Venous Anatomy of the Orbit

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Purpose. To define the normal and variant venous anatomy in the human orbit.

Methods. Orbital dissections , focusing on the venous system, were performed on 17 formalin-preserved human cadavers (34 orbits) and two fresh orbits. Dissections were carefully documented photographically. Results were compared with those in previous reports on the venous anatomy of the orbit.

Results. The superior ophthalmic vein (SOV) is the most consistent vein within the superior orbit. The inferior ophthalmic vein (IOV) demonstrated more variation, but important variations were noted in both. Smaller veins demonstrated the largest variability. Several formerly published observations on the venous anatomy of the orbit could not be confirmed in this study. A previously unreported variation in the SOV was found in 9 of 36 orbits, with the SOV having a duplicated segment, which is likely to be a variant medial ophthalmic vein.

Conclusions. The venous anatomy of the orbit demonstrates considerable variability. Some of these variations may have implications in surgical management and natural history of ophthalmic conditions, such as carotid-cavernous sinus fistula (CCSF). (*Invest Ophthalmol Vis Sci.* 2003;44:988–995) DOI: 10.1167/iovs.02-0865

Anatomic study of the orbital venous system appears to be warranted because of its recently emerging importance in the surgical management of the carotid–cavernous sinus fistula (CCSF). Unlike the arterial system in the orbit, orbital veins are less well defined and vary considerably among individuals.[1] Orbital veins also do not generally follow a course parallel to the arteries, as do veins in other parts of body.

Studies of the anatomic organization of the orbital veins date back over a century. Most investigators have relied solely on schematic diagrams without providing photographic documentation. In addition, there has been some disagreement among the findings in the studies, presumably because of the variability in the venous system. In this study, we sought to document carefully the venous system in a significant number of dissected orbits, to define the normal and variant anatomy more clearly. Dissections were also photographed.

Materials and Methods

Eighteen adult cadavers (nine male; nine female) of donors aged from 70 to 102 years, were provided by the Department of Anatomy and Cell Biology from the Faculty of Medicine at the University of Melbourne. In all except one, a superior approach was used to dissect the orbits.

Orbital Dissections in Formalin-Preserved Cadavers

The skull was sectioned and the scalp and brain were removed (see Fig. 2, top for detail). The orbital dissection began with removal of the orbital roof. The periorbita was incised and reflected, exposing the retrobulbar fat. The superior root of the SOV in the anteromedial orbit was identified first, and, from there, the entire orbital venous network was traced. The orbital veins were noted to be compacted densely within the connective and adipose tissues, and therefore careful removal of fat and connective tissue without tearing the veins was crucial. The frontal nerve, supraorbital artery, levator palpebrae superioris, and superior rectus muscles were cut anteriorly and reflected posteriorly to allow deeper dissection. This was also necessary for maximizing the view of the entire superior orbital venous network and its collateral communications with the inferior orbital venous system.

Orbital Dissections in Fresh Cadavers

The exploration of the inferior venous system of the orbits in the 17 formalin-preserved cadavers dissected from above was limited by the small size of these veins and their positions deep within the confined space of the inferior orbit (see Fig.1 for detail). Consequently, an anterior approach was used to dissect the last two orbits from a cadaver immediately after death. A circular incision was made on the facial skin along the orbital borders. Cautious dissection was performed to separate any bony attachments from all orbital contents. Another incision was then made proximal to the annulus of Zinn (common tendinous ring) to sever all structures passing through the optic canal and the superior and inferior orbital fissures. All the intraorbital contents were removed from the orbit. Minute dissection, for both superior and inferior orbital venous systems, was immediately performed on the orbits.

The detail of the arrangement and variability of the orbital veins as well as their relationship with the surrounding structures were documented in various formats: digital photographs, schematic diagrams, and written descriptions.

Results

The normal anatomy of the principal veins and tributaries will be described in turn. Next, the common variations of the orbital veins are discussed.

The veins of the human orbit are organized into two systems: the superior and inferior orbital venous systems. The two systems communicate with each other abundantly through collateral veins.

Superior Orbital Venous System

Superior Ophthalmic Vein. The orbital contents are drained by many orbital veins, of which the largest in diameter is the superior ophthalmic vein (SOV). In the retrobulbar fat, the SOV is embedded in and supported by highly organized connective tissue that forms septal layers. It originates as two roots at the superomedial orbital rim (Figs. 1, 2, top). The superior root is the orbital continuation of the supraorbital vein, whereas the inferior root is the terminal part of the angular vein from the facial venous system. On entry into the

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This study was performed as part of the Advanced Medical Science component of the Bachelor of Medicine and Surgery degree of the University of Melbourne, Australia.

Submitted for publication August 24, 2002; accepted October 8, 2002.

