mere nothing, or an imaginary something: all this, indeed,
1033 has already been refuted, and is, besides, contrary both to sense
1034 and reason. For if it be a necessary effect of the dilatation of the
1035 heart that its ventricles become filled with blood, it is equally so

1036 that, contracting, these cavities should expel their contents; and
1037 this not in any trifling measure. For neither are the conduits small,
1038 nor the contractions few in number, but frequent, and always in
1039 some certain proportion, whether it be a third or a sixth, or an
1040 eighth, to the total capacity of the ventricles, so that a like
1041 proportion of blood must be expelled, and a like proportion
1042 received with each stroke of the heart, the capacity of the ventricle
1043 contracted always bearing a certain relation to the capacity of the
1044 ventricle when dilated. And since, in dilating, the ventricles cannot
1045 be supposed to get filled with nothing, or with an imaginary
1046 something, so in contracting they never expel nothing or aught
1047 imaginary, but always a certain something, viz., blood, in
1048 proportion to the amount of the contraction. Whence it is to be
1049 concluded that if at one stroke the heart of man, the ox, or the
1050 sheep, ejects but a single drachm of blood and there are one
1051 thousand strokes in half an hour, in this interval there will have
1052 been ten pounds five ounces expelled; if with each stroke two
1053 drachms are expelled, the quantity would, of course, amount to
1054 twenty pounds and ten ounces; if half an ounce, the quantity would
1055 come to forty-one pounds and eight ounces; and were there one
1056 ounce, it would be as much as eighty-three pounds and four
1057 ounces; the whole of which, in the course of one-half hour, would
1058 have been transfused from the veins to the arteries. The actual
1059 quantity of blood expelled at each stroke of the heart, and the
1060 circumstances under which it is either greater or less than ordinary,
1061 I leave for particular determination afterwards, from numerous
1062 observations which I have made on the subject.

1063 Meantime this much I know, and would here proclaim to all,
1064 that the blood is transfused at one time in larger, at another in
1065 smaller, quantity; and that the circuit of the blood is accomplished
1066 now more rapidly, now more slowly, according to the
1067 temperament, age, etc., of the individual, to external and internal
1068 circumstances, to naturals and non-naturals—sleep, rest, food,
1069 exercise, affections of the mind, and the like. But, supposing even
1070 the smallest quantity of blood to be passed through the heart and
1071 the lungs with each pulsation, a vastly greater amount would still
1072 be thrown into the arteries and whole body than could by any
1073 possibility be supplied by the food consumed. It could be
1074 furnished in no other way than by making a circuit and returning.

1075 This truth, indeed, presents itself obviously before us when we
1076 consider what happens in the dissection of living animals; the great
1077 artery need not be divided, but a very small branch only (as Galen

1078 even proves in regard to man), to have the whole of the blood in
1079 the body, as well that of the veins as of the arteries, drained away
1080 in the course of no long time—some half-hour or less. Butchers
1081 are well aware of the fact and can bear witness to it; for, cutting
1082 the throat of an ox and so dividing the vessels of the neck, in less
1083 than a quarter of an hour they have all the vessels bloodless—the
1084 whole mass of blood has escaped. The same thing also
1085 occasionally occurs with great rapidity in performing amputations
1086 and removing tumors in the human subject.

1087 Nor would this argument lose of its force, did any one say that
1088 in killing animals in the shambles, and performing amputations,
1089 the blood escaped in equal, if not perchance in larger quantity by
1090 the veins than by the arteries. The contrary of this statement,
1091 indeed, is certainly the truth; the veins, in fact, collapsing, and
1092 being without any propelling power, and further, because of the
1093 impediment of the valves, as I shall show immediately, pour out
1094 but very little blood; whilst the arteries spout it forth with force
1095 abundantly, impetuously, and as if it were propelled by a syringe.
1096 And then the experiment is easily tried of leaving the vein
1097 untouched and only dividing the artery in the neck of a sheep or
1098 dog, when it will be seen with what force, in what abundance, and
1099 how quickly, the whole blood in the body, of the veins as well as
1100 of the arteries, is emptied. But the arteries receive blood from the
1101 veins in no other way than by transmission through the heart, as
1102 we have already seen; so that if the aorta be tied at the base of the
1103 heart, and the carotid or any other artery be opened, no one will
1104 now be surprised to find it empty, and the veins only replete with
1105 blood.

