Section of the History of Medicine.

President—Mr. WALTER G. SPENCER, O.B.E., M.S.

[*October* 5, 1927.]

Valves in Veins: An Historical Survey.

By K. J. FRANKLIN, D.M.

(From the Pharmacological Laboratory, Oxford.)

A LITERATURE extending over four centuries cannot be checked experimentally by any one observer. The writer has, therefore, contented himself in this paper with recording the observations of others, and has not attempted too critical a review of their works. Conflicting statements, where they occur, must be judged on their merits, but it should not be forgotten in this connexion that the wide variations found in the venous system as a whole have a parallel in the particular part of that system now under consideration. To individual differences, and to differences between individual veins, must be added those due to age, sex and species, and possibly also others.

(I) TERMINOLOGY.

(See fig. 1.)

The valves of veins have been called by various names, *membranæ* [155], *membranulæ*, *ostiola* [1], *apophyses membranarum* [47, p. 122], *membranarum epiphyses* [47, p. 357; 147], *valvulæ* and σιγμοειδεῖς *membranæ* [1]. In this last, the word *sigmoid* refers to the *old* Greek letter sigma, which was semilunar in shape, like a capital C. In addition to the above names, *exilia opercula* [115] and ἐπανθισμοὶ [132] are terms which some writers have referred to valves.

Valves have been divided into two classes, first, those over the entries of tributary veins, variously called *platismata* or *platismatia* [123], *soupapes* [140], *valvules en toupie* [78], *Astklappen* [80], or ostial valves [78], and secondly, those in the lumen of the veins—*Taschenklappen* [80], or parietal valves [78].

The sinus of the parietal valve has been called *nid de pigeon* [140] or *Klappentasche* [45], the thickened attachment of the cusp framework to the vein-wall *agger* [107], *limbus*, *tuberculum* [99], *bourlet* [140], *bourrelet bourrelet fibreux*, *cintre fibreux*, *liséré fibreux* [78], and *Wulst* or *Klappenwulst* [45]. The cusp, apart from or with the agger, has been called *repli séreux*, *repli membraneux* [78], or *Klappensegel* [45]. The *cornua* are the continuations of the free border of the cusp where it meets the vein-wall [66]. The free border and the agger join here, and the structure so formed reaches proximally, as a ridge, for a short distance in the vein-wall. "Proximally" in this paper means "away from, in the direction of the blood-stream"; "distally," "away from, in the opposite direction."

In the past the word valve has often been used to describe a single cusp, and this has led to confused descriptions [e.g., 3]. In this paper valve means the whole valvular apparatus at any particular level in a vein, whether it be formed of one, two, three, four, or five cusps. In addition, Houzé de l'Aulnoit's terms "ostial" and "parietal" will be employed, as also the names sinus, cusp, agger, cornua, and free and attached borders.

The modern nomenclature of the valves is indicated in fig. 1.

(II) Development of Valves.

(See figures 22, 23, 24.)

Investigation of the embryological development of valves is very recent, and one can only regret that it was not attempted earlier, for the two papers by Kampmeier and Birch [81] and Jäger [80] have already cleared up many points previously in dispute. Jäger worked on pig embryos, Kampmeier and Birch on human material. Their general conclusions were similar.

"Fœtuses ranging in age from two months *in utero* to full term constituted the material used for study. The first valves arise in the peripheral veins at approximately 3·5 months, those of the upper extremity somewhat earlier than this, those of the lower slightly later. The earliest valves of the lower extremity appear in the deep veins in the territories of the femoral trigone and popliteal fossa and in the upper end of the saphena magna. The full quota of valves in the saphenous district originates during the next two months of development, after which no further ones are laid down.

"The bicuspid valve begins as a pair of inconspicuous and more or less transversely placed endothelial ridges inside the vein. By the invasion of the mesenchyme, the elongation and slanting of the ridges, and the formation of a concavity on their leeward face, the anlagen are gradually converted into valval sacs. Coincident with such changes, the venous cavity flares outward at the level of these sacs, so aiding in the production of their sinus. The bulging occurs sequential to a local retardation in growth and a deficiency in circular muscle development of the tunica media, which at such points in the new-born is only one-fourth to one-fifth as wide as elsewhere in the contracted vein.

"Arbitrarily, but conveniently, the formative period of a venous valve may be demarcated into five genetic phases (see fig. 22).

"Of atypical venous valves in the fœtus, both unicuspid and tricuspid are described. They may be derived from the typical bicuspid variety (see fig. 24). What seemed to be vestigial valves were also found several times.

"The most constant position of the valves in the chief peripheral venous trunks is just distal to the entrance of tributaries. A number of other common varieties of locality are also enumerated. Occasionally valves may follow each other in immediate succession.

"Numerical variability already is evident in the fœtus. The statements regarding marked reduction in the number of valves, during the period from prenatal to the second decade of postnatal life, must be received with scepticism" [81].

(III) Structure of Valves.

(See figures at end of paper.)

Ostial Valves.—These occur less frequently than the parietal, and they have no agger. They are situated at the entrance of small veins into larger ones, and consist usually of a single fold, whose insertion occupies about two-thirds of the circumference of the entry [78, 116], although this amount may vary [135]. Sometimes they consist of two folds, arranged somewhat in the manner of a bicuspid parietal valve, but with an ostial origin [135]. Or they may consist of a double fold, like an oyster-shell, and in these cases reflux of blood bellies out one fold into the main stream, and flattens the other against the tributary vein entry [78]. A valve which is not inserted into the circumference of the actual entry is not an ostial, but a parietal valve, no matter how near it is to the entry [136]. This distinction is not always clearly drawn in the literature, and in consequence the writer may have in places misinterpreted an author's meaning. The single-fold ostial valve directs the tributary blood-stream into the main veins and towards the heart; a large one, if flattened over the entry, would prevent regurgitation into the tributary, but it would act in exactly the opposite way if at the moment its free border extended out into the main stream. The two-fold ostial valve (the second variety of ostial valve referred to above), of which an example is found at the thoracic duct entry [135], prevents regurgitation. Kerkring gives drawings of pyriform ostial valves in man and the horse (fig. 14); a photograph of one is also available (fig. 21). Salter and Pettigrew should be consulted for further details about ostial valves.

Parietal Valves.—These may have from one to five cusps. Bardeleben, working only on human material, says that all true valves possess two cusps, neither more nor less [10]. Bicuspid valves are no doubt the rule in man, at least in the extremities [56, 86, 88], but Friedreich occasionally saw unicuspid and tricuspid, Hesse and Schaack tricuspid, and Houzé speaks of all forms up to quadricuspid, while Kerkring gives drawings of tricuspid valves. In animals tricuspid, quadricuspid [163] and quincuspid [85] have been found. A number of unicuspid valves are shown in the plates of Fabricius. Pettigrew states that in the smallest veins unicuspid valves are present, in the medium and large-sized veins of the extremities bicuspid, while in very large veins, such as the internal jugular of the horse, tricuspid and quadricuspid valves are by no means uncommon. The free border of a cusp is somewhat stronger in structure than the main part of it, according to Senac and Morgagni, the agger than either. Haller finds that the cornua are longer the shorter the stream length of the cusp. The attached border of a parietal unicuspid valve occupies rather more than half of the interior of the vein [116]. In a bicuspid valve the vertical length of the cusps may often be twice the diameter of the vessel, and the free borders of the cusps run together for some distance from the vein-wall owing to the fibrous structure in them. Kerkring found sometimes that one cusp occupied two-thirds of the lumen, the other one-third. In the tricuspid valve one segment is usually greater than the other two [78, 116]. These valves are shallower than the bicuspid, and intermediate between them and the tricuspid valves of the aortæ. When four cusps are present, two are more or less rudimentary [116], and the valve is possibly less efficient than with fewer cusps [158].

The microscopical structure of a parietal valve is as follows [45, 111, etc.] :—

(*A*) *Cusp.*

(*a*) *Endothelium.*—The long axis of the cells is parallel to that of the vein on the proximal side, transverse on the distal side (Ranvier in 120).

(*b*) *Smooth Muscle.*—This is said to be present, transverse to the long axis of the vein, especially near the free border, by Remak, Ranvier, Bardeleben [10] ; to occur in some valves, but not in others, by Epstein, in the larger valves, by Wahlgren [see 10], not to do so in sheep's mesenteric valves by Haynes [55]. In the agger, or crescent-shaped junction of the cusp with the vein-wall, there are smooth muscle-fibres running parallel to the course of the agger. Some of these fibres pass over into the neighbouring parts of the cusp. The fibres lie in an elastic network derived from a fraying-out of the elastic membrane of the intima, and the agger contains in addition a large amount of homogeneous cement-substance, and some connective-tissue cells. The agger reaches a short distance (proximally) beyond the free border of the cusp to form the "cornua valvulæ." It is fairly rich in blood-capillaries [45].

(*c*) *Other Components.*—The two surfaces of the cusp show no close correspondence. Under the endothelium of the "capillary" surface is a fine elastic network, under that of the "heart" surface are traces only of elastic tissue in the midst of connective tissue [45]. For the arrangement of the fibrous and elastic tissue see fig. 16.

(*B*) *Sinus.*

(*a*) *Intima.*—External to the endothelium of the vein-wall is a layer of *longitudinal* muscle-bundles, traversed by delicate branches of the elastic intima, and embedded in an homogeneous cement-substance, containing a few connective-tissue cells. These muscle-fibres reach proximally a point just beyond the free border of the cusp; distally most of them join the agger, but a few are prolonged for a short distance in the intima.

(*b*) *Media.—Longitudinal* muscle-fibres reach from the same proximal point as those of the intima to become incorporated distally with the agger valvulæ. The circular muscle of the vein-wall decreases or disappears completely (e.g., in the femoral vein) in the area of the sinus. In the femoral vein of man Epstein found that for a distance of 0·1 mm. proximal to the sinus the vein-wall was completely devoid of muscle. The thinning of the media, and the disappearance of the circular muscle, occurs in the last stage of development of the venous valves, shortly after birth [81]. According to Sappey, valves have no nerve supply.

Unusual Types of Valve.—Hyrtl, in his Lehrbuch (1882) describes a spiral valve of three to eight revolutions as occurring in the portal vein of rodents. Perrault speaks of solid fleshy valves in certain fishes. These valves have pores on their proximal side, and a reflux of blood fills the pores and closes the valves; blood flowing in the opposite direction encounters a pore-free surface, the passage of the blood empties the pores and opens the valve.

(IV) Before Harvey.

(See figures 2-8.)