Disclosure: **N. Cheung**, None; **A.A. McNab**, None

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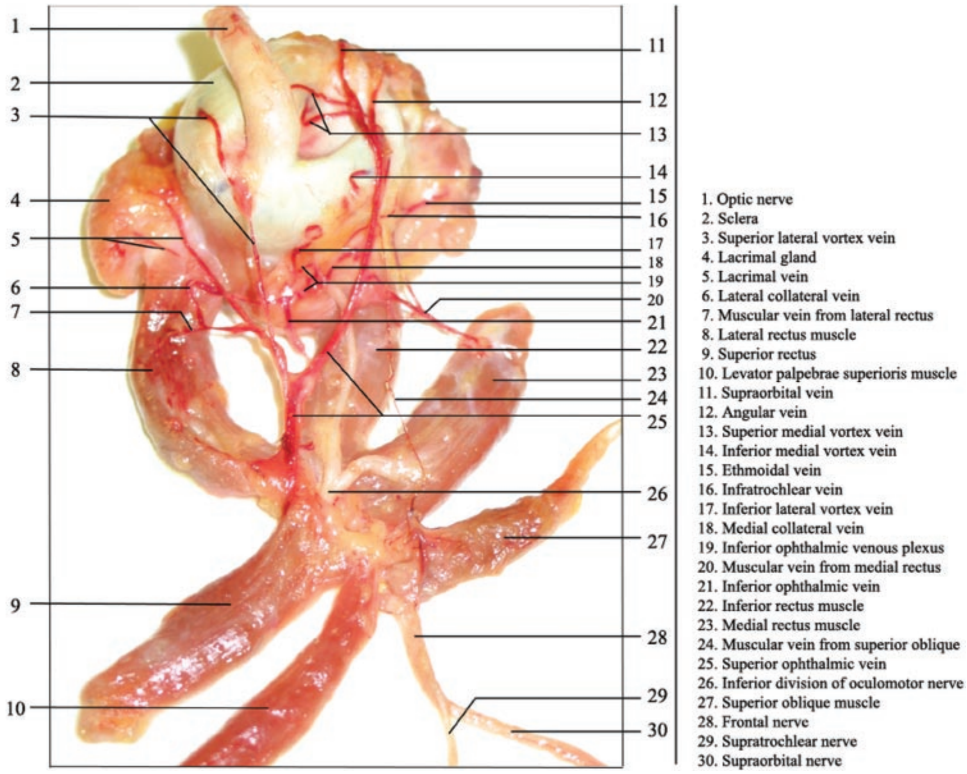


FIGURE 1. A superior view of the left orbit. To maximize the view of both superior and inferior orbital venous systems, the following modifications were made on the specimen: The superior rectus, levator palpebrae superioris, superior oblique muscles, and frontal nerve are reflected posteriorly; the medial rectus muscle is reflected medially; and the optic nerve is reflected anteriorly.

orbit, the supraorbital vein runs superiorly, and the angular vein travels inferiorly in relation to the trochlea (Fig. 3). They join to form the SOV just posterior to the trochlea and medial to the tendinous insertion of the superior rectus muscle. A communicating branch superior to the trochlea is occasionally found, linking the two roots before their union. The SOV can be divided into three parts (Fig. 2, bottom). The first arises from the union of the two roots in the anterior orbit. It then travels a short distance laterally to reach the anterior part of the medial border of the superior rectus muscle (Fig. 2, top). From there, it changes direction to extend posteriorly alongside the medial border of the superior rectus muscle. The second part, which is usually the largest in caliber, begins as the SOV travels under the superior rectus muscle in the midorbital region. Above the optic nerve, ciliary (long and short) nerves, and posterior ciliary arteries, it proceeds in a posteriorly extending diagonal course, crossing from medial to lateral to reach the lateral border of the superior rectus muscle. This is where the third part of the SOV starts. It continues to extend posteriorly along the lateral edge of the superior rectus muscle, passing through the annulus of Zinn. Through the superior orbital fissure, it eventually drains into the cavernous sinus.

Lacrimal Vein. The lacrimal gland, located in the anterolateral orbit, is drained by the lacrimal vein (Fig. 1). It arises from the gland as one, sometimes two, afferent branches that join to form the lacrimal vein. It runs along the superior border of the lateral rectus muscle in intimate contact with the lacrimal nerve and artery (Fig. 4). As it extends to the posterior orbit, it approaches the lateral border of the superior rectus muscle. At the transition of the second and third parts of the SOV, the lacrimal vein joins the SOV. However, before its union with the SOV, it receives various branches, commonly the lateral collateral and superior lateral vortex veins (Fig. 5).

Vortex or Vorticose Veins. A different set of veins, the vortex veins, drain the uvea. There are four vortex veins, but only two of them, the superior medial and the lateral, are located in the superior orbital venous system (Figs. 1, 2, bottom). They emerge from the episcleral space between the sclera and the fascial sheath of the eyeball (Tenon's capsule). The superior medial vortex vein has a short course and drains invariably into the first part of the SOV. The superior lateral vortex vein proceeds in a longer route. After its emergence from the episcleral space superolateral to the origin of the optic nerve, it runs posteriorly for some distance to drain into either the lacrimal vein (Fig. 1) or sometimes the second part of the SOV (Fig. 2, bottom). Furthermore, the vortex veins have a unique characteristic among orbital veins—a comparatively tortuous course, especially the inferior medial and lateral vortex veins.