1106 And now the cause is manifest, why in our dissections we
1107 usually find so large a quantity of blood in the veins, so little in the
1108 arteries; why there is much in the right ventricle, little in the left,
1109 which probably led the ancients to believe that the arteries (as their
1110 name implies) contained nothing but spirits during the life of an
1111 animal. The true cause of the difference is perhaps this, that as
1112 there is no passage to the arteries, save through the lungs and
1113 heart, when an animal has ceased to breathe and the lungs to move,
1114 the blood in the pulmonary artery is prevented from passing into
1115 the pulmonary veins, and from thence into the left ventricle of the
1116 heart; just as we have already seen the same transit prevented in
1117 the embryo, by the want of movement in the lungs and the
1118 alternate opening and shutting of their hidden and invisible
1119 porosities and apertures. But the heart not ceasing to act at the

1120 same precise moment as the lungs, but surviving them and
1121 continuing to pulsate for a time, the left ventricle and arteries go
1122 on distributing their blood to the body at large and sending it into
1123 the veins; receiving none from the lungs, however, they are soon
1124 exhausted, and left, as it were, empty. But even this fact confirms
1125 our views, in no trifling manner, seeing that it can be ascribed to
1126 no other than the cause we have just assumed.

1127 Moreover, it appears from this that the more frequently or
1128 forcibly the arteries pulsate, the more speedily will the body be
1129 exhausted of its blood during hemorrhage. Hence, also, it happens,
1130 that in fainting fits and in states of alarm, when the heart beats
1131 more languidly and less forcibly, hemorrhages are diminished and
1132 arrested.

1133 Still further, it is from this, that after death, when the heart has
1134 ceased to beat, it is impossible, by dividing either the jugular or
1135 femoral veins and arteries, by any effort, to force out more than
1136 one-half of the whole mass of the blood. Neither could the butcher
1137 ever bleed the carcass effectually did he neglect to cut the throat of
1138 the ox which he has knocked on the head and stunned, before the
1139 heart had ceased beating.

1140 Finally, we are now in a condition to suspect wherefore it is
1141 that no one has yet said anything to the purpose upon the
1142 anastomosis of the veins and arteries, either as to where or how it
1143 is effected, or for what purpose. I now enter upon the investigation
1144 of the subject.

1145 **Chapter X. The First Position: Of the Quantity of Blood**
1146 **Passing from the Veins to the Arteries. And That There Is**
1147 **a Circuit of the Blood, Freed from Objections, and Farther**
1148 **Confirmed by Experiment**

1149 **Chapter XI. The Second Position Is Demonstrated**

1150 **Chapter XII. That There Is a Circulation of the Blood Is**
1151 **Shown from the Second Position Demonstrated**

1152 **Chapter XIII. The Third Position Is Confirmed: And the**
1153 **Circulation of the Blood is Demonstrated from It**

1154 Thus far we have spoken of the quantity of blood passing
1155 through the heart and the lungs in the centre of the body, and in
1156 like manner from the arteries into the veins in the peripheral parts
1157 and the body at large. We have yet to explain, however, in what
1158 manner the blood finds its way back to the heart from the
1159 extremities by the veins, and how and in what way these are the
1160 only vessels that convey the blood from the external to the central
1161 parts; which done, I conceive that the three fundamental
1162 propositions laid down for the circulation of the blood will be so
1163 plain, so well established, so obviously true, that they may claim
1164 general credence. Now the remaining position will be made
1165 sufficiently clear from the valves which are found in the cavities of
1166 the veins themselves, from the uses of these, and from experiments
1167 cognizable by the senses.

1168 The celebrated Hieronymus Fabricius of Aquapendente, a
1169 most skilful anatomist, and venerable old man, or, as the learned
1170 Riolan will have it, Jacobus Silvius, first gave representations of
1171 the valves in the veins, which consist of raised or loose portions of
1172 the inner membranes of these vessels, of extreme delicacy, and a
1173 sigmoid or semilunar shape. They are situated at different
1174 distances from one another, and diversely in different individuals;
1175 they are connate at the sides of the veins; they are directed
1176 upwards towards the trunks of the veins; the two—for there are for
1177 the most part two together—regard each other, mutually touch, and
1178 are so ready to come into contact by their edges, that if anything
1179 attempts to pass from the trunks into the branches of the veins, or
1180 from the greater vessels into the less, they completely prevent it;
1181 they are farther so arranged, that the horns of those that succeed
1182 are opposite the middle of the convexity of those that precede, and
1183 so on alternately.

