are no muscular fibres in the middle coat. In the larger veins, such as the abdominal vena cava, the iliac, crural, popliteal, mesenteric and axillary veins, there are both longitudinal and circular fibres. In the smaller veins, the fibres are circular. In the smallest veins, the middle coat is composed of fine fibres of connective tissue with a very few muscular fibres.

The external coat of the veins is composed of ordinary fibrous tissue, like that of the corresponding coat of the arteries. In the largest veins, particularly those of the abdominal cavity, this coat contains a layer of longitudinal, non-striated muscular fibres. In the veins near the heart, are found a few striated fibres, which are continued on to the veins from the auricles. In some of the inferior animals, as the turtle, these fibres are quite thick, and pulsation of the veins in the immediate vicinity of the heart is very marked. In nearly all veins, the external coat is several times thicker than the internal coat. This is most marked in the larger veins, in which the middle coat, particularly the layer of muscular fibres, is very slightly developed.

The venous sinuses and the veins which pass through bony tissue have only the internal coat, to which are superadded a few longitudinal fibres, the whole being closely attached to the surrounding parts. As examples, may be mentioned the sinuses of the dura mater and the veins of the large bones of the skull. In the first instance, there is little more than the internal coat of the vein firmly attached to the surrounding layers of the dura mater. In the second instance, the same thin membrane is adherent to canals formed by a layer of compact bony tissue. The veins are much more closely adherent to the surrounding tissues than the arteries, particularly when they pass between layers of aponeurosis.

The peculiarities in the anatomy of the veins indicate considerable differences in their properties as compared with the arteries. When a vein is cut across, its walls fall together, if not supported by adhesions to surrounding tissues, so that its caliber is nearly or quite obliterated. The elastic tissue, which gives to the larger arteries their great thickness, is very scanty in the veins, and the thin walls collapse when not sustained by liquid in the interior of the vessels.

Although with much thinner and apparently weaker walls, the veins, as a rule, will resist a greater pressure than the arteries. Wintringham (1740) showed that the inferior vena cava of a sheep, just above the opening of the renal veins, was ruptured by a pressure of one hundred and seventy-six pounds (79·8 kilos.), while the aorta, at a corresponding point, yielded to a pressure of one hundred and fifty-eight pounds (71·7 kilos). The strength of the portal vein was even greater, supporting a pressure of nearly five atmospheres, bearing a relation to the vena cava of six to five; yet these vessels had hardly one-fifth the thickness of the arteries. In the lower extremities in the human subject, the veins are much thicker and stronger than in other situations, a provision against the increased pressure to which they are habitually subjected in the upright posture. Wintringham noticed a singular exception to the general rule just given. In the vessels of the glands and of the spleen, the strength of the arteries was much greater than that of the

veins. The splenic vein gave way under a pressure of little more than one atmosphere, while the artery supported a pressure of more than six atmospheres.

The different influences to which the venous and arterial circulations are subject serve to indicate the physiological importance of the great difference in the strength of the two varieties of vessels. It is true that in the arteries the constant pressure is greater than in the veins; but it is nearly the same throughout the arterial system, and the great extent of the outlet at the periphery provides against any very great increase in pressure, so long as the blood is in a condition which enables it to pass into the capillaries. The muscular fibres of the left ventricle have but a limited power, and when the pressure in the arteries is sufficient, as it sometimes is in asphyxia, to close the aortic valves so firmly that the force of the ventricle will not open them, it can not be increased. At the same time, the pressure is being gradually relieved by the capillaries, through which the blood slowly filters even when completely unaërated. With the veins it is different. The blood has a comparatively restricted outlet at the heart and is received by the capillaries from all parts of the system. The vessels are provided with valves, which render a general backward action impossible. Thus, restricted portions of the venous system, from pressure in the vessels, increase of fluid from absorption, accumulation by force of gravity and other causes, may be subjected to great and sudden variations in pressure. The great strength of these vessels enables them ordinarily to suffer these variations without injury; although varicose veins in various parts present examples of the effects of repeated and continued distention.