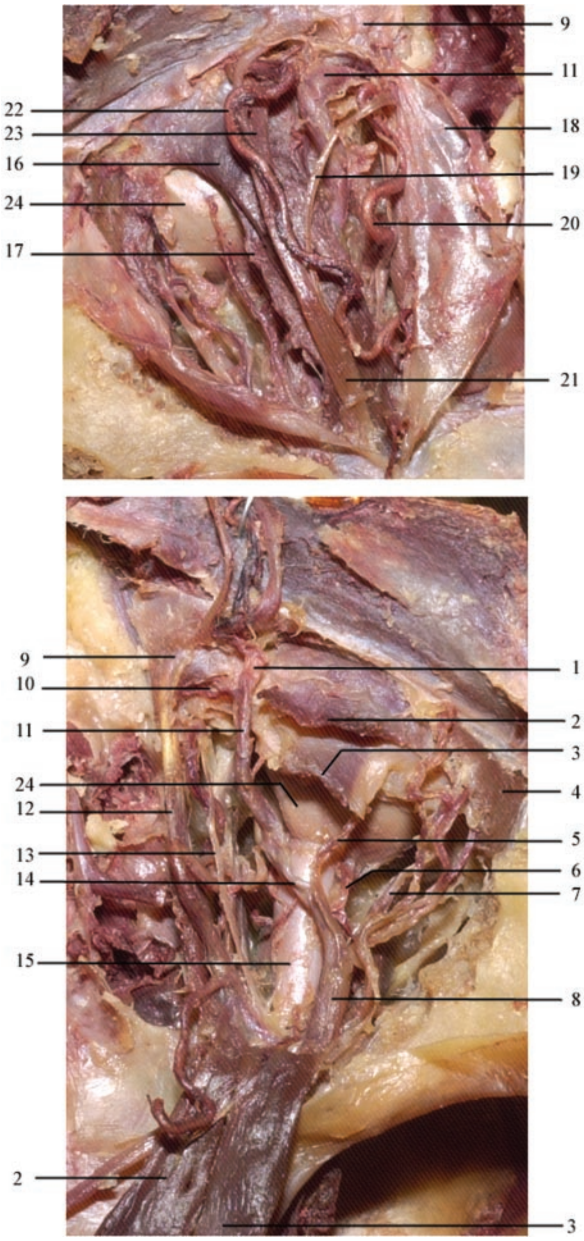
Collateral Veins. The superior venous system communicates with the inferior venous system through collateral veins (Fig. 5). The medial collateral vein invariably connects the SOV, whereas the lateral collateral vein bridges the lacrimal vein (occasionally the SOV) to the inferior venous plexus (Fig. 1).

Other Veins. There are other veins in the superior orbital venous system. Abundant muscular branches from the extraocular muscles were observed. Moreover, the medial ophthalmic vein was evident in six of the dissected orbits. These are discussed in more detail in the Variation section. The functionally important central retinal vein was convincingly found in only two orbits. It has a very short course and directly drains into the cavernous sinus. Finally, an ethmoidal vein was also observed, arising from the nasal cavity. Commonly, it drains directly into the SOV. However, in the presence of a medial ophthalmic vein, the ethmoidal vein frequently joins it, draining indirectly into the SOV (Fig. 4).

Inferior Orbital Venous System

The IOVs are relatively difficult to dissect. Of the 36 orbital dissections, only 10 showed sufficient detail to document. Based on the collective data from these dissections, the general organization of the inferior orbital venous system is described.

In the midorbit, slightly superior to the inferior rectus muscle, there is an inferior ophthalmic venous plexus formed



1. Supraorbital vein
2. Levator palpebrae superioris muscle (cut/reflected)
3. Superior rectus muscle (cut/reflected)
4. Lacrimal gland
5. Superior medial vortex vein
6. Superior lateral vortex vein
7. Lacrimal vein
8. Superior ophthalmic vein (3rd part)
9. Trochlea
10. Angular vein
11. Superior ophthalmic vein (1st part)
12. Superior oblique muscle
13. Infratrochlear nerve
14. Superior ophthalmic vein (2nd part)
15. Optic nerve
16. Levator palpebrae superioris muscle
17. Superior rectus muscle
18. Periorbita
19. Supratrochlear nerve
20. Ophthalmic artery
21. Frontal nerve
22. Supraorbital artery
23. Supraorbital nerve
24. Sclera

FIGURE 2. *Top*: superior view of a superficial dissection of a left orbit. *Bottom*: superior view of a deep dissection of a right orbit.

by veins with abundant interconnections (Fig. 1). These interconnected veins are extremely small in diameter and short in length. At the anterior end of the venous plexus, it receives contributing veins from the sclera, namely the inferior medial and lateral vortex veins. Muscular branches from the inferior rectus, inferior oblique, and, variably, the medial rectus muscles also join the plexus. From the posterior end of the venous plexus, the IOV arises. Proximal to its origin, several communicating branches, the medial and lateral collateral veins from the superior orbital venous system, drain into it. These are the main communications between the two orbital venous systems. Directly inferior to the optic nerve, the IOV continues to run backward superior to the inferior rectus muscle. As it extends into the posterior orbit, it shifts to the lateral border of the inferior rectus muscle. In the length of its course, communicating veins bridging the IOV with the pterygoid plexus and the orbital floor are noticed in only two orbital dissections. Before it enters the annulus of Zinn, it curves upward, usually lateral to the optic nerve (Fig. 6), to join the SOV.