1184 The discoverer of these valves did not rightly understand their
1185 use, nor have succeeding anatomists added anything to our
1186 knowledge: for their office is by no means explained when we are
1187 told that it is to hinder the blood, by its weight, from all flowing
1188 into inferior parts; for the edges of the valves in the jugular veins
1189 hang downwards, and are so contrived that they prevent the blood
1190 from rising upwards; the valves, in a word, do not invariably look
1191 upwards, but always toward the trunks of the veins, invariably
1192 towards the seat of the heart. I, and indeed others, have sometimes

1193 found valves in the emulgent veins, and in those of the mesentery,
1194 the edges of which were directed towards the vena cava and vena
1195 portæ. Let it be added that there are no valves in the arteries, and
1196 that dogs, oxen, etc., have invariably valves at the divisions of
1197 their crural veins, in the veins that meet towards the top of the os
1198 sacrum, and in those branches which come from the haunches, in
1199 which no such effect of gravity from the erect position was to be
1200 apprehended. Neither are there valves in the jugular veins for the
1201 purpose of guarding against apoplexy, as some have said; because
1202 in sleep the head is more apt to be influenced by the contents of
1203 the carotid arteries. Neither are the valves present, in order that the
1204 blood may be retained in the divarications or smaller trunks and
1205 minuter branches, and not be suffered to flow entirely into the
1206 more open and capacious channels; for they occur where there are
1207 no divarications; although it must be owned that they are most
1208 frequent at the points where branches join. Neither do they exist
1209 for the purpose of rendering the current of blood more slow from
1210 the centre of the body; for it seems likely that the blood would be
1211 disposed to flow with sufficient slowness of its own accord, as it
1212 would have to pass from larger into continually smaller vessels,
1213 being separated from the mass and fountain head, and attaining
1214 from warmer into colder places.

1215 But the valves are solely made and instituted lest the blood
1216 should pass from the greater into the lesser veins, and either
1217 rupture them or cause them to become varicose; lest, instead of
1218 advancing from the extreme to the central parts of the body, the
1219 blood should rather proceed along the veins from the centre to the
1220 extremities; but the delicate valves, while they readily open in the
1221 right direction, entirely prevent all such contrary motion, being so
1222 situated and arranged, that if anything escapes, or is less perfectly
1223 obstructed by the cornua of the one above, the fluid passing, as it
1224 were, by the chinks between the cornua, it is immediately received
1225 on the convexity of the one beneath, which is placed transversely
1226 with reference to the former, and so is effectually hindered from
1227 getting any farther.

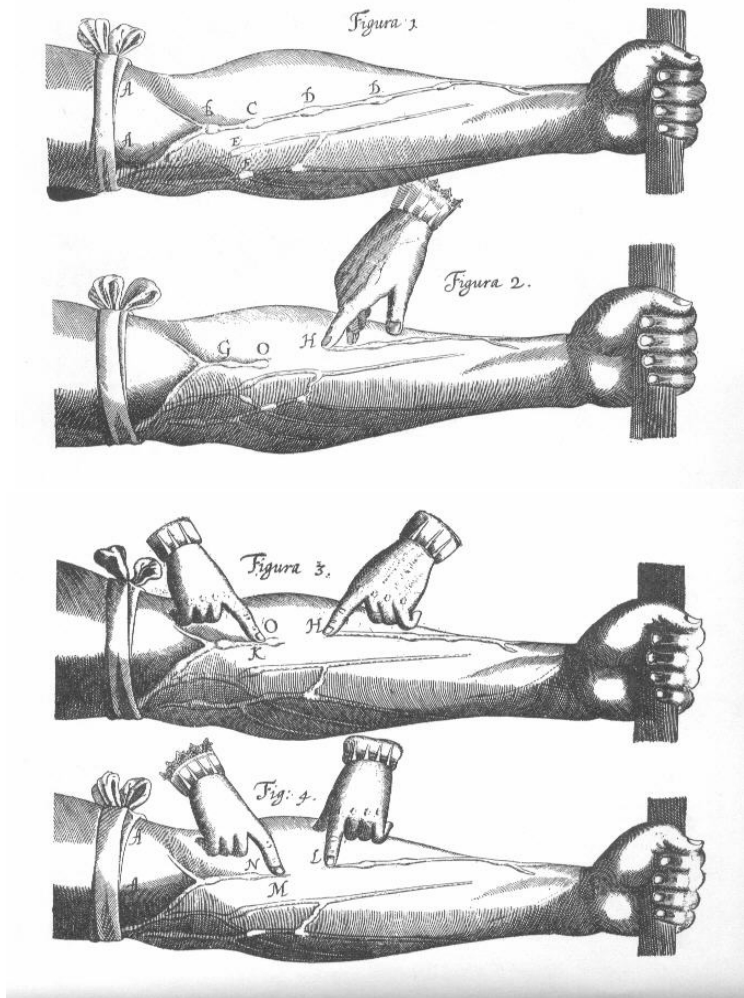
1228 And this I have frequently experienced in my dissections of
1229 the veins: if I attempted to pass a probe from the trunk of the veins
1230 into one of the smaller branches, whatever care I took I found it
1231 impossible to introduce it far any way, by reason of the valves;
1232 whilst, on the contrary, it was most easy to push it along in the
1233 opposite direction, from without inwards, or from the branches
1234 towards the trunks and roots. In many places two valves are so
1235 placed and fitted, that when raised they come exactly together in