The veins possess a considerable degree of elasticity, although this property is not so marked as it is in the arteries. If a portion of a vein distended with blood be included between two ligatures and a small opening be made in the vessel, the blood will be ejected with some force, and the vessel becomes much reduced in caliber.

It has been shown by direct experiment that the veins are endowed with the peculiar contractility characteristic of the action of the non-striated muscular fibres. On the application of electric or mechanical stimulation, they contract slowly and gradually, the contraction being followed by a correspondingly gradual relaxation. There is never any rhythmical or peristaltic movement in the veins, sufficient to assist the circulation. The only regular movements which occur are seen in the vessels in immediate proximity to the right auricle, which are provided with a few fibres similar to those which exist in the walls of the heart.

Nerves from the vaso-motor system have been demonstrated in the walls of the larger veins but have not been followed out to the smaller ramifications of the vessels.

Valves of the Veins.—In all parts of the venous system, except, in general terms, in the abdominal, thoracic and cerebral cavities, there exist little membranous, semilunar folds, resembling the aortic and pulmonic valves of the heart. When the valves are closed, their convexities look toward the periphery. In the great majority of instances, the valves exist in pairs, but they are occasionally, although very rarely in the human subject, found in groups of three. They are seldom if ever found in veins of a less diameter than one line (2·1 mm.). The valves are formed in part of the lining membrane of the veins, with fine fibres of connective tissue, elastic fibres and non-striated muscular fibres. There exists, also, a fibrous ring following the line of attachment of the valvular curtains to the vein, which renders the vessel much stronger and less dilatable here than in the intervals between the valves. The valves are most abundant in the veins of the lower extremities. They are generally situated just below the point where a small vein empties into one of larger size, so that the blood as it enters finds an immediate obstacle to passage in the wrong direction. The situation of the valves may be readily observed in any of the superficial veins. If the flow of blood be obstructed, little knots will be formed in the congested vessels, which indicate the position and action of the valves. When the vein is thus congested and knotted, if the finger be pressed along the vessel in the direction of the blood-current, a portion situated between two valves may be emptied of blood; but it is impossible to empty any portion of the vessel by pressing the blood in the opposite direction (Harvey). On slitting open a vein, it is easy to observe the shape, attachment and extreme delicacy of structure of the valves. When the vessel is empty or when fluid moves toward the heart, the valves are closely applied to the walls; but if liquid or air be forced in the opposite direction, they project into its caliber, and by the application of their free edges to each other, effectually prevent any backward current. When closed the application of their free edges form a line which runs across the vessel. It is found that in successive sets of valves, these lines are at right angles to each other, so that if, in one set, this line have a direction from before backward, in the sets above and below, the lines run from side to side (Fabricius).

There are certain exceptions to the general proposition that the veins of the great cavities are not provided with valves. Valves are found in the portal system of some of the inferior animals, as the horse. They do not exist, however, in this situation in the human subject. Generally, in following out the branches of the inferior vena cava, no valves are found until the crural vein is reached; but occasionally there is a double valve at the origin of the external iliac. In some of the inferior animals, there exists constantly a single valvular fold in the vena cava at the openings of the hepatic, and one at the opening of the renal vein. This is not constant in the human subject. Valves are found in the spermatic, but not in the ovarian veins. A single valvular fold has been described at the opening of the right spermatic into the vena cava. There are two valves in the azygos vein near its opening into the superior vena cava. There is a single valve at the orifice of the coronary vein. There are no valves at the openings of the brachio-cephalic into the superior vena cava; but there is a strong, double valve at the point where the internal jugular opens into the brachio-cephalic. Between this point and the capillaries of the brain, the vessels have no valves, except in very rare instances, when one or two are found in the course of the jugular.

In addition to the double, or more rarely triple valves which have just been described, there is another variety, found in certain parts, at the point where a tributary vein opens into a main trunk. This consists of a single fold, which is attached to the smaller vessel but projects into the larger. Its action is to prevent regurgitation, by the same mechanism as that by which the ileo-cæcal valve prevents the passage of matters from the large into the small intestine.

The veins are adapted to the return of blood to the heart in a comparatively slow and unequal current. Distention of certain portions is provided for; and the vessels are so protected with valves, that whatever influences the current must favor its flow in the direction of the heart.