Variations

The orbital venous system is highly variable compared with the venous systems elsewhere in the body. However, in the superior orbital venous system, the SOV has a remarkably constant course with only a few variations. First, like other orbital veins, the diameter of the SOV varies considerably, ranging from 2 mm (Figs. 1, 2, bottom) to 1 cm (Fig. 3). Moreover, the roots of the SOV are also subject to considerable variation. A single origin of the SOV was found in four orbits (Fig. 7). The supraorbital vein shown in these four orbital dissections joined the angular vein anterior to the trochlea, establishing a single inferior origin for the SOV. Furthermore, an uncommon communicating branch was observed in one orbit, connecting the angular vein with the first part of the SOV. This vein was suspected to be a variant medial ophthalmic vein. Apart from this orbit, the medial ophthalmic vein was evident in eight other orbital dissections. It has a highly inconsistent origin, arising from either the first (Fig. 8) or second (Fig. 9) part of the SOV. With a moderately short course, it always runs medial to

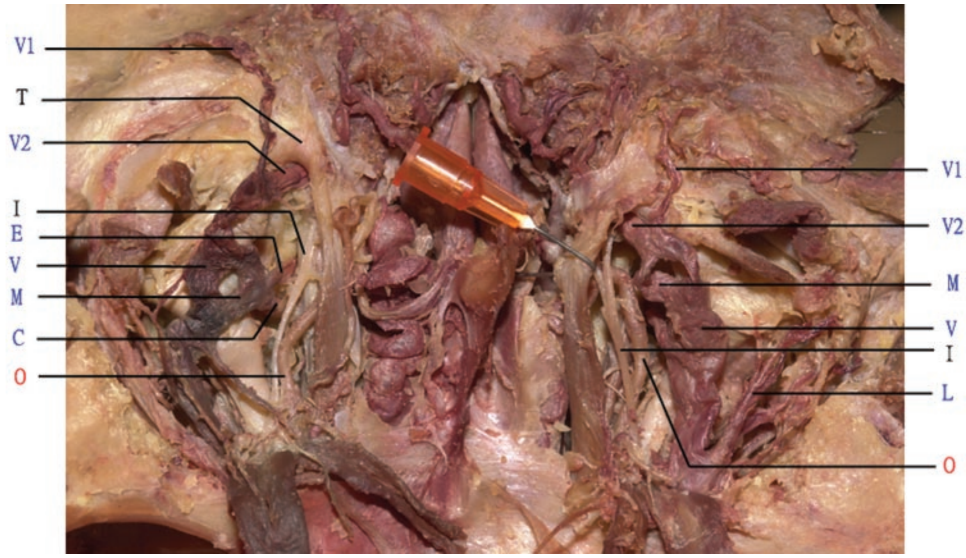


FIGURE 3. Superior view of both orbits, showing bilateral medial ophthalmic veins (M) forming a circular venous loop interconnecting various contributing veins: superior ophthalmic vein (V), ethmoidal vein (E), and medial collateral vein (C). I, infratrochlear nerve; L, lacrimal vein; O, ophthalmic artery; T, trochlea; V1, supraorbital vein; V2, angular vein.

the SOV. Depending on its origin, it rejoins either the second or third part of the SOV. The medial ophthalmic vein also appears to form a circular venous loop, linking the medial collateral and ethmoidal vein and sometimes the muscular vein from the medial rectus muscle to the SOV (Fig. 4). The medial ophthalmic vein is usually found unilaterally (Fig. 4) but sometimes in both orbits (Fig. 3).

Similar to the SOV, the lacrimal vein has a reasonably consistent course. Nonetheless, the afferent branches that drain into it are variable. In six orbits, the lacrimal vein does not receive any drainage from branches other than its own origin (Figs. 2, bottom, and 4), but in others, it communicates with the lateral collateral and superior lateral vortex vein (Fig. 1). Occasionally, it communicates with the second part of the SOV through a collateral branch.

The muscular veins are the most variable veins in the superior orbital venous system. Their origins and courses are often diversely organized. Nevertheless, the veins from the superior rectus and superior oblique muscles consistently join the SOV, whereas the ones from the medial and lateral rectus muscles may drain into either the SOV, IOV, or lacrimal vein.

Regardless of these variations, the superior orbital venous system presents a reasonably consistent arrangement that allowed us to depict an accurate account of its general topography. Conversely, the inferior orbital venous system has an even more diverse organization. First, the size of the inferior ophthalmic venous plexus, where the IOV arises, varies considerably. In 3 of the 10 orbital dissections, the venous plexus extended very close to the posterior end of the muscle cone, just inferior to the posterior third of the optic nerve. This gives rise to an extremely short IOV. Despite the length, it also drains into the cavernous sinus through different routes. An indirect route was observed in most dissections (Fig. 1). The IOV curved upward laterally (Fig. 6), or, infrequently, medially to the optic nerve to join the third part of the SOV. However, two