It is not easy among all the conflicting evidence to decide who first discovered the venous valves. The claim made on behalf of Canano, however, is a strong one, and is supported by Morgagni, Haller, and more recently again by Streeter [33]. About 1536 Gianbattista Canano and his kinsman, Antonio Maria Canano, began demonstrating at Ferrara to an audience which included Piccolomini and Francis Vésal, the brother of the great anatomist. In 1541 Gianbattista Canano, then twenty-six years of age, became Professor of Anatomy at Ferrara, where he was visited between August and November by Vesalius. Four years after this, at Regensburg, and by the sick-bed of Lord Franceso d'Este, the two great anatomists met again. It was at this meeting that Canano told Vesalius of his discovery of valves in the opening of the azygos and renal veins, and of the veins overlying the upper part of the sacrum [155]. Canano did not publish his results, and this meagre account, printed several years afterwards, may well be an incomplete statement of what Canano had done. From Amatus Lusitanus, who was at Ferrara from 1542-1548, comes further corroboration of Canano's knowledge of the azygos valves. Amatus stated that these were demonstrated at Ferrara, in 1547, to a large audience, the bodies of men and animals being used for the purpose [5]. But Amatus, unfortunately, in publishing his work in 1551, said that the valve at the orifice of the azygos opposed the flow of blood from that vein into the vena cava, and he involved Canano's name in this erroneous idea. The leading anatomists, Vesalius [156], Eustachius, Falloppius, and also Franciscus Valesius, combined to pour scorn on Amatus, and as a result progress in the study of the valves generally received a set-back for several years.

Another claimant is Charles Estienne, who described *apophyses membranarum* in the liver veins in 1545, and who had observed them, according to Streeter [33], as early as 1538. These valves, said Estienne, opposed the back-flow in the same way as the heart-valves. His description, however, is very vague, and he confines his observations to the liver veins.

A third claimant is Jacobus Sylvius (1478-1555). In his *Isagoge*, published posthumously and in the year of his death, mention is made of valves at the mouth of the azygos, and often of other large vessels, such as the jugulars, brachial and crural veins, and the trunk of the cava as it leaves the liver. But Sylvius [153], in 1541, seems to have had no knowledge of these structures, and never claimed to have discovered them.

After this time, possibly as the result of the book of Amatus and its sequel, interest in the question of valves died out until Fabricius ab Aquapendente rediscovered them in 1574. Realdo Colombo, it is true, had mentioned valves in the mesenteric veins in his posthumous work published in 1559, but after that all knowledge of such structures seems to have disappeared, and Fabricius believed he had found what no one had seen before (but see Morgagni §§ 63 sq.). In the early part of 1579 [1] he began to demonstrate them publicly, as also did Salomon Alberti later in the same year in Germany. Alberti, in his book in 1585, acknowledged his indebtedness to Fabricius. In this book appear the first drawings of valves (figs. 2 and 3). Next year, a further account was given by Piccolomini, one of Canano's earliest pupils. He described his delight at the sight of the countless valves in the veins, and attached great importance to them.

In 1603 the valves at last received full recognition through the publication of the *De venarum ostiolis* of Fabricius, with its definite statements and its fine plates (see figs. 4-8). The structure, distribution and position of the valves were described, and also the fact that they opposed the back-flow of blood. But Fabricius thought that the lumen was only partially closed by the valves, and so failed to deduce their true function. It was left for his pupil, William Harvey, who was at Padua from 1600 to 1602, to grasp the true significance of the valves, and to make the greatest single contribution ever made to physiological knowledge.

(V) The Occurrence of Valves in Various Veins.

(See figures at end of paper.)

Although Harvey saw the true importance of the valves, he did so at a time when the knowledge of their distribution was still incomplete. Fabricius had stated that valves were common in the veins of the extremities, but absent in the vena cava, in the internal jugular except at its orifice, and in numerous small cutaneous veins. Harvey himself mentions also occasional valves in the coronary, mesenteric, splenic, and renal veins. It is to bridge the gap between then and now that the following review of the occurrence of valves has been attempted.

(*A*) *Miscellaneous Observations.*

Swammerdam is said to have denied the presence of valves in amphibia, but Suchard more recently has shown them to exist in very large numbers in the frog (*Rana esculenta*) and toad (*Bufo vulgaris*). In the frog they are usually bi-, sometimes tri-cuspid [145].

Carrier gives a figure of valves in the veins of the bat's wing, first described by Wharton Jones in 1852. (*Phil. Trans. Roy. Soc.*, part I, 131-136).

Hildebrandt states that valves are much less common in birds than in mammals. Ellenberger and Baum give a distribution of valves in the domestic mammals very similar to that found in man.

In the whale there are no venous valves, according to the author of Moby-Dick [103], and Burow saw none, except in the azygos vein, in the seal [23].

Valves do not occur in veins less than 1 mm. in diameter, nor in certain of the larger veins, among which have been placed the uterine, umbilical, placental, periosteal and bronchial veins. Other veins in which they are not present are indicated below.

(*B*) *The Venous Valves of the Heart, the Cardiac and Pulmonary Veins.*

The venous valves of the heart, found in fishes, amphibians, and reptiles at the junction of sinus and right auricle have practically disappeared in the higher animals although out of the right one has been evolved the right *taenia terminalis* [82, 83], The Thebesian and Eustachian valves derive part of their musculature from the remnants of the right venous valve, and a thin muscular layer along the lower border of the *fossa ovalis* occupies the position of the left venous valve, and is probably derived from it [83]. In this connexion Turner's notice of a heart in which the superior vena cava possessed a valve at its auricular orifice is of interest. Houzé called the Eustachian valve the ostial valve of the inferior vena cava. Durocicz deals with the sphincter mechanism at the entry of the cavæ and cardiac veins.

Piersol states that the cardiac veins do not possess valves in their course, but certain of them possess unicuspid or bicuspid valves at their entry into the coronary sinus. The oblique vein of the left auricle has no valves, the ostial valve of the great coronary is the valve of Vieussens, which, according to Gruber [63, quoted in 81], is a bicuspid valve in the young and is retained, in a reduced state, in 80 per cent. of adults. The valves of the coronary veins are often insufficient. In the seal, Burow [23] found no valve but a constriction of the cardiac vein just before its entry into the auricle.

The other veins connected with the heart, the pulmonary veins, are said by Lancisi to possess valves in their branches, but not in the main trunks. The presence of valves in these veins is denied, on the other hand, by most writers. In animals, valves are recorded by Boissier de Sauvages in the sheep, while Richelmann finds ostial valves in the pulmonary branches in the dog and calf. Mayer [see 75] stated that an ostial valve is present where a pulmonary tributary joins a larger vein at an acute angle, but never, or very rarely (Kelch), in man when the angle of junction is a right angle. According to the same author, valves are more common in man than in the pig, and he also states that Cuvier found them quite common in several amphibia. In the hippopotamus [61] there are said to be no valves in the venæ cavæ, cardiac and pulmonary veins.

(*C*) *The Superior Caval System.*

The Superior Vena Cava and Innominate Veins.—These have no valves [118].

The Tributaries of the Innominate Veins other than the Subclavian and Internal Jugular.—Piersol states that the vertebral, inferior thyroid, and superior phrenic are guarded at their orifices; Piersol, and Braune and Fenwick, that the internal mammary is valved in its course; and Houzé that all the small tributaries of the innominates, e.g., internal mammary and superior phrenic, have an ostial and two or three parietal valves. The vertebral, however, has none in its continuity (Haller and Houzé). A valve, either unicuspid or tricuspid, occurs at the entry of the deep cervical into the vertebral [81]. In domestic mammals (horse, donkey, mule, ox, sheep, pig, goat, dog and cat), according to Mobilio, the valves at the entries of tributaries into the superior vena cava and its large branches are distributed similarly to those in man, but show somewhat greater variations on the left side.

Internal Jugular Vein.—There is a bicuspid valve at the upper part of the bulbus [49 Plate I.A., 12, 66, 78, 118, 144, etc.], or else a unicuspid [118]. In either case it is insufficient, although it is possible that it is sufficient in fœtal life (Betsche, Haller, Houzé and others), and in animals (Dionis). Kerkring found a tricuspid occasionally. When the valve is bicuspid, one cusp is anterior, one posterior, according to Morgagni, but not according to Houzé. Haller disagrees with Riolan's statement that there are other valves in the internal jugular. Kampmeier and Birch say that a valve may occasionally be present at both ends of the bulb.

Tributaries of the Internal Jugular Vein.—Haller says valves are present in the facial, lingual, tonsillar and other branches, which do not enter the cranium. In the facial Houzé says valves are rare and variable, while Piersol admits their occasional presence in this and the angular vein, but says they are insufficient. The lingual and its branches have valves (Houzé and Piersol), likewise the superior thyroid and laryngeal (Houzé). The cerebral and ophthalmic veins have no valves (Verneuil, Houzé, Piersol), nor do the meningeal [81], the sinuses (Verneuil, Houzé), or the veins of the diploë (Houzé). According to Spalteholtz [81], however, the emissary veins, particularly the parietal ones joining the superior sagittal sinus and the veins of the diploë and the scalp, do possess valves directed peripherally.

External Jugular Vein.—Riolan [124], Diemerbroeck, and Dionis deny the presence of valves in this vein and Houzé their presence in its trunk; Piersol states that there is a bicuspid valve at its entry into the subclavian, usually another about the middle of the neck, and sometimes a third between these. All are insufficient. Struthers gives two in his figure, and some in the branches.

Tributaries of the External Jugular.—The temporal veins have valves at their mouths [81], and also in their course [78], the internal maxillary ostial valves only [78]. The anterior jugular has no valves [118].

Miscellaneous Remarks on the Jugulars.—Kerkring gives figures of a human jugular vein with three tricuspid valves, a boy's jugular with one tricuspid, one quincuspid and one tricuspid in a dog's jugular, and two tricuspid in that of an ox (see fig. 14). Bidloo gives a drawing of a tricuspid jugular valve. Stephen Hales found the jugular valve insufficient in a mare. In the Museum of the Royal College of Surgeons are specimens showing a bicuspid value in the camel, and bi-, tri-, and quadricuspid in the horse.

Subclavian Vein.—Haller and Houzé find one bicuspid valve, Piersol one bicuspid valve at its junction with the internal jugular, and one at its junction with the axillary. The Royal College of Surgeons' Museum has a specimen of a camel's subclavian valve.

Axillary Vein.—T. Bartholin says the upper limb is well valved *post alarum glandulas*, Riolan [124] that there are two valves, one behind the other, in the axillary vein, and Houzé gives two or three. Piersol says there is one bicuspid valve, usually situated at the lower border of the subscapularis.

Arm Veins.—Houzé states that all the arm veins have valves with few exceptions, Houzé and Piersol that the deep veins have more valves than the superficial. Bardeleben finds the deep veins of the forearm, like those of the calf, very well supplied. His general remarks on the leg veins apply also to the arm veins (see below). For details as to the number of valves in the various veins his paper should be consulted [10]. Houzé finds that the blood-flow, where directed by valves, is always from superficial to deep veins.