Course of the Blood in the Veins.—The experiments of Hales and Sharpey, showing that defibrinated blood can be made to pass from the arteries into the capillaries and out at the veins by a pressure less than that which exists in the arterial system, and the observations of Magendie upon the circulation in the leg of a living dog, showing that ligation of the artery arrests the flow in the vein, have established the fact that the force exerted by the left ventricle is sufficient to account for the venous circulation. The heart must be regarded as the prime cause of the movement of blood in the veins. Regarding this as definitely ascertained, there remain to consider, in the study of the course of the blood in the veins, the character of the current, the influence of the vessels themselves, the question of the existence of forces which may assist the *vis a tergo* from the heart, and conditions which may interfere with the flow of blood.

As a rule, in the normal circulation, the flow of blood in the veins is continuous and uniform. The intermittent impulse of the heart, which progressively diminishes toward the periphery but is still felt even in the smallest arteries, is lost in the capillaries. Here, for the first time, the blood moves in a constant current; and as the pressure in the arteries is continually supplying fresh blood, that which has circulated in the capillaries is forced into the venous radicles in a steady stream. As the supply to the capillaries of different parts is regulated by the action of the small arteries, and as this supply is subject to great variations, there must necessarily be corresponding variations in the current in the veins and in the quantity of blood which these vessels receive. Consequently, the venous circulation is subject to very great variations due to irregularity in the supply of blood, aside from any action of the vessels themselves or any external disturbing influences.

It often happens that a vein becomes obstructed from some cause which is entirely physiological, such as the action of muscles. The great number of veins, as compared with the arteries, and their free communications with each other, provide that the current, under these conditions, is simply diverted, passing to the heart by another channel. When any part of the venous system is distended, the vessels react on the blood and exert a certain influence on the current, always pressing it toward the heart, for the valves oppose a flow in the opposite direction.

The intermittent action of the heart, which pervades the whole arterial system, is generally absorbed, as it were, in the passage of the blood through the capillaries; but when the arterioles of any part are very much relaxed, the cardiac impulse may extend to the veins. When the glands are pouring out their secretions, the quantity of blood which they receive is very much increased. It is then furnished to supply material for the secretion, and not exclusively for nutrition. If the vein be opened at such a time, it is found that the blood has not lost its arterial character, that the quantity which escapes is increased, and that the flow is in an intermittent jet, as from a divided artery (Bernard). This is due to the relaxed condition of the arterioles of the part, and the phenomenon thus observed constitutes the true venous pulse. What thus occurs in a restricted portion of the circulatory system may take place in all the veins, though in a less marked degree. Physicians have frequently noticed, after the blood has been flowing for some time in the operation of venesection, that the color changes from black to red and the stream becomes intermittent, often leading the operator to fear that he has pricked the artery. In all probability this is due to the relaxation of the arterioles as one of the effects of abstraction of blood, producing the same condition that has been noted in some of the glands during their activity.

Pressure of Blood in the Veins.—The pressure in the veins is always much less than in the arteries. It is very variable in different parts of the venous system and in the same part at different times. As a rule, it is in an inverse ratio to the arterial pressure. Whatever favors the passage of blood from the arteries into the capillaries has a tendency to diminish the arterial pressure, and as it increases the quantity of blood which passes into the veins, it must increase the venous pressure. The great capacity of the venous system, its frequent anastomoses and the presence of valves which may shut off a portion from the rest, are conditions which involve considerable variations in pressure in different vessels. It has been ascertained that as a rule, the pressure is greatest at the periphery and progressively diminishes in the direction of the heart. In an observation on the calf, Volkmann found that with a pressure of about 6·5 inches (165·1 mm.) of mercury in the carotid, the pressure in the metatarsal vein was 1·1 inch (28 mm.), and but 0·36 (9·1 mm.) in the jugular. Analogous results were obtained in the more recent experiments by Jacobson. Muscular effort has a marked influence on the force of the circulation in certain veins and produces an elevation in the pressure. As the reduced pressure in the veins is due in a measure to the great relative capacity of the venous system and the free communications between the vessels, it would seem that if it were possible to reduce the capacity of the veins in a part and force all the blood to pass to the heart by a single vessel corresponding to the artery, the pressure in this vessel would be greatly increased. Poiseuille has shown this to be the fact by the experiment of tying all the veins coming from a part, except one which had the volume of the artery by which the blood was supplied, forcing all the blood to return by this single channel. This being done, he found the pressure in the vein very much increased, becoming nearly equal to that in the artery.