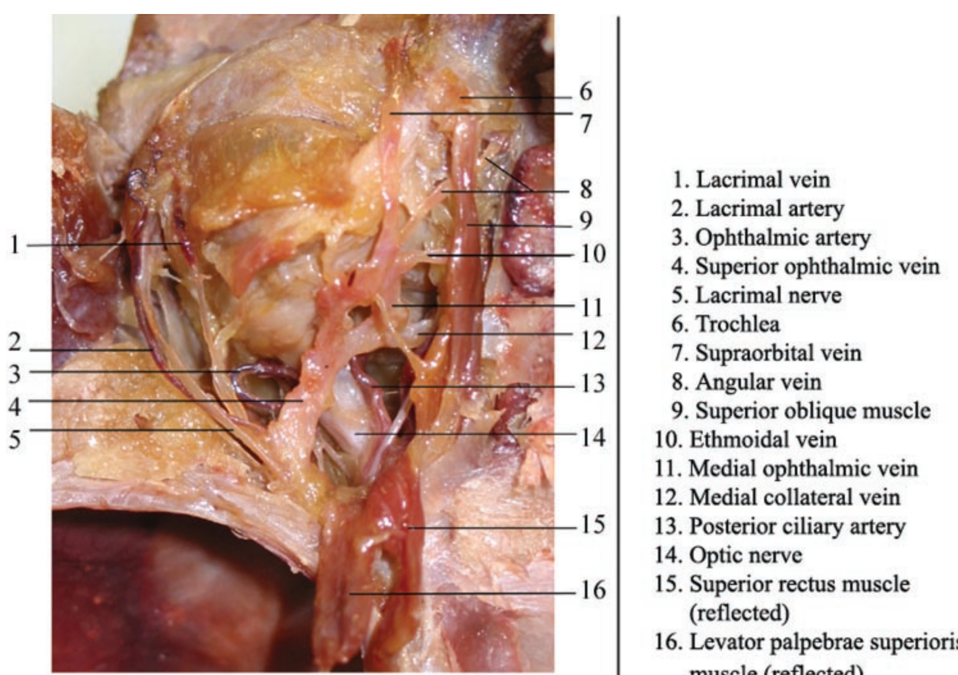


FIGURE 4. A superior view of the left orbit, showing various veins draining into the superior ophthalmic vein indirectly through the medial ophthalmic vein.

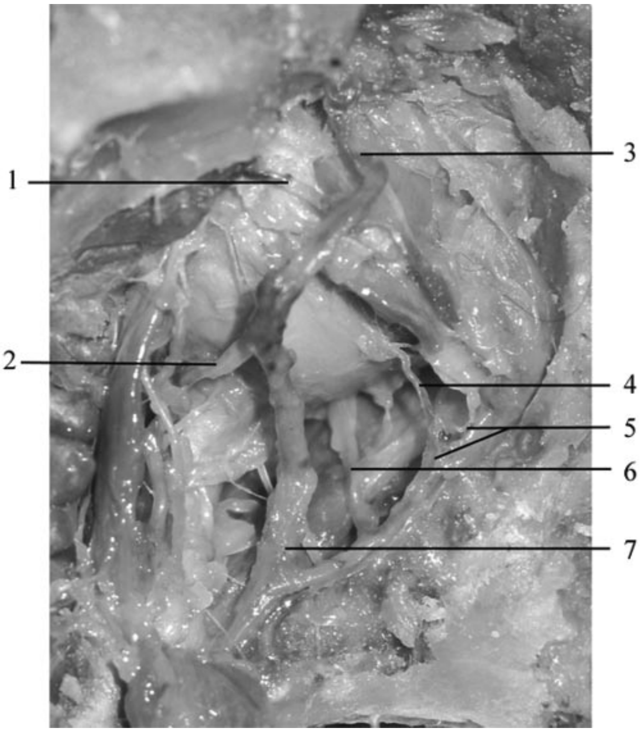


Figure 5. A superomedial view of the right orbit, showing the collateral veins. (1) Angular vein; (2) medial collateral vein; (3) supraorbital vein; (4) superior lateral vortex vein; (5) lacrimal vein; (6) lateral collateral vein; (7) superior ophthalmic vein.

orbital dissections demonstrated a direct drainage to the cavernous sinus, where it bypassed the SOV.

Discussion

The systematic study of the orbital veins began in the 18th century.[2] Almost up to the present, anatomic records show two different views of the organization of the orbital venous system. One of these is that the SOV corresponds fairly accurately to the ophthalmic artery in its course and branching pattern.[3] This view is challenged, however, by a second, com-

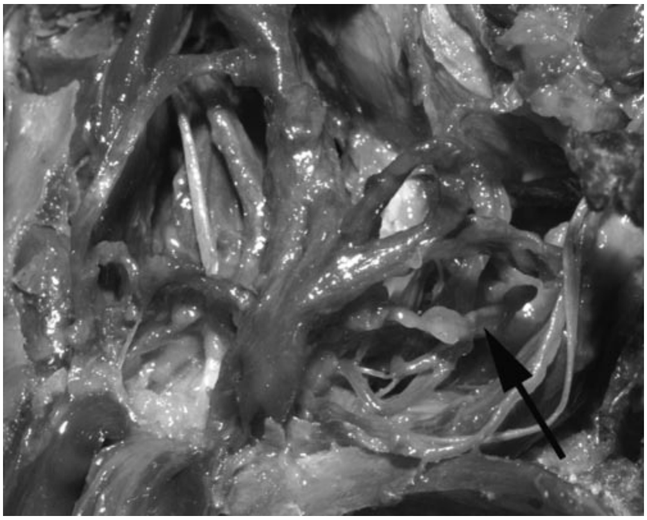


Figure 6. A superolateral view of the right orbit, showing the IOV (*arrow*) joining the SOV in the posterior orbit.