(*D*) *The Azygos System.*

The Azygos Veins.—Besides the statements mentioned in Section IV above there are those of Riolan, who re-discovered the azygos valves in the seventeenth century, and also of C. and T. Bartholin, Haller, Hebenstreit, Hollerius, Houzé, Lancisi, du Laurens, Molinetti, Morgagni, Richelmann, Roden, Rolfink, Sappey, Sclanus and Senac. Riolan found 2-4 valves in this vein. Morgagni summarized the position in 1765. In the last century Gruber [62] re-investigated the whole question, working on 100 human subjects, eighty-eight male, and twelve female. According to him, valves occur in the majority of cases, but some veins are quite destitute of them. Their number is usually from 2-4, they are partially insufficient, and occur chiefly in the arch of the vein. The vena hemiazyga only very seldom possesses ostial or parietal valves. When a left azygos vein occurs, it is usually provided with valves. The left superior intercostal has only exceptionally ostial or parietal valves, the lower intercostals occasionally have ostial valves, the upper intercostals more often have an ostial valve than not. They are not always sufficient.

The one azygos vein of a newborn child mentioned in the paper of Kampmeier and Birch contained three valves, ostensibly well-formed, two being in its upper reaches, near its union with the pre-cava, and the third at the level of the diaphragm. None of the metamerically arranged ostia of its intercostal branches were valveless.

The Intercostal Veins.—Those veins which connect anteriorly with the internal mammary or musculo-phrenic may each be divided into three portions:—

(1) Anterior: valves direct blood anteriorly to internal mammary or musculo-phrenic.

(2) Middle: destitute of valves.

(3) Posterior: valves direct blood to azygos or hemiazygos. The middle portion is connected with the costo-axillary veins, so that blood in this portion may also travel from the upper six or seven veins to the axilla. In the lowest veins there is no double flow, the valves all being directed towards the azygos veins.

For further details Braune and Fenwick should be consulted.

The Spinal Veins.—The two longitudinal veins and the anastomosing veins are avalvular. The small veins coming from the interior of the vertebræ are furnished in their extra-osseous course with *petites cloisons membraneuses*, which prevent reflux. The veins of the spinal cord itself are avalvular (Houzé). Valves are found where the chief channels discharge into the intervertebral veins, and these in turn into the vertebral, the intercostal, the lumbar, and the sacral veins (Kampmeier and Birch).

(*E*) *The Inferior Caval System.*

Inferior Vena Cava.—Most observers [2, 56, 66, 78, 118, 140, etc.] deny the existence of parietal valves between the heart and the common iliac veins, but Bardeleben [10] records finding one cusp of a bicuspid valve persisting below the entrance of two tributaries on the posterior wall of the cava, the anterior cusp presumably having atrophied. Riolan [124] says there is no valve in the cava near the liver. Highmore found ostial valves at the entrance of many tributaries of the cavæ, and Kerkring gives figures of such valves in man and the horse (fig. 14). Richelmann likewise gives ostial valves to the phrenic, renal, adipose, and lumbar veins, but not to the hepatic, at the entrance of which ostial valves had been seen by others in the ox, cat and dog. Houzé found ostial valves in the case of the lumbar and right spermatic veins. The occurrence of ostial valves will be dealt with in more detail in describing the caval tributaries. Parietal valves occur in the stomach tributaries of the horse's cava [17]. Houzé notes a spur, sometimes perforate, at the bifurcation of the cava to form the iliacs.

Phrenic Veins.—According to Diemerbroeck, some writers state that these veins are valved at their entries. Among such writers is Highmore [74].

Lumbar Veins.—These may have ostial valves. They also may have one or two parietal valves, concave towards the cava, but nearly always insufficient [78, 118].

Hepatic Veins.—C. Bartholin gives ostial valves, T. Bartholin valves at the entry of small branches, as found previously by Estienne in man, and in the ox by Conring. Highmore finds valves in many animals, Meibom in the goat (*capreolus*), but not in ox or dog. Diemerbroeck found valves in the ox, but is doubtful about man. Houzé denies the presence of valves in man. McDonnell finds ostial valves in many animals. Wintringham gives them valves, and Winslow ostial valves, or an ostial valve-like structure. Piersol states that in the adult these veins are valveless. Kampmeier and Birch agree, but say that in consequence of their oblique entry into the vena cava a sickle-shaped fold may occur at the lower margin of each orifice;

the same authors found no evidence of valves or their rudiments in a 5·5 months' fœtus, either in the main trunks, or at the ostia of their tributaries, or at their confluence with the vena cava.

Renal Veins.—Ostial valves are described by Diemerbroeck and Henle; they are said to occur sometimes in man and commonly in the sheep and horse by McDonnell, in oxen by Alberti [2]. Parietal valves occur at the entry of the spermatic, according to Haller, and near the opening into the cava, according to Epstein. They have been seen in the renal veins of cat and rabbit by Franklin [54], and a specimen from the camel is in the Museum of the Royal College of Surgeons. Rivington found parietal valves in a certain number of cases in human beings. Renal valves have also been mentioned by Bauhin [13], Harvey, Riolan [124], T. Bartholin, Schmiedt, Gerike, Wintringham and Roden. They are denied by Haller and Houzé, and Piersol states that they are of rare occurrence in the renals, and absent or insufficient in the renal tributaries. Kampmeier and Birch found that in development the margins of the connexions of both renal veins with the vena cava protruded into the lumen as relatively massive thickenings of the media, which resembled sphincters (fig. 23). Apart from this, they found perfectly formed and competent valves in both renal veins in the newborn. Highmore (fig. 13) shows valves in both renals and both spermatics.

Suprarenal Veins.—Petrucci puts valves in these veins in his figures, but in so doing reverses the normal blood-flow. Glisson describes a valve in what may be the suprarenal, but his wording is not too clear. The apertures of the suprarenal veins are equipped with efficient valves in the fœtus [81].

Spermatic and Ovarian Veins.—In the earlier references no differentiation is made between these veins. Ostial valves are described by Rolfink (right), Richelmann and Diemerbroeck (left), Chevers, Houzé (fairly frequent), Brinton (right spermatic), and Henle (occasionally). Parietal valves are mentioned by Highmore, Molinetti, Dionis, Haller, and Houzé (sometimes insufficient). Monro found ostial and parietal valves in the spermatic veins and their branches in man, but none in human ovarian veins. The spermatic are specially rich in valves in some quadrupeds, but have few or none in others, such as the hedgehog. Rivington concludes that there is a bicuspid valve near the orifices of human spermatic and ovarian veins, with few exceptions. Piersol states that the right spermatic has an ostial valve, but otherwise there are no valves in the spermatic or ovarian trunks. Franklin [54] found the ovarian well-valved in the cat. Kampmeier and Birch found the spermatic veins furnished with efficient valves in the fœtus, the short upper segment of the left spermatic excised for study containing three of them.

Iliac Veins.—The earlier statements by Canano, Piccolomini, Fabricius, Harvey, Riolan and Diemerbroeck are overshadowed by later work, and need not be detailed. Friedreich examined the veins of 185 subjects, and published the results in 1881. The common iliac has valves in only 1·4 per cent., the external iliac in 35 per cent., and of these one-third are insufficient. The valve is usually in the upper part of the external iliac, especially below the entry of the internal iliac. In only one case were there two valves in this vein and the distal one was rudimentary. McMurrich gives figures from thirty-one subjects, which are somewhat higher than those of Friedreich. Three per cent. of McMurrich's specimens had two valves in the external iliac.

There are no valves in the internal iliac, but they exist in its branches, the gluteal, sacral and obturator, opinions differing as to their presence either at the terminations or in the path of these vessels beyond the pelvic confines. Nor is there agreement as to their existence in the various venous plexuses of the pelvis, such as the middle and inferior hæmorrhoidal, vesical, pudendal and utero-vaginal [81].

For the valves in the deep epigastric reference should be made to Braune and Fenwick.

The Venous System of the Bladder and Its Surroundings.

Highmore mentioned valves in the pudendal veins, and Petsche saw some in the pampiniform plexus, while Cowper gives a drawing of the valves in the dorsal vein of the penis. Fenwick described the whole system in 1885, and Haberer the testicular part in 1898. Fenwick states that "all the many veins which converge from the buttocks, genitals, and lower extremities to the pelvis, be it to the true or false divisions of that cavity, are valved at their entrance into it. These valves—some of the veins have two or even three sets—allow the venous blood to flow freely into the abdomen, but prevent its escape therefrom. Hence the abdomino-pelvic venous blood-pressure is entirely shut off from that of the lower extremities and genitals. The accuracy of closure and the constancy of position of these entrance-valves is most striking." Details must be sought in the original paper, but from his description "it will easily be appreciated how designedly and carefully the veins of the pelvis have been valved, and in such a manner as to reduce, in so far as possible, the liability to congestion to which this, 'the venous province par excellence,' as Luschka calls it, must necessarily be subjected."

Veins of the Lower Extremity.—These were noted from the earliest times for their richness in valves. Recently they have been made the subject of much investigation of a more quantitative nature [10, 56, 86, 19, 73, 88, 81], with a view to determining the relative distribution of valves within the various veins, and in the superficial as compared with the deep veins, and also to finding out the direction of the blood-flow between the deep and superficial veins. Bardeleben finds the deep veins have more valves than the superficial in children, but that by adult life other factors have affected the question, so that now one can only say that valves are more numerous in the narrower than in the wider veins. He states that valves are apt to disappear in the neighbourhood of the joints. Friedreich found the upper part of the femoral between Poupart and the entry of the v. profunda very efficiently valved in his 185 subjects, thus recalling T. Bartholin, Pecquet [in 34], and Houzé, who remarked the same thing without Friedreich's quantitative authority. Klotz, working on ten subjects, and investigating especially the saphena magna, does not agree with Bardeleben that there are large areas in the neighbourhood of joints, especially the knee-joint, without valves. He states that there are fewer valves below the knee than above. The number of functioning valves, according to Klotz, decreases with age, whereas Bardeleben found individual variations. In cross-anastomoses between veins of equal size Klotz finds no valves; between veins of unequal size there are valves so directed that the blood flows from smaller into larger. Hesse and Shaack, investigating 100 cadavers, found a single valve in the femoral above the saphena magna entry in 72 per cent, and two in 5 per cent. Below the saphena entry valves were always present, two in 73 per cent., three or more in 18 per cent., one only in 9 per cent. There is always one competent valve within the 10 cm. of femoral vein below the saphena. In almost all cases the saphena magna has a valve at or very near its entry into the femoral, and usually 2-5 or more additional valves in its course. They are usually bicuspid. Anlagen were often seen.

Kosinski, examining 124 legs, finds the valves in the saphena parva so arranged that the blood flows from that vein into the saphena magna, and not *vice versa*. The number and arrangement of the valves in the saphena parva depend on the number of afferent tributaries, and on an average is eight. In the majority of cases age and sex have little influence on the number. The flow of blood is from the superficial to deep veins, the calibre of the great saphenous vein often being smaller at its termination than it is lower down. According to Magnus, only 10 per cent. of the venous return from the lower limb makes its exit via the saphena magna. For further details as to the number of valves in different veins the original papers should be consulted.

Kampmeier and Birch state that all the branches of the femoral, indeed all the deep and superficial veins of the hind-limb, are well supplied with valves. The number and position varies much in the saphena magna. Bardeleben gives 4-14, Monro and Cunningham 8-10-20, Kosinski 7-11 in 60 per cent., Kampmeier and Birch 6-14.