1236 the middle of the vein, and are there united by the contact of their
1237 margins; and so accurate is the adaptation, that neither by the eye
1238 nor by any other means of examination, can the slightest chink
1239 along the line of contact be perceived. But if the probe be now
1240 introduced from the extreme towards the more central parts, the
1241 valves, like the floodgates of a river, give way, and are most
1242 readily pushed aside. The effect of this arrangement plainly is to
1243 prevent all motion of the blood from the heart and vena cava,
1244 whether it be upwards towards the head, or downwards towards
1245 the feet, or to either side towards the arms, not a drop can pass; all
1246 motion of the blood, beginning in the larger and tending towards
1247 the smaller veins, is opposed and resisted by them; whilst the
1248 motion that proceeds from the lesser to end in the larger branches
1249 is favoured, or, at all events, a free and open passage is left for it.

1250 But that this truth may be made the more apparent, let an arm
1251 be tied up above the elbow as if for phlebotomy (A, A, fig. 1). At
1252 intervals in the course of the veins, especially in labouring people
1253 and those whose veins are large, certain knots or elevations (B, C,
1254 D, E, F) will be perceived, and this not only at the places where a
1255 branch is received (E, F), but also where none enters (C, D): these
1256 knots or risings are all formed by valves, which thus show
1257 themselves externally. And now if you press the blood from the
1258 space above one of the valves, from H to O, (fig. 2,) and keep the
1259 point of a finger upon the vein inferiorly, you will see no influx of
1260 blood from above; the portion of the vein between the point of the
1261 finger and the valve O will be obliterated; yet will the vessel
1262 continue sufficiently distended above the valve (O, G). The blood
1263 being thus pressed out and the vein emptied, if you now apply a
1264 finger of the other hand upon the distended part of the vein above
1265 the valve O, (fig. 3,) and press downwards, you will find that you
1266 cannot force the blood through or beyond the valve; but the greater
1267 effort you use, you will only see the portion of vein that is between
1268 the finger and the valve become more distended, that portion of the
1269 vein which is below the valve remaining all the while empty (H, O,
1270 fig. 3).

1271 It would therefore appear that the function of the valves in the
1272 veins is the same as that of the three sigmoid valves which we find
1273 at the commencement of the aorta and pulmonary artery, viz., to
1274 prevent all reflux of the blood that is passing over them.

1275 Farther, the arm being bound as before, and the veins looking
1276 full and distended, if you press at one part in the course of a vein
1277 with the point of a finger (L, fig. 4), and then with another finger
1278 streak the blood upwards beyond the next valve (N), you will



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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 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.

1319 **Chapter XIV. Conclusion of the Demonstration of the**
1320 **Circulation**

1321 **Chapter XV. The Circulation of the Blood Is Further**
1322 **Confirmed by Probable Reasons**

1323 **Chapter XVI. The Circulation of the Blood Is Further Proved**
1324 **from Certain Consequences**

1325 **Chapter XVII. The Motion and Circulation of the Blood Are**
1326 **Confirmed from the Particulars Apparent in the Structure**
1327 **of the Heart, and from Those Things Which Dissection**
1328 **Unfolds**