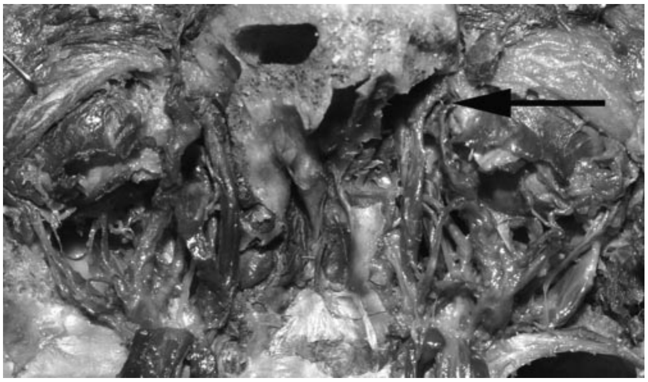


Figure 7. A superior view of both orbits, showing the unilateral single origin of the SOV (*arrow*) in the right orbit.

pletely opposing view that is supported by most investigators and appears today to be generally accepted. Among these are early anatomists, including Soemmering[4] and later investigators,[5–11] who stated that in contrast to veins elsewhere in the body, orbital veins do not accompany the arterial system. In regard to the degree of variability of the orbital venous system, most investigators agree. The SOV presents an especially constant course amid a number of variations.[12] In particular, the muscular branches appear to be far less constant than the principal veins,[13] and of the principal veins, the SOV is more constant than the IOV.[14]

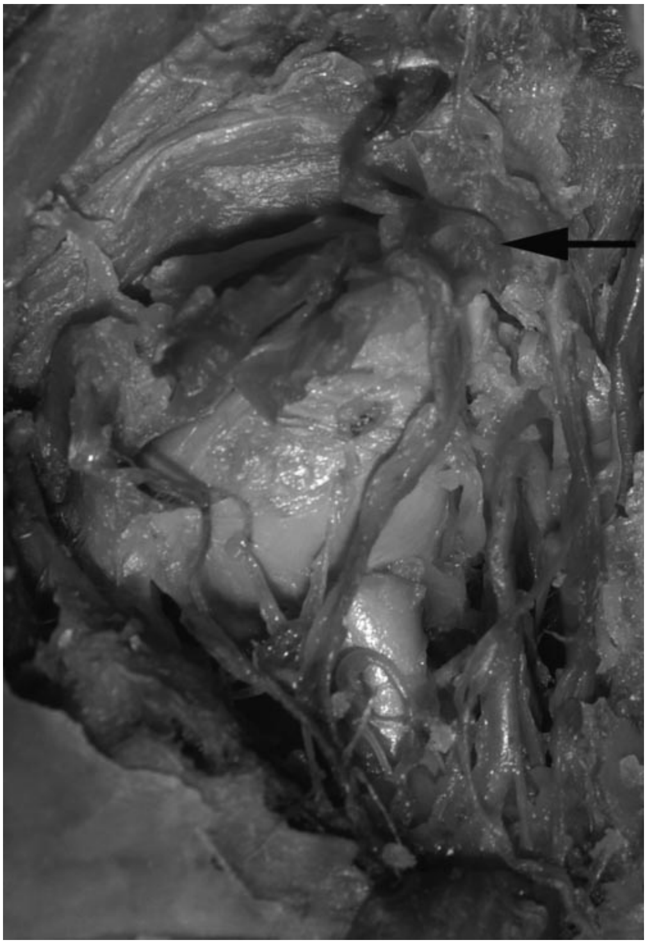


Figure 8. A superior view of the left orbit, showing the medial ophthalmic vein (*arrow*) originating from the first part of the SOV.