Valves occur in the deep veins of the lower extremity before they do in the superficial, and in greater numbers, according to the last-named authors.

(*F*) *The Portal System.*

Portal Vein.—No one has found valves in the human portal trunk in the adult, and Kampmeier and Birch were unable to do so in the portal vein and its liver branches of a 5·5-month fœtus. Houzé, however, noticed a serous fold and a slight constriction at the point of union of the mesenteric and splenic, and the writer has also seen this in one instance [54]. Richelmann stated that unicuspid valves occurred in the portal branches, and Diemerbroeck noted valves in large and small portal branches. Weigel denied valves in human portal branches, but admitted their occurrence in the ox and horse, Hildebrandt also in the case of the latter animal. Bourgelat stated that the portal vein branches coming from the stomach of the horse have valves. Crisp found no valves in the quadrumana, young walrus, rodents (including the largest, the *Capybara*), or large birds, but they were found in "the splenic and other portal veins" of a marsupial, *Macropus major*. Hyrtl stated the existence of a spiral valve of three to eight revolutions in the portal vein of rodents [79].

Small Gastric Branches of Portal Vein.—Hochstetter states that valves occur to some extent in these veins in man and monkeys, and occasionally in the rabbit, but not in the hedgehog or bat. Wilkie finds that there are valves in the gastric and omental tributaries of the portal vein in the newborn infant and young child and also in the adult human subject. Bicuspid valves occur near the entry of tributaries into larger veins. The numbers decrease between 2 months and 18 years, but some valves are seen in quite elderly people.

Small Gastro-splenic Branches of Portal Vein.—Hochstetter notes the occurrence of valves in these veins in ruminants, Dorcas antelope, sheep, she-goat; in carnivora, dog, cat, fox, otter, especially the first two; and also in the horse and pig.

Splenic Vein.—Bauhin, Harvey, and Wintringham state that the splenic has valves, and Lower gives valves to the splenic and coronary branches of the splenic. On the other hand, Riolan, Marchettis, Haller, Houzé, Crisp and Piersol deny these structures in man. Kampmeier and Birch found no valves in the splenic-vein systems of a 5·5-month and an 8-month fœtus, except in the openings of the gastric and pancreatic tributaries.

Highmore finds the splenic valved in pig, deer, ox, sheep, dog, horse and other species (figs. 11 and 12). Muralt and Ent found the splenic branches valved in the horse. Crisp found no valves in a young walrus, several dogs and birds. In only one carnivorous animal, an old mastiff with a large stomach, were valves present. Valves probably occur in all pachyderms: they are most numerous in the horse. He mentions valves in giraffe, sheep, tapir, pig, ox, zebra, one marsupial only (*Macropus major*), an edentate (*Dasypus peba*), the Indian sow, reindeer, leucoryx, and Indian gazelle (coronary branches). Crisp's specimens from the giraffe, horse, tapir, and addax are in the Museum of the Royal College of Surgeons. Franklin found valves in the splenic of the sheep and calf [55]. Crisp thinks that valves do not as a rule occur in the splenic vein in animals with small stomachs.

Mesenteric Veins.—Valves are said to occur in human mesenteric veins by Colombo, Harvey, T. Bartholin, Ludovicus de Bils and Plempius [quoted in 36], Tassin, and, in one instance only, by Sellors. They are not found, according to Highmore, Marchettis, Haller, Houzé, Crisp, Piersol, Sellors (in all other cases but the one mentioned), and Franklin [54]. Wilkie found valves in the veins from the large intestine in every one of ten stillborn children he examined. They were most abundant in the veins from the pelvic colon. He was not able to demonstrate them in the colic veins of the adult, nor in the veins from the small intestine. Crisp found them in the reindeer (forty-eight valves in one vein) and horse in large numbers, and also reports them in the guanaco; Franklin has found them in the giraffe [54], sheep and calf [55]. Crisp did not find them in quadrumana, rodents, peccary and Indian sow.

Intestinal Veins.—The observations of Colombo and Tassin, mentioned under the heading of mesenteric veins, may really refer to the smaller veins, but one cannot be certain. Köppe describes a very complete system of valves in the long and short intestinal veins, apparently, although not stated, in dogs. Bryant finds valves in the venæ breves in man, their number decreasing with increasing age; in the cat, and especially in the dog, they are very plentiful; they are rare in the rabbit, and absent in the guinea-pig.

(VI) General Considerations.

Distance Between Valves.—Bardeleben [10], without examining fœtal material, suggested that in the veins of the extremities in human beings there is a fixed distance between the sites of valves. In the adult this is approximately 5·5 mm. for the upper, 7·0 mm. for the lower limb, but the actual measurements differ according to the individual limb-length. All persisting valves are separated by these distances or multiples of them. As the number of valve-sites is the same, about 106, in the long veins of the two extremities (saphena magna and capitalis brachii), he suggests that they are laid down at that period in embryonic life when the two limbs are of equal length. Retrogressive changes take place very early in some of these sites. Bardeleben saw them, at least in the superficial veins, as early as the third month, and states that degenerative processes can be found in every body, child or adult. The retrogressive changes occur in the following order:—

(i) Insufficiency in all degrees, measurable in mm. Hg.
(ii) Breaking through of the valvular membrane.
(iii) Partial or complete disappearance of the cusp with the exception of the agger.

These remnants are often only found on spacing out the valve-distances, and they have a tendency to be displaced distally. In adults it is sometimes hard to see them with the naked eye, but they can be traced histologically, as the circular muscle is replaced by longitudinal at the level of valves.

Klotz disagrees with Bardeleben's *Klappen-Distanz-Gesetz*, and the work of Kampmeier and Birch does not encourage one to place confidence in its ultimate proof.

Connexion Between Valves and Tributary Veins.—The general rule, according to Bardeleben, is that "Distal from every tributary lies a valve, proximal from every valve is a tributary-entry." Exceptions are only apparent, and are due to disappearance of valve or tributary. Fundamentally, then, a vein consists of a number of divisions segmentally arranged, each division formed by a piece of cylindrical wall, a conical widening (sinus), a tributary vein entry, and a bicuspid valve. Later writers have disagreed with various points in Bardeleben's theories. (For further details see the section on leg veins above.)

Obstacles to Valvular Insufficiency.—Houzé enumerates these as :—

(i) The aggeres.

(ii) The connexions of the vein-wall with the aponeuroses in certain situations, especially near articulations. These *gaines fibreuses* keep the lumen of the vein patent in flexion, and also prevent distension of the vessel.

(iii) The numerous anastomoses.

(iv) The membranous septa, 5 mm. to 40 mm. long, found sometimes in the lumen of certain veins, e.g., in the leg. These presumably prevent distension. Haller refers to them, as far as one can interpret his words.

Atrophy of Valves.—The cause or causes are unknown. Bardeleben suggests hereditary influences, blood-pressure, muscular movements, traction, and growth-displacements. Klotz found the valves decreased with age, Kosinski that age and sex made no difference in the majority of cases in certain veins. Kampmeier and Birch attempt an explanation for the propensity to retrogression of valves in post-natal life. "It is conceivable that during growth to maturity, as muscular movements become more stereotyped, certain ruts, so to speak, are worn also in the vascular plexus. Some veins have become distended more than others because of the greater volume of blood they were called to carry early in their career by reason of their situation. Perchance when such habits become fixed and equilibrium is being attained between vessels in relation to their muscular environment, valves are increasingly less essential as regulatory mechanisms."

Valves and Varicosis.—Nicholson states that valvular insufficiency and static pressure are not the primary cause of varicosis, but that valvular insufficiency may be an important secondary factor. He says that the primary cause is mechanical, toxic, inflammatory, or trophic. Fischer and Schmieden's work would indicate that weakening of the vein-wall is the essential factor. In the leg Kosinski attributes the liability to varicosis not to valve trouble, but to the developmental changes in the superficial venous system. In animals other than man, in which these changes do not occur, varicosis is unknown.

The Valves in Action.—Pettigrew found that on pouring fluid into sections of vein provided with valves the closing was so rapid that not a drop passed through. Ducceschi noted in an interesting experiment that a valve never completely opens owing to eddies acting on the proximal surface and keeping it out in the stream. The greater the pressure of the circulating fluid the more the valves opened. The incomplete opening helps to explain Pettigrew's findings. The sinus is of use in the closure of the valves [116]. Ducceschi also examined the pressure necessary to produce insufficiency or rupture of the valves in various veins, and found in some that it required a pressure of more than three atmospheres. As Fabricius said: "*verum et illud insuper est adnotandum, quod summa cum tenuitate, summa etiam densitas adiuncta sit.*" Carrier's description of the working of the valves in the bat's wing is well worthy of perusal.

The Function of Valves.—Valves prevent reflux of blood, but they are not anti-gravity mechanisms (Hyrtl, Wintringham, Nicholson, Kampmeier and Birch, etc.). By their aggeres they help to prevent distension of the vein-wall, a function not disturbed by atrophy of the rest of the cusp (Houzé). They act against venule and capillary stasis, and retardation of the arterial stream (Gerike). In co-operation with the muscular movements they assist the return of blood from the extremities to the thorax or abdomen. They direct the blood-flow towards the heart, and prevent the blood being forced backward by intermittent muscular or mechanical pressure

(Nicholson). Hasebroek believes that when a reflux of blood occurs into a valve-sinus, it causes a contraction of the vein as a reaction to the distension, and emptying of the vein to the next valve, but this attractive theory is too little supported by his evidence. According to Kampmeier and Birch, it is not easy to say when a back-flow occurs in veins, and it has never been shown that a back-flow may occur for any considerable distance. A back-wave may not be an indication of back-flow, and Ledderhose demonstrated that back-waves are not checked by the valves [93]. It is not, however, difficult to imagine a very localized back-flow—caused, for instance, by muscular contraction—checked by valves.

The Distribution of the Valves.—Kampmeier and Birch think that the factors underlying the presence and integrity of valves must be sought for not in the circulation itself, but extrinsically. Valves are found in those vessels which are subject to pressure from without and in those in the immediate sphere of muscular performance, such as the veins of the extremities and stomach. It is significant, they say, though possibly a coincidence, that the valves of the peripheral vascular system are engendered at a time when the fœtus begins to execute movements of its skeletal musculature, whereas the extrinsic ones of the heart are established much earlier [81].

If more knowledge were available on the comparative distribution of valves in animals, one might be able to correlate it with muscular activity, or with the diet (carnivora and herbivora). The horse seems to be the best provided with valves among the animals examined.