Rapidity of the Venous Circulation.—It is impossible to fix upon any definite rate as representing the rapidity of the current of blood in the veins. It will be seen that various conditions are capable of increasing very considerably the rapidity of the flow in certain veins, and that under certain conditions, the current in some parts of the venous system is very much retarded. Undoubtedly, the general movement of blood in the veins is very much slower than in the arteries, from the fact that the quantity of blood is greater. If it be assumed that the quantity of blood in the veins is double that contained in the arteries, the general average of the current would be diminished one-half. Near the heart, however, the flow becomes more uniform and progressively increases in rapidity.

As the effect of the heart's action upon the venous circulation is subject to so many modifying influences through the small arteries and capillaries, and as there are other forces influencing the current, which are by no means uniform in their action, estimates of the general rapidity of the venous circulation or of the variations in different vessels must necessarily be very indefinite.

Causes of the Venous Circulation.

In the veins the blood is farthest removed from the influence of the contractions of the left ventricle; and although these are felt, there are many other causes which combine to carry on the venous circulation, and many influences by which it is retarded or obstructed.

The great and uniform force which operates on the circulation in these vessels is the *vis a tergo*. Reference has been made to the entire adequacy of the arterial pressure, propagated through the capillaries, to account for the movement of blood in the veins, provided there be no great obstacles to the current. The other forces which concur to produce movement of blood in the veins are the following:

1. Muscular action, by which many of the veins are at times compressed, thus forcing the blood toward the heart, regurgitation being prevented by the action of the valves.

2. A suction force exerted by the action of the thorax in respiration, operating, however, only on the veins in the immediate neighborhood of the chest.

3. A possible influence from contraction of the coats of the vessels themselves. This is marked in the veins near the heart, in some of the inferior animals.

4. The force of gravity, which operates only on vessels which carry blood from above downward to the heart, and a slight suction force which may be exerted upon the blood in a small vein as it passes into a larger vessel in which the current is more rapid.

The obstacles to the venous circulation are: pressure sufficient to obliterate the caliber of a vessel, when, from the free communications with other vessels, the current is simply diverted into another channel; expiratory efforts; the contractions of the right side of the heart; and the force of gravity, which operates, in the erect posture, on the current in all excepting the veins of the head, neck and parts of the trunk above the heart.

Influence of Muscular Contraction.—That the action of muscles has considerable influence on the current of blood in the veins situated between them and in their substance, has long been recognized; and this action is so marked, that the parts of the venous system which are situated in the substance of muscles have been compared by Chassaignac to a sponge full of liquid, vigorously pressed by the hand. It must always be remembered, however, that although the muscles are capable of acting on the blood contained in veins in their substance with great vigor, the heart is fully competent to carry on the venous circulation without their aid; a fact which is exemplified in the venous circulation in paralyzed parts.

It has been shown by actual observations with the hæmadynamometer, that muscular action is capable of increasing the pressure in certain veins. Bernard found that the pressure in the jugular of a horse, in repose, was 1·4 inch (31·8 mm.); but the action of the muscles in raising the head increased it to a little more than five inches (127 mm.), or nearly four times. Such observations show at once the great variations in the current and the important influence of muscular contraction on the venous circulation.

In order that contractions of muscles shall assist the venous circulation, two conditions are necessary:

1. The contraction must be intermittent. This is always the case in the voluntary muscles. It is a view entertained by many physiologists that each muscular fibre relaxes immediately after its contraction, which is instantaneous, and that a certain period of repose is necessary before it can contract again. However this may be, it is well known that all active muscular contraction, as distinguished from the efforts necessary to maintain the body in certain ordinary positions, is intermittent and not very prolonged. Thus the veins, which are partly emptied by the compression, are filled again during the repose of the muscle.