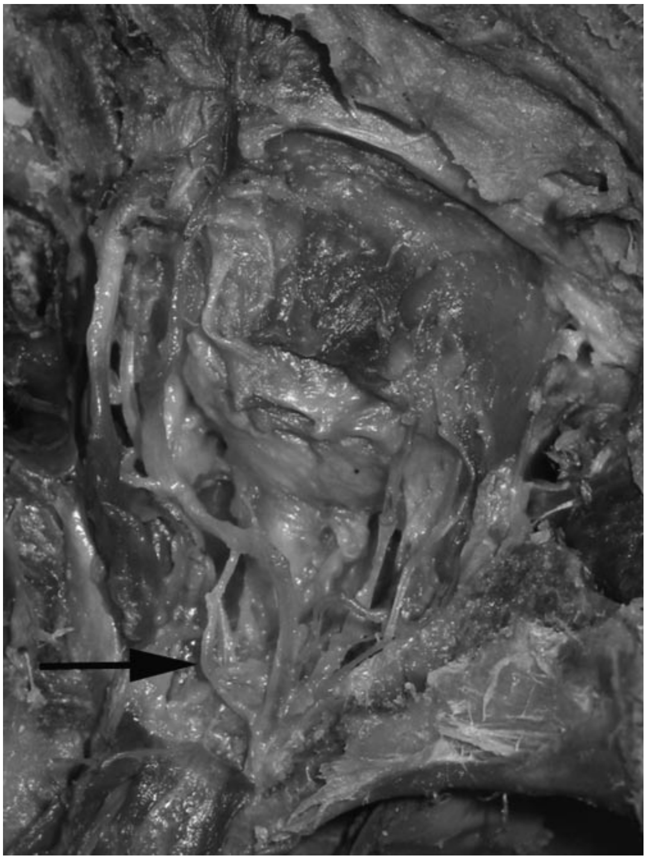


FIGURE 9. A superior view of the right orbit, showing the medial ophthalmic vein (*arrow*) originating from the second part of the SOV.

The SOV is convincingly the most frequently described vein. Most investigators have described it as formed by the joining of two contributing veins, the superior (supraorbital vein) and inferior (angular vein) roots of the SOV.[5,15] Nevertheless, some investigators have stated that the SOV has only a single origin, arising predominantly or even exclusively from one trunk anteriorly.[16] As Brismar[10] suggested, the finding of a single origin on phlebograms may be due to the technique used (i.e., angular vein approach without sufficient compression of the angular and frontal veins). An accurate account of the topography of the roots of the SOV is given by Murakami et al.[17] The superior root enters the orbit, running slightly backward, medially and cranially, under the orbital roof. It then unites with the inferior root at the cranial aspect of the medial extension of the levator palpebrae superioris muscle, a few millimeters behind the reflected tendon of the superior oblique muscle. The inferior root arrives in the orbit through an opening in the orbital septum, perforating the orbicularis oculi muscle before joining the superior root at the anteromedial orbit. As most have described,[5,17] from the point of union of the two roots, the SOV runs through the anterosuperior part of the orbital cone in adipose tissue to the medial border of the superior rectus muscle. It is surrounded by elastic tissue, which connects it with neighboring structures, such as muscles. From its entry into the muscle cone, the SOV runs backward and laterally under the superior rectus muscle and above the optic nerve before crossing to reach the medial border of the superior rectus muscle. Koornneef[18–20] described the SOV as being suspended in a hammock of connective tissue septa beneath the superior rectus muscle. Next, it follows the lateral border of the superior rectus muscle, descending dorsomedially into the tight connective tissue of the superior orbital fissure.[5] Finally, the SOV drains into the cavernous sinus.

In contrast to the SOV, the IOV is often not clearly described. Three different veins are described. One of these is the IOV, and the other is either the infraorbital vein[21] or, in more recent reports, the veine ophthalmique moyenne (middle ophthalmic vein).[5] Some investigators explicitly deny the existence of an infraorbital vein and consider the IOV comparable with the infraorbital artery in course and position.[22] Huber[23] stated that the inferior venous system exists only as a venous network or plexus. Most investigators agree that an IOV originates from a plexus.

Henry[13] was the first to describe a veine ophthalmique moyenne. He considered the vein to be a posterior muscular vein, arising within the muscle cone from one of several origins: the lateral side of the medial rectus muscle at its caudal end, the medial collateral vein, the lateral collateral vein, or the inferior aspect of the lateral rectus muscle. According to Brismar,[11] the veine ophthalmique moyenne was present in approximately 20% of his phlebograms. Jo and Trauzettel[15] were able to identify the vein in only 1% of their dissections.

Brismar[11] was also one of the few investigators who saw the medial ophthalmic vein. Forty percent of his phlebograms demonstrated such a vein. The medial ophthalmic vein arises from either the angular vein or the anterior segment of the SOV. It runs posteriorly along the orbital roof close to the medial orbital wall to either descend into the cavernous sinus directly or rejoin the SOV in the posterior orbit.[1]

There are many tributaries from the SOV and IOV. Among these, the most clinically significant is the central retinal vein. The vein leaves the optic sheath at a variable distance from the globe, anterior to the central retinal artery. It has a large anastomosis with the SOV.[24]

Two ethmoidal veins have been observed by most investigators. The anterior ethmoidal vein normally drains into the inferior root of the SOV, whereas the posterior ethmoidal vein often drains into a venous network under the orbital roof.[5]

Another group of veins, mostly four but sometimes five, is called the vortex (or vorticose) veins. They obliquely perforate the sclera of the globe just posterior to its equator and drain the choroidal network.[14]

According to Bergen,[5] Sesemann[22] was one of the first to note the presence of collateral veins connecting the SOV with the IOV. They are the anterior, medial, lateral and posterior collateral veins. Brismar[11] was able to identify the anterior and medial collateral veins in more than 90% of his phlebograms. The lateral collateral vein was visible in approximately 70% and the posterior collateral vein in only approximately 20%.