The Venous Cistern.—In an interesting paper Keith described a venous cistern in man, formed by the superior and inferior venæ cavæ, the innominate, iliac, hepatic, and renal veins, that is to say, the valveless area of the trunk veins (fig. 20). Jugular vein tracings represent the fluctuations of the blood-pressure in this cistern, which has a capacity in man, if the veins are distended, of about 430 c.c., i.e., about eight beat-outputs of blood for the heart. The greater part of this system is in the abdominal cavity, and therefore subject to compression. The liver, if compressed, could probably add about 500 c.c. to the cistern, and the portal system also contains about 500 c.c. in moderate distension. The venous cistern in man and the higher animals has taken the functional place of the sinus venosus, and its six pairs of valves that of the venous valves of the sino-auricular junction in lower animals. Barnard found that on squeezing the abdomen it was possible to force blood through a passive right heart and lungs into the left auricle. The right auricle is less resistant than the venous cistern or the right ventricle, and hence is the most liable to distension, which is prevented from becoming too great by the pericardium. The pressure in the abdominal part of the venous cistern is always positive, and hence the inferior caval orifice is guarded neither by sphincter nor competent valve. In the thoracic part of the cistern the pressure may be negative, and hence the superior caval orifice is furnished with a muscular mechanism—the right *tænia terminalis*—which may be competent at low pressures [82]. Insufficiency of this and the jugular valve under more extreme pressures may be a safety mechanism preventing dilatation of the right auricle.

(VII) Summary.

The history of the knowledge of valves in veins is traced from the sixteenth century, when they were first described, to the present day.

Valves are of two kinds, ostial and parietal; the former are inserted into part of the circumference of a tributary vein-entry, the latter rise from the vein-wall. The number of cusps in a single valve may be from one to five, but the most frequent form, at all events in man, is the bicuspid.

Canano was probably the first to mention venous valves, and Alberti was the first to publish drawings of them. Fabricius gave the earliest detailed account of their distribution in the body, but failed to grasp their physiological significance. William Harvey saw more clearly than Fabricius, and was led by his deductions to the discovery of the circulation.

Since his time much work has been done on the distribution of valves in man, and, to a smaller extent, in the lower animals. This work, in its beginnings qualitative, has in later times become more and more quantitative, and the relation of valves to age, sex, and other variable factors has been, at all events partially, investigated. The development of the valves in fœtal life has been studied, and has produced most important findings.

With the progress in anatomical knowledge has come more certainty as to the physiology. The function of valves is to give irreversibility of direction to the blood-stream in the veins; they are not anti-gravity mechanisms, nor are they directly concerned with varicosis. In the higher animals they occur chiefly in the veins of the limbs, and are relatively deficient in the large veins of the abdomen and thorax. In co-operation with the muscular movements they effect the return of blood from the extremities to the centre of the body. Here the absence of valves makes the large veins into a venous cistern, whose capacity can be varied by contraction of the abdominal muscles and the movements of respiration. The supply of blood to the right heart can therefore be adjusted to the requirements of the organisms.

(VIII) Concluding Remarks.

In preparing the above review of the knowledge on valves, and in the pursuit of his own investigations, the writer has experienced great help from the generous assistance of others. He wishes to acknowledge here his special indebtedness to Professor J. A. Gunn and Professor Arthur Thomson at Oxford, and to Sir Arthur Keith and Dr. Charles Singer in London. His thanks are also due to Mr. R. H. Burne and Mr. Victor G. Plarr, of the Royal College of Surgeons, to Mr. Powell, of the Royal Society of Medicine, to Mr. T. Gambier Parry, of the Bodleian Library, and to Mr. Ford and his assistants at the Radcliffe Library. For facilities at the Zoological Gardens he wishes to thank Dr. Chalmers Mitchell, Dr. Vevers, Dr. Scott, and Dr. Beattie: for most of the photographs, Mr. W. Chesterman.

Permission to reproduce figures has been granted by the courtesy of Sir Arthur Keith, Professor Kampmeier, the Royal Society of Edinburgh (Pettigrew), and Julius Springer (Klotz and Hochstetter). The writer makes grateful acknowledgment of privileges so freely extended.

Every effort has been made to cover all the important literature on valves in this review, but it is possible that omissions may be found. Information as to extra references would therefore be much appreciated.

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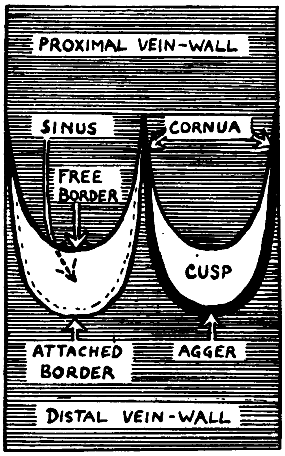

FIG. 1.

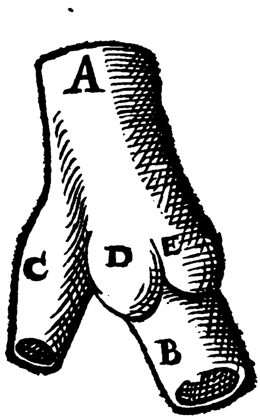

FIG. 2.

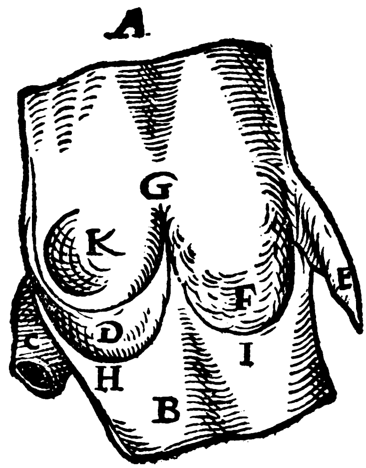

FIG. 3.

FIG. 1.—Diagram of a portion of a vein and a bicuspid parietal valve to illustrate the nomenclature of the different parts of the valve. The vein is supposed to be slit open longitudinally.

FIGS. 2 and 3.—From Salomon Alberti, *De valvulis, etc.*, 1585, showing the outside and inside of part of a leg vein, *AB*, with a muscle tributary vein ; *C*, *D* and *E* are the two cusps of a bicuspid valve in the main vein. These are the first drawings of a valve.

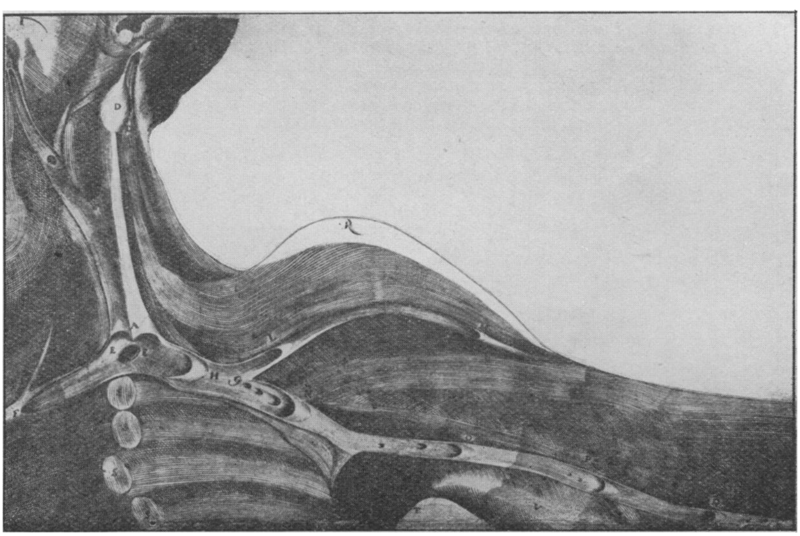

FIG. 4.

FIGS. 4 to 9.—From Fabricius, *De venarum ostiolis*, 1603.

4.—Figure of neck and left upper arm, showing valves at the entry of the internal jugular, and in the course of the axillary, cephalic, and basilic veins.

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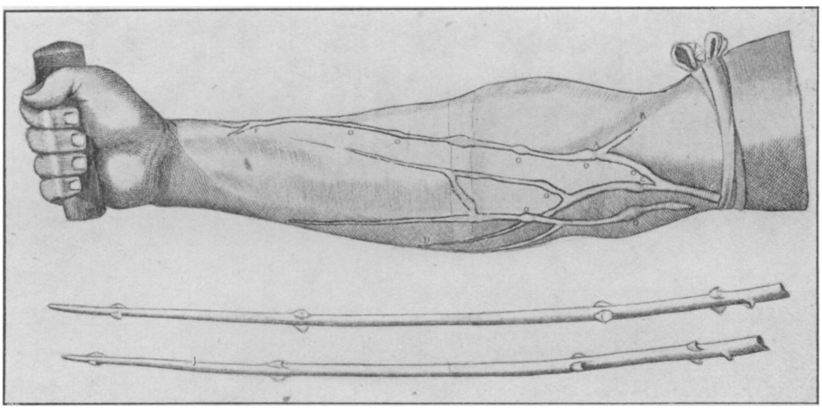


FIG. 5.

5.—Figure of a right arm, with a ligature round its upper part. The veins below the ligature are turgid, and show swellings at the site of valves. Below are two veins from the leg turned inside out to show, in each case, four bicuspid valves.

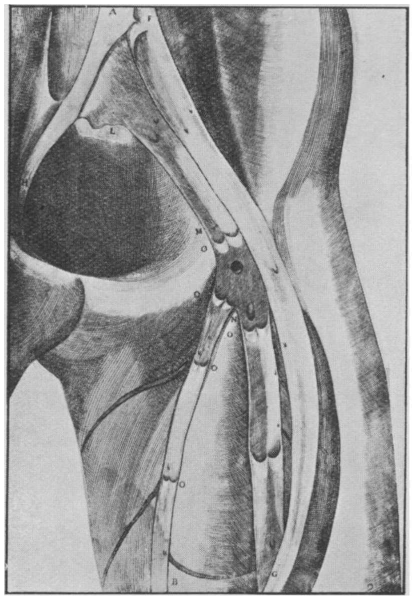
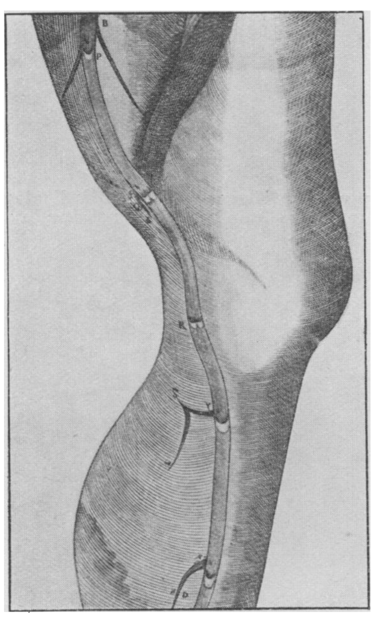


FIG. 6.



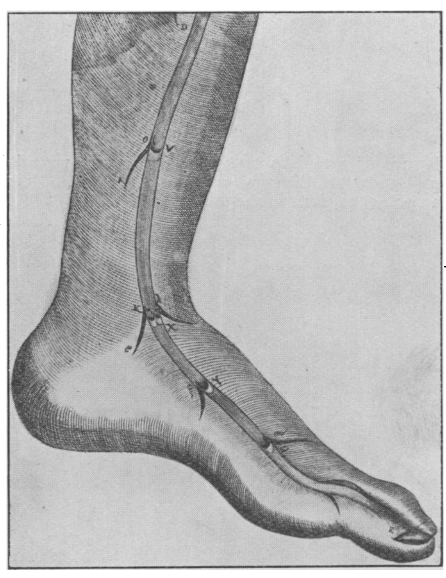


FIG. 7. FIG. 8.