2. There should be no possibility of a retrograde movement of the blood. This condition is fulfilled by the action of the valves. Anatomical researches have shown, also, that these valves are most abundant in veins situated in the substance of or between the muscles, and they do not exist in the veins of the cavities, which are not subject to the same kind of compression.

Force of Aspiration from the Thorax.—During the act of inspiration, the enlargement of the thorax, by depression of the diaphragm and elevation of the ribs, affects the movements of fluids in all the tubes in its vicinity. The air enters by the trachea and expands the lungs so that they follow the movements of the thoracic walls. The flow of blood into the great arteries is somewhat retarded, as is indicated by a diminution in the arterial pressure; and finally, the blood in the great veins passes to the heart with greater facility and in increased quantity. This last-mentioned phenomenon can be readily observed, when the veins are prominent, in profound or violent inspiration. The veins at the lower part of the neck are then seen to empty themselves of blood during inspiration, and they become distended during expiration, producing a sort of pulsation which is synchronous with respiration. This can always be observed after exposure of the jugular in the lower part of the neck in an inferior animal. Direct observations on the jugulars show conclusively that the influence of inspiration can not be felt much beyond these vessels. They are seen to collapse with each inspiratory act, a condition which limits this influence to the veins near the heart. The flaccidity of the walls of the veins will not permit the extended action of any suction force. In the circulation the veins are moderately distended with blood by the *vis a tergo*, and, to a certain extent, they are supported by connections with surrounding tissues, so that the force of aspiration is felt farther than in experiments on vessels removed from the body. The blood, as it approaches the thorax, impelled by other forces, is considerably accelerated in its flow; but it is evident that beyond a certain point, and that point very near the chest, ordinary aspiration has no influence, and violent efforts rather retard than favor the venous current.

In the liver the influence of inspiration becomes a very important element in the mechanism of the circulation. This organ presents a vascular arrangement which is exceptional. The blood, distributed by the arteries in a capillary plexus in the mucous membrane of the alimentary canal and in the spleen, instead of being returned directly to the heart by the veins, is collected into the portal vein, carried to the liver, and is there distributed in a second set of capillary vessels. It is then collected in the hepatic veins and carried by the vena cava to the heart. The three hepatic veins open into the inferior vena cava near the point where it passes the diaphragm, where the force of aspiration from the thorax would materially assist the current of blood. On following these vessels into the substance of the liver, it is found that their walls are so firmly adherent to the tissue of the organ, that when cut across, they remain patulous; and it is evident that they must remain open under all conditions. The thorax can therefore exert a powerful influence upon the hepatic circulation; for it is only the flaccidity of the walls of the vessels which prevents this influence from operating throughout the entire venous system. Although this must be a very important element in the production of the circulation in the liver, the fact that the blood circulates in this organ in the fœtus before any movements of the thorax take place shows that it is not essential.

A farther proof, if any were needed, of the suction force of inspiration is found in an accident which is not infrequent in surgical operations on the lower part of the neck. When the veins in this situation are kept open by a tumor or by induration of the surrounding tissues, an inspiratory effort has occasionally been followed by the entrance of air into the vessels, an accident which is likely to lead to the gravest results. This occurs only when a divided vein is kept patulous; and the accident proves both the influence of inspiration on liquids in the veins near the chest and its restriction to the vessels in this particular situation by the flaccidity of their walls.

The cause of death from air in the veins is purely mechanical. The air, finding its way to the right ventricle, is mixed with the blood in the form of minute bubbles and is carried into the pulmonary artery. Once in this vessel, it is impossible for it to pass through the capillaries of the lungs, and death by suffocation is the result, if the quantity of air be large. It is because no blood can pass through the lungs, that the left cavities of the heart are usually found empty.

Air injected into the arteries produces no such serious effects as air in the veins. It is arrested in the capillaries of certain parts and in the course of a short time is absorbed.

Aside from the pressure exerted by the contraction of muscles and the force of aspiration from the thorax, the influences which assist the venous circulation are very slight. There is a slight contraction in the venæ cavæ in the immediate proximity of the heart, which is much more extended in many of the lower vertebrate animals and may be mentioned as having an influence—very insignificant it is true—on the flow of blood from the great veins.