Description of another functionally important vein, the lacrimal vein, varies greatly between different reports depending on the method the investigators used. Brismar,[11] who used phlebograms, was unable to identify the vein at all in 75% of his cases. The lacrimal vein is better described by those investigating through dissection. The origin of the vein is formed by the union of a principle lacrimal vein and an accessory branch.[14,17] It also has abundant communications with extraorbital and intraorbital veins. For instance, it frequently communicates with the palpebral and conjunctival veins.[13]

The muscular veins appear to be far less constant in their distribution and trajectory than the principal veins. Because of their relative variability, most investigators provide only a rough outline of the course of these veins. Basically, muscular veins for the superior oblique, superior rectus, medial rectus, and lateral rectus join the SOV, whereas for inferior rectus and inferior oblique muscles, the veins drain into the inferior venous plexus.[13]

According to the literature, the orbital venous system also has abundant interconnections with extraorbital venous structures. The cavernous sinus is the most important posterior communication.[5] Another frequently mentioned communicating vein is that which travels through the inferior orbital fissure and connects the IOV with the pterygoid plexus.[14,24] Anteriorly, the orbital venous system communicates with the facial venous system through two connections. One is the angular vein, which directly bridges the inferior root of the SOV to the facial vein.[5] This communication is often used by radiologists for contrast-filling of the orbital veins.[25] A second communication to the facial venous system is the supraorbital vein, which links the frontal vein.[5]

In the present study, there were several findings that reveal previously undescribed aspects of the orbital venous system, whereas others confirm the results of past studies. The SOV in this study showed some significant variations. One is the variant anatomy of its roots. A single origin was seen in more than 10% of the dissections. Although it appears to be an uncommon variation, it may have clinical implications, as, for example, in the SOV approach to CCSFs, where localization of the roots of the SOV is important.[26] Thus, in cases in which a search for the superior root (supraorbital vein) is difficult, the clinician should be aware of the existence of a possible single origin, which is invariably found inferior to the trochlea.

Another clinically relevant finding in this study is the variant anatomy of the medial ophthalmic vein, which was present in 25% of the dissections. As illustrated in Figures 3 and 4, it forms a circular loop bridging the SOV with other surrounding veins. This may promote development of venous thrombosis due to the potential increase in turbulent flow in that area. In 2 of 12 cases of embolization of the CCSF through the SOV (McNab A, personal communication, 2002), partial thrombosis of the SOV was evident from a midpoint of the orbit extending anteriorly. This partial thrombosis could have arisen at a point of sluggish or turbulent flow, as might occur in a venous system (Figs. 3, 4, 8, 9). The connective tissue hammock suspending the SOV under the superior rectus, as described by Koornneef,[18] could also provide a point of kinking and possible thrombosis anterior to this point.

In many reports, it is emphasized that the SOV proceeds in a course completely separate to that of the ophthalmic artery.[10,17] However, the anterior portion of the first part of the SOV is sometimes found to be accompanied by the ophthalmic artery. Although the ophthalmic artery has an observably convoluted course, its anterior part is usually fairly straight, running just inferior to the first part of the SOV. Moreover, according to the results, the vortex veins were observed to be very tortuous compared with other orbital veins. Their tortuosity, which has been commented on infrequently in past studies, probably allows free rotation of the eyeball without stretching the veins. Another major contradictory finding is the anatomy of the medial ophthalmic vein. As this study shows, the medial ophthalmic vein has a very short course, running within the muscle cone and draining invariably into the SOV (Figs. 3, 4, 8, 9). This is, however, inconsistent with some textbooks,[1] and the results from most of the past studies.[5,10] For instance, Dutton and Waldrop[1] state that the medial ophthalmic vein runs along the medial orbital wall in the extraconal space, and their schematic illustration shows that the vein proceeds in a long course, draining directly into the cavernous sinus.

The dissections of the inferior orbit also demonstrated variable anatomy. Only one IOV was evident in the inferior orbit, originating from the inferior ophthalmic venous plexus (Fig. 1). This finding is contradictory to those in many previous studies. Despite much effort, the veine ophthalmique moyenne controversially described by many investigators[5,13] was not found in any of the dissections. Because the inferior medial and lateral vortex veins are also closely associated with the IOV, it is possible for them to be mistaken for an additional IOV.

In conclusion, the orbital venous system has a complex structural organization. It can be separated into two systems: the superior orbital venous system and the inferior orbital venous system. The principal vein in the superior orbital venous system is the SOV, which arises from the joining of two extraorbital veins: the supraorbital and angular veins. The SOV is divided into three parts, and each part proceeds in a different course and communicates with different tributaries. The course of the SOV is generally constant, running backward medially to laterally in relation to the superior rectus muscle. It terminates in the cavernous sinus after passing through the superior orbital fissure. The IOV is the main vein in the inferior orbital venous system. It originates as a venous plexus between the inferior rectus muscle and the optic nerve. Running inferior to the optic nerve and with a very small caliber, the IOV is often very difficult to locate. In the posterior orbit, the IOV usually joins the SOV, but it occasionally drains directly into the cavernous sinus. Between the two venous systems, there are abundant communications through medial and lateral collateral veins.

Both of the systems exhibit several variations, but the inferior orbital venous system appears to be less consistent than the superior orbital venous system. Nevertheless, the variations of the SOV have more relevant clinical implications.

In this study, the anterior approach used to dissect the fresh specimen had one significant limitation. The veins communicating with the orbital floor and the pterygoid plexus had to be incised to allow the dissection to be performed. Therefore, details of these connections could not be identified.

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