6 to 8.—Upper part of the femoral vein, and the whole of the vena saphena magna, showing a number of bicuspid and unicuspid valves, especially just distal to the entries of tributaries. These figures follow one on the other to make a complete picture of the whole leg (see fig. 9).

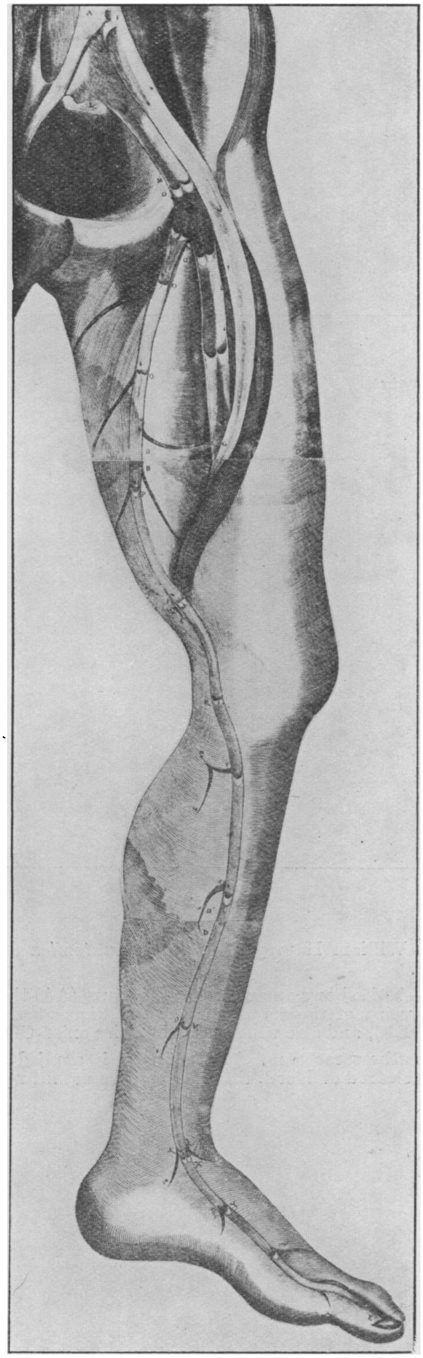


FIG. 9.

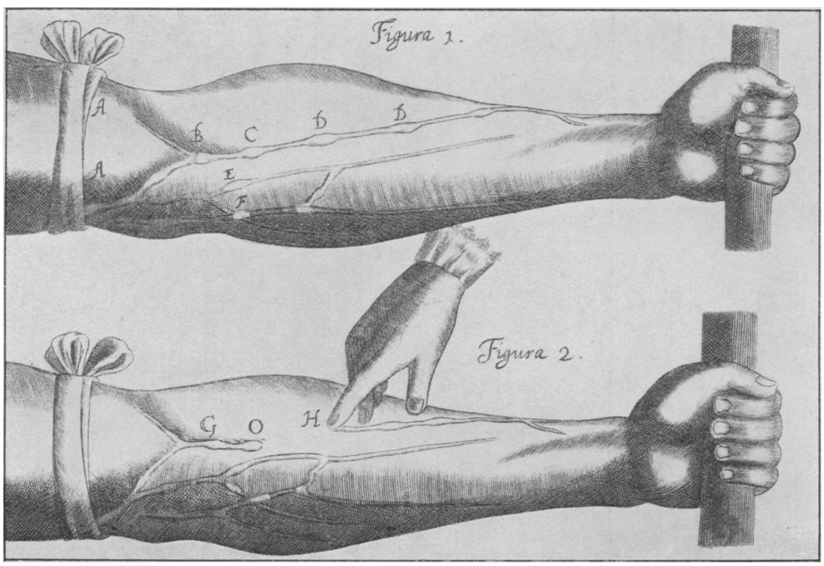


FIG. 10A.

FIGS. 10A and 10B.—From William Harvey, *Exercitatio anatomica de motu cordis et sanguinis in animalibus*, Francofurti, 1628.

FIG. 10A. *Upper Figure.*—This shows an arm with a ligature (AA) tied round its upper part, as in phlebotomy. The distended veins of the forearm show swellings at the sites of valves, both where tributaries enter larger veins (EF), and also where no tributaries exist (CD).

Lower Figure.—This shows the same arm. If the finger is applied at H, and the portion of vein between H and the valve O is cleared of blood, this portion does not fill up again with blood from above the valve.

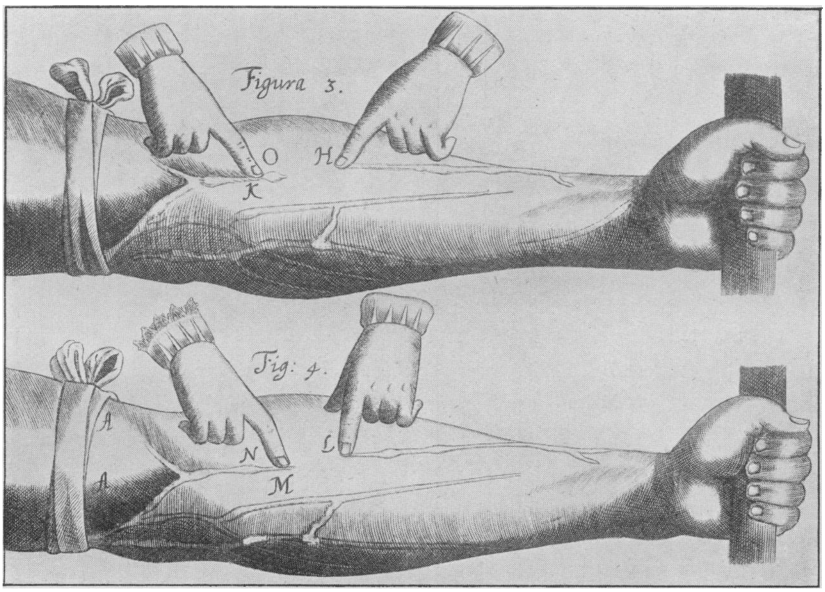


FIG. 10B.

FIG. 10B. *Upper Figure.*—The situation being as in the lower figure of fig. 10A, no amount of pressure on the distended portion of vein proximal to the valve O will make that valve incompetent and fill the portion OH.

Lower Figure.—If the vein is compressed at L and the blood stroked with the finger M towards the valve N so that the portion of vein LM is emptied of blood, then on lifting the finger at L this portion LM is filled with blood coming from the more distal portion. This procedure can be repeated a thousand times in a short space of time. It is obvious from all these facts that a large and rapid circulation exists in the veins, and that the blood in them flows in a direction from the periphery towards the heart.

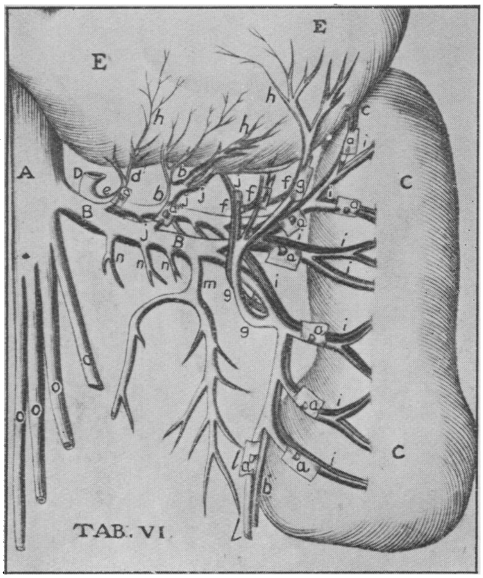


FIG. 11.

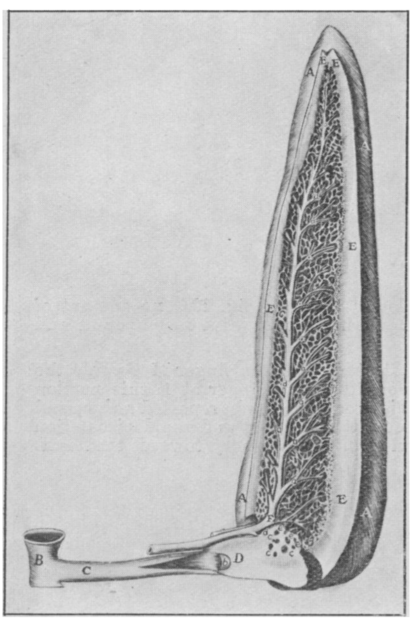


FIG. 12.

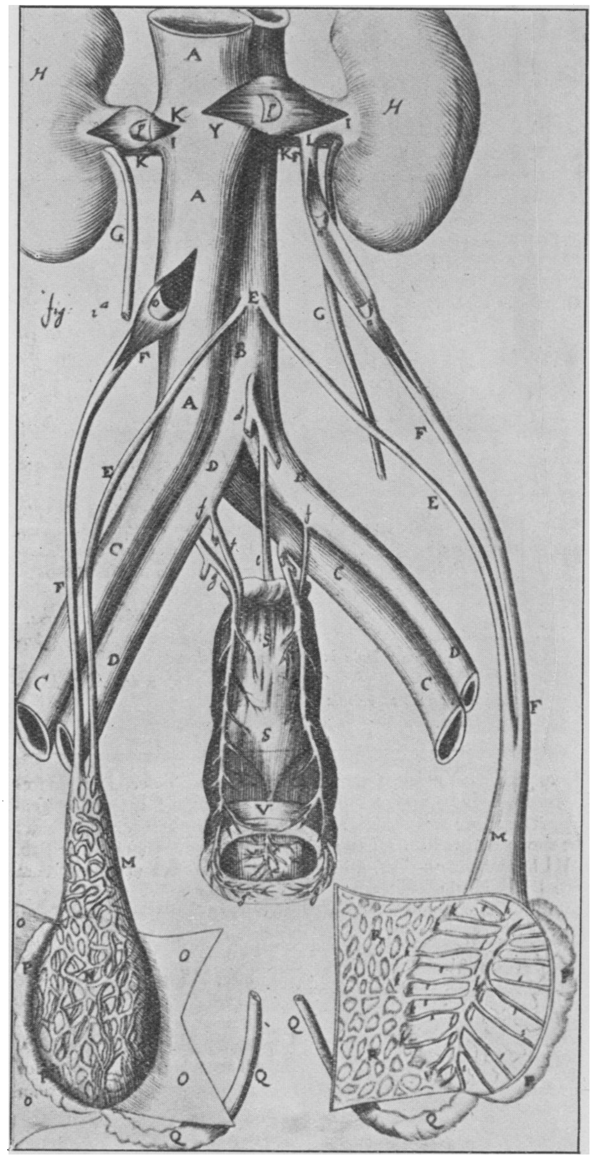


FIG. 13.

FIG. 11.—From Highmore, *Corporis humani disquisitio anatomica*, 1651, showing valves in dog's splenic vein tributaries. *A*, portal vein ; *B*, splenic vein ; *C*, spleen ; *E*, fundus of stomach.