In the veins which pass from above downward, the force of gravity favors the flow of blood. This is seen by the turgescence of the veins of the neck and face when the head is kept for a short time below the level of the heart. If the arm be elevated above the head, the veins of the back of the hand will be much reduced in size, from the greater facility with which the blood passes to the heart, while they are distended when the hand is allowed to hang by the side and the blood has to rise against the force of gravity.

Some physiologists are of the opinion that the right ventricle exerts an active suction force during its diastole; but experiments on animals do not fully sustain this view, and if such a force be exerted, its effect upon the circulation, even in the veins near the heart, must be very slight. In the great irregularity in the rapidity of the circulation in different veins, it must frequently happen that a vessel empties its blood into another of larger size, in which the current is more rapid. In such an instance, as a physical necessity, the more rapid current in the large vein exerts a certain suction force on the fluid in the smaller vessel.

Uses of the Valves of the Veins.

It is evident that the principal use of the valves of the veins is to present an obstacle to the reflux of blood toward the capillaries; and it remains only to study the conditions under which they are brought into action.

There are two distinct conditions under which the valves of the veins may be closed. One of them is the arrest of circulation, from any cause, in veins in which the blood has to rise against the force of gravity; and the other, compression of veins, from any cause—generally from muscular contraction—which tends to force the blood from the vessels compressed, into others, when the valves offer an obstruction to a flow toward the capillaries and necessitate a current in the direction of the heart. In the first of these conditions, the valves are antagonistic to the force of gravity, and when the caliber of any vessel is temporarily obliterated, they aid in directing the current into anastomosing vessels. It is but rarely, however, that they act thus in opposition to the force of gravity; and it is only when many of the veins of a part are simultaneously compressed that they aid in diverting the current. When a single vein is obstructed, it is not probable that the valves are necessary to divert the current into other vessels, for this would take place in obedience to the *vis a tergo*; but when many veins are obstructed in a dependent part and the avenues to the heart become insufficient, the valves divide the columns of blood, so that the pressure is equally distributed throughout the extent of the vessels. This is, however, but an occasional action of the valves; and it is evident that their influence is only to prevent the weight of the entire column of blood, in vessels thus obstructed, from operating on the smallest veins and the capillaries. It can not make the work of the heart, when the blood is again put in motion, any less than if the column were undivided, as this organ must have sufficient power to open successively each set of valves.

It is in connection with the intermittent compression of the veins that the valves have their principal and almost constant use. Their situation alone would lead to this supposition. They are found in greatest numbers throughout the muscular system, having been demonstrated in vessels one line (2·1 mm.) in diameter. They are also found in the upper parts of the body, where they certainly do not operate against the force of gravity; while they do not exist in the cavities, where the venous trunks are not subject to compression. It has already been made sufficiently evident that the action of muscles seconds most powerfully the contractions of the heart. The *vis a tergo* from the heart is, doubtless, generally sufficient to turn this influence of muscular compression from the capillary system, and the valves of the veins are open; but they stand ready, nevertheless, to oppose regurgitation.

In the action of muscles, the skin is frequently stretched over the part, and the cutaneous veins are somewhat compressed. This may be seen in the hand, by letting it hang by the side until the veins become somewhat swollen, and then contracting the muscles, when the skin will become tense and the veins are very much less prominent. Here the valves have an important action. The compression of the veins is much greater in the substance of and between the muscles than in the skin; but the blood is forced from the muscles into the skin, and the valves act to prevent it from taking a retrograde course.

A full consideration of the venous anastomoses belongs to descriptive anatomy. It is sufficient to state, in this connection, that they are very abundant and provide for a return of the blood to the heart by a number of channels. The azygos vein, the veins of the spinal canal and veins in the walls of the abdomen and thorax connect the inferior with the superior vena cava. Even the portal vein has been shown to have its communications with the general venous system. Thus, in all parts of the organism, temporary compression of a vein merely diverts the current into some other vessel, and permanent obliteration of a vein produces enlargement of communicating