FIG. 12.—From Highmore, *ibid.*, showing a valve (*b*) in the splenic vein of an ox. *CD*, splenic vein.

FIG. 13.—From Highmore, *ibid.*, showing valves in human right (*o*) and left (*nn*) spermatic veins, and right and left (*pp*) renal veins.

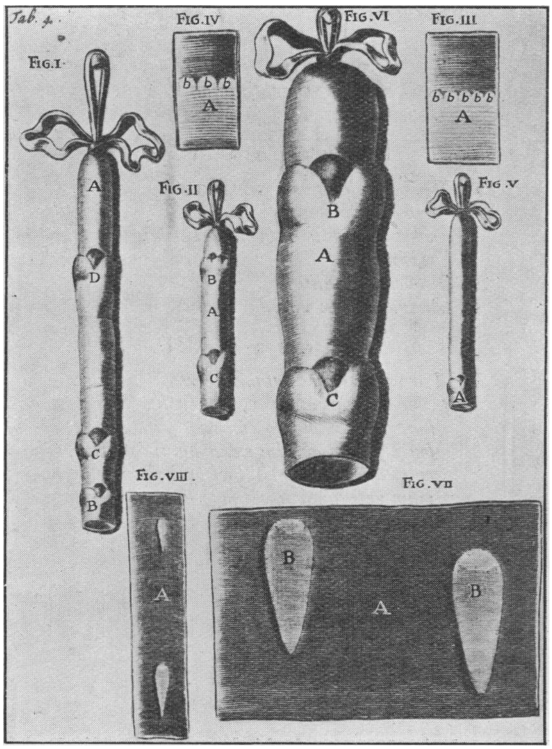


FIG. 14.

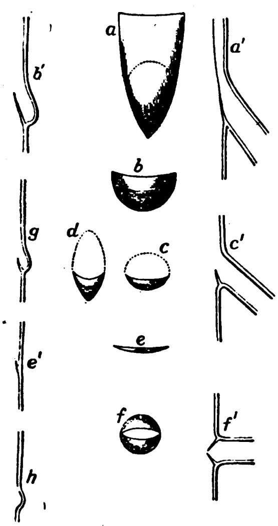


FIG. 15.

FIG. 14.—From Kerckring, *Spicilegium anatomicum*, 1670, showing:—

1.—Three tricuspid valves in human jugular vein.
2.—Quincuspid (*B*) and tricuspid (*C*) valves in dog's jugular vein.
3.—Same vein as in fig. 2 slit open to show detail of quincuspid valve.
4.—Human jugular vein slit open to show tricuspid valve.
5.—Tricuspid valve in boy's jugular vein.
6.—Two tricuspid valves in jugular vein of ox.
7.—Pyriform ostial valves at entries of tributary veins into vena cava of horse.
8.—Similar valves from human vena cava.

FIG. 15.—From Salter, in Todd's *Cyclopædia of anatomy and physiology*, 1849-1852. Diagram exhibiting different forms of valves: *a*, valve placed at the orifice of the renal vein in the sheep, seen in face; *a*¹, the same in ideal section; *b*, the ordinary semilunar valve from the tube of a vein; *b*¹, the same in section; *c*, imperfect valve at orifice of intercostal vein; *c*1, section of imperfect valve at orifice of hepatic vein; *d*, the same in face (the dotted lines in *a*, *c* and *d* correspond to the orifices of the respective veins); *e*, very imperfect valve; *e*1, the same in section; *f*, plan of double valve at orifice of vein; *f*', the same in section; *g*, ideal section of small valve and sinus; *h*, section of sinus without a valve.

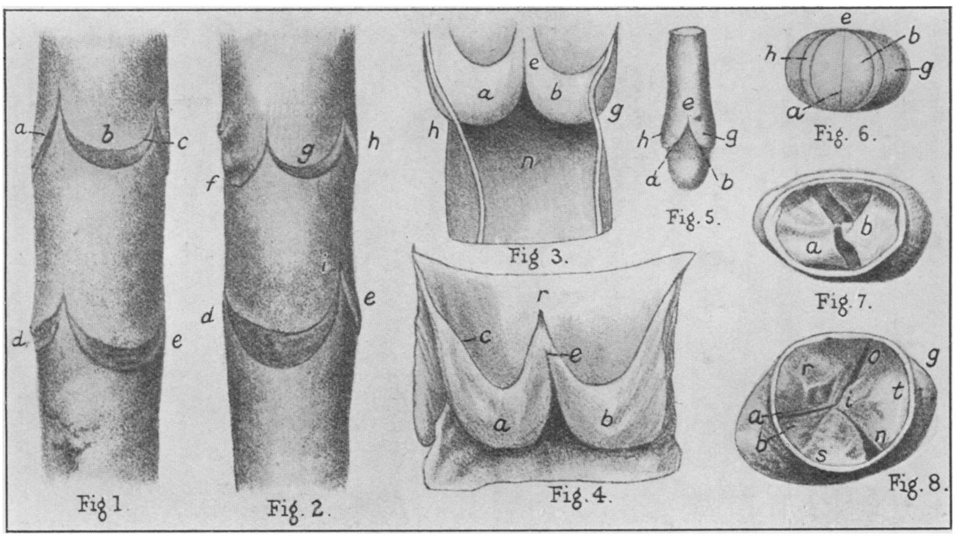


FIG. 16A (1-8).

FIG. 16.—From Pettigrew, *Trans. Roy. Soc. Edin.*, 1863-1864 (by kind permission of the Royal Society of Edinburgh).

1 and 2.—External jugular veins of horse inverted. Shows valves, consisting of two (*de*), three (*abc*), and four (*fgh*) cusps.

3.—Section of external jugular vein of horse. Shows valve, consisting of two cusps *ab*), with dilatations (*g*), corresponding to the sinuses of Valsalva in the arteries.

4.—External jugular vein of horse opened. To show the relations of the cusps (*ab*) above (*re*).

5.—Portion of femoral vein distended with plaster of Paris. Shows dilatations (*hg*) in the course of the vessel corresponding to the position of the valve.

6.—Shows venous valve, consisting of two cusps (*ab*), in action.

7.—The same, not in action.

8.—Venous valve from external jugular of horse, consisting of three cusps.

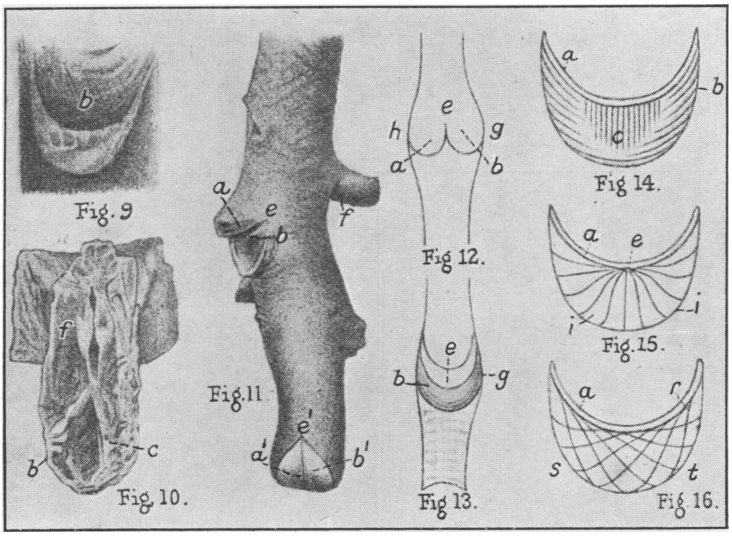


FIG. 16B (9-16).

9.—Venous valve, consisting of one cusp, situated at the entrance of a smaller into a larger vein.

10.—Venous sinus from auricle of heart of sturgeon.

11.—Femoral vein distended with plaster of Paris. Shows venous valves in action, where a smaller vessel enters the larger one (*ab*), and in the main trunk (a^1b^1).

12.—Vertical section of vein distended with plaster of Paris. Shows the nature of the union between the cusps (*e*).

13.—The same, the section being carried between (*e*) instead of across or through the cusps.

14, 15, and 16 show the structure of the venous valves below the endothelium.

14.—Shows delicate fibres, chiefly yellow elastic, running along the free margin (*a*), and also (*b*) on the body of the cusp, especially where the cusps join one another—"*horizontal fibres*"; (*c*) are equally delicate fibres, confined chiefly to the body of the segment—"*vertical series*"; (*a*) (*b*) and (*c*) are superficial.

15.—Radiating from the centre of the cusp (*e*) to the attached border (ii^1), and seen through the more delicate horizontal and vertical fibres are white fibrous and yellow elastic tissue fibres, the former predominating.

16.—Showing still stronger and deeper fibres (*st*), the "*oblique series*," continuous often with similar fibres in the middle coat of the vein, running from the attached border of the cusp. They cross each other with great regularity, and form the principal portion of the cusps. They are most marked at the margin of the free border, where they form a fibrous zone or ring, supporting the cusp and carrying it away from the sides of the vein into the lumen.

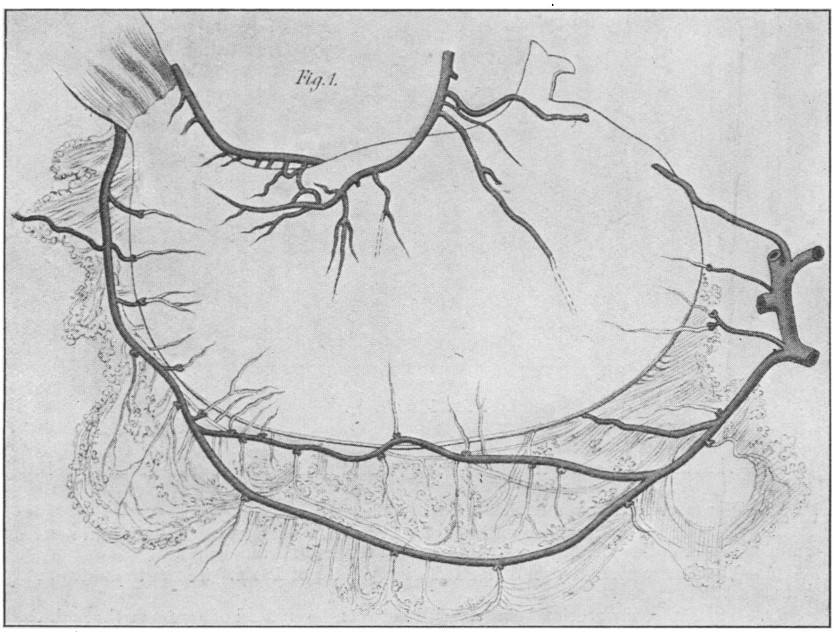


FIG. 17.—From Hochstetter, *Arch. f. Anat.*, 1887 (by kind permission of Julius Springer), showing the valves in the stomach veins of a child a few weeks old.

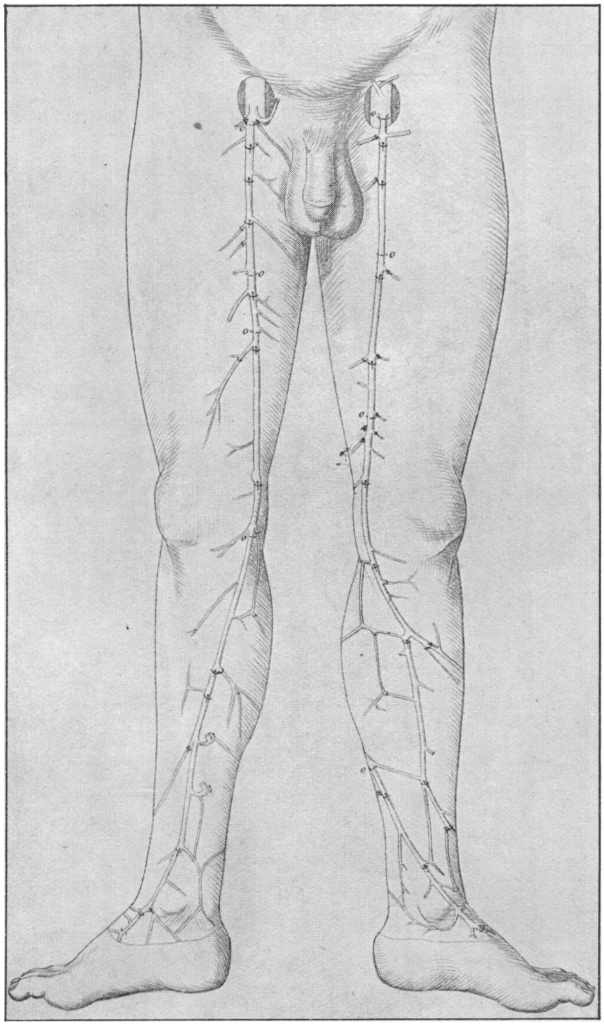


FIG. 18.

FIG. 18.—Showing valves in superficial leg veins of a muscular adult.

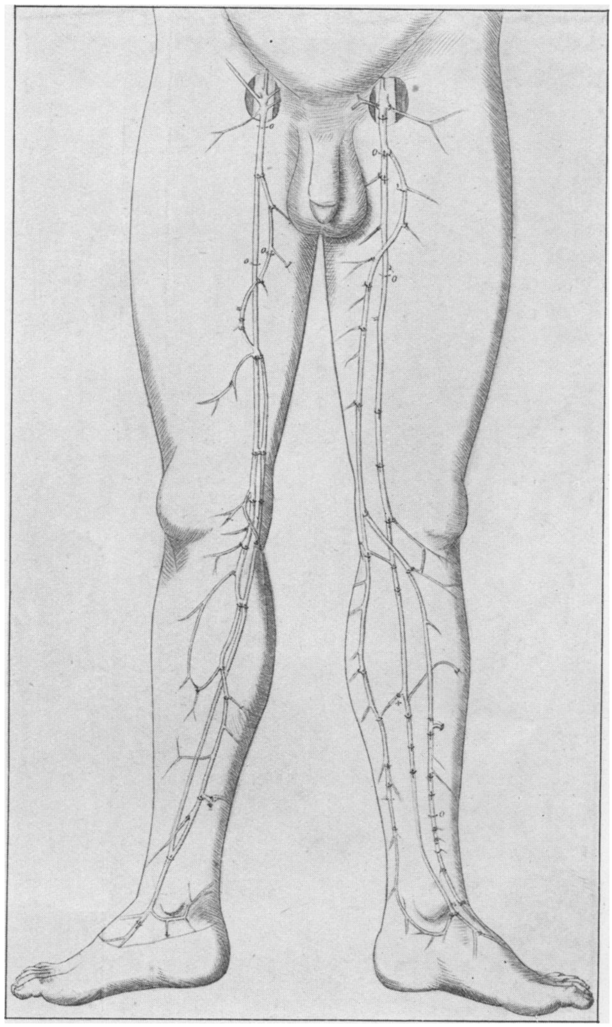


FIG. 19.

FIG. 18.—Valves in superficial leg veins in a 25-year old man. functioning valve, atrophied valve.

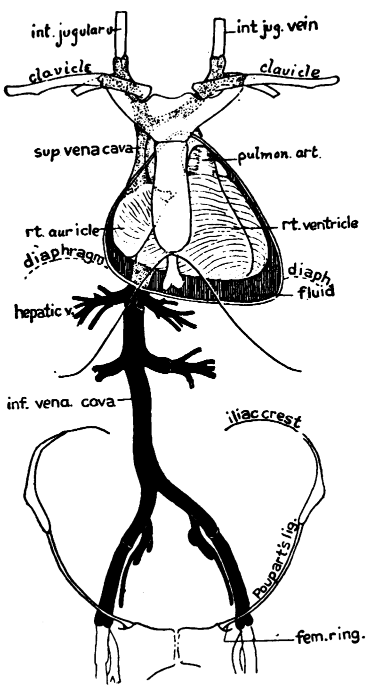


FIG. 20.

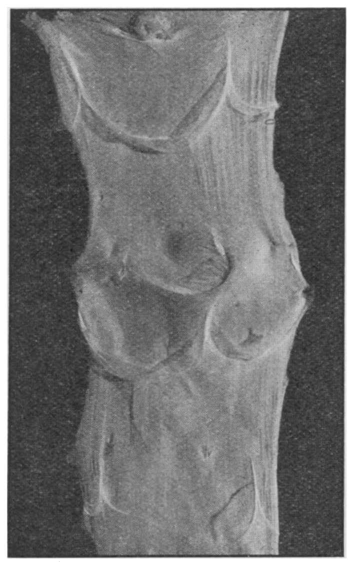


FIG. 21.

FIG. 20.—From Keith, *Journ. Anat.*, 1907 (by kind permission of Sir Arthur Keith), being a diagram of the venous cistern from which the heart is filled, as seen in a man aged 55, in whom the pericardium was distended and the heart compressed by a large effusion of fluid. The abdominal or infra-diaphragmatic part of the cistern is indicated in black; the thoracic or supra-diaphragmatic is stippled. The heart is compressed upwards and backwards against its attachments.

FIG. 21.—Franklin, as in *Journ. Anat.*, 1926, showing two parietal valves, an atrophied parietal valve, and an ostial valve, in a large mesenteric vein of a sheep.

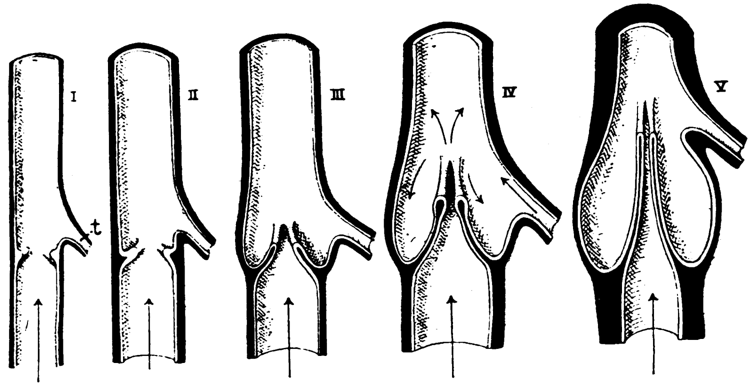


FIG. 22

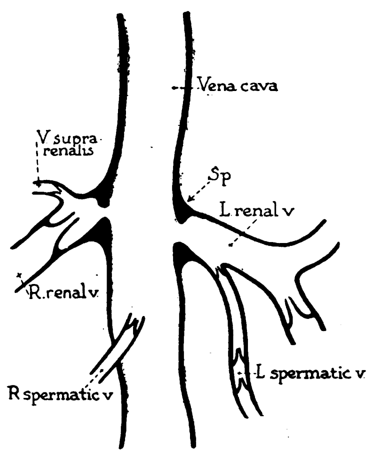


FIG. 23.

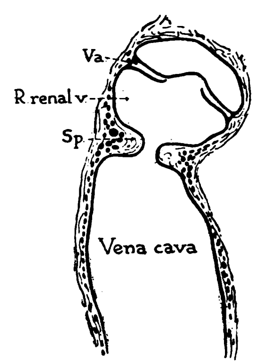


FIG. 23.

FIGS. 22 to 24.—From Kampmeier and Birch, *Amer. Journ. Anat.*, 1927 (by kind permission of Professor Kampmeier).

22.—Schematic representation of the development of a bicuspid venous valve. Stages I to IV, from the 3·5 to 5th month of intra-uterine life. Stage V, at term. Endothelial layer, white; mesenchymal layer, black; *t*, tributary.

23.—Diagram, based on graphic reconstruction, of postcava, renal and spermatic veins of a new-born female, showing the locations of the sphincters (?), *sp.*, and the true valves.

Outline drawing of the termination of the right renal vein in the postcava of the same specimen showing the sphincter at the junction.

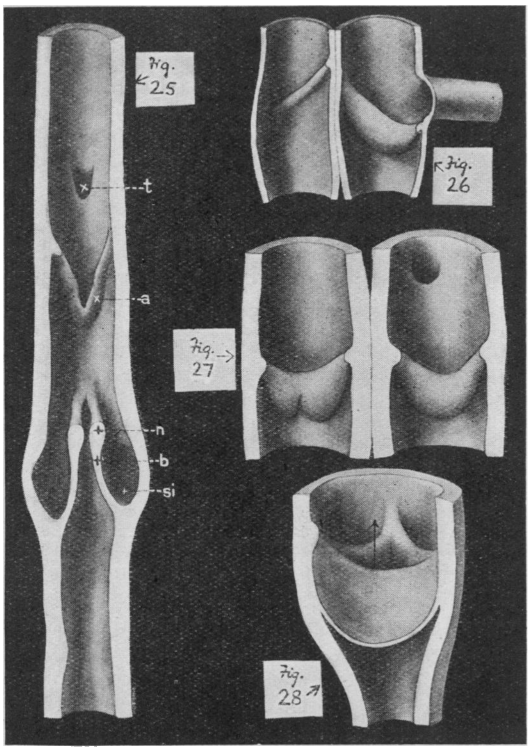


FIG. 24.

25.—Reconstruction of a segment of the vena saphena magna of a 186 mm. (5·5 months) fœtus × 100, showing a perfect bicuspid valve, *b*; immediately followed by a vestigial one, *a*; *t*, tributary; *si*, sinus; *n*, nodular thickening of cusps.
26.—The same of the vena saphena parva of a 105 mm. (3·8 months) fœtus, × 200, showing the inequality of the two cusps, one being in stage I of development, the other in stage III.
27.—The same of the vena saphena parva of the 5·5 months fœtus, × 100, showing the derivation of a tricuspid valve from an original bicuspid anlage.
28.—The same of the saphena magna of a 130 mm. (4·3 months) fœtus, × 133, showing a well-formed tricuspid valve.
N.B.—The total width of this plate in the original reproduction is 13·4 cm.; the magnification in the present figure must be calculated from this.