Venous organization in the transverse foramen: dissection, histology, and magnetic resonance imaging

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OBJECT The anatomical arrangement of the venous system within the transverse foramen is controversial; there is disagreement whether the anatomy consists of a single vertebral vein or a confluence of venous plexus. Precise knowledge of this arrangement is necessary in imaging when vertebral artery dissection is suspected, as well as in surgical approaches for the cervical spine. This study aimed to better explain anatomical organization of the venous system within the transverse foramen according to the Trolard hypothesis of a transverse vertebral sinus.

METHODS This was an anatomical and radiological study. For the anatomical study, 10 specimens were analyzed after vascular injection. After dissection, histological cuts were prepared. For the radiological study, a high-resolution MRI study with 2D time-of-flight segment MR venography sequences was performed on 10 healthy volunteers.

RESULTS Vertebral veins are arranged in a plexiform manner within the transverse canal. This arrangement begins at the upper part of the transverse canal before the vertebral vein turns into a single vein along with the vertebral artery running from the transverse foramen of the C-6. This venous system runs somewhat ventrolaterally to the vertebral artery. In most cases, this arrangement is symmetrical and facilitates radiological readings. The anastomoses between vertebral veins and ventral longitudinal veins are uniform and arranged segmentally at each vertebra.

CONCLUSIONS These findings confirm recent or previous anatomical descriptions and invalidate others. It is hard to come up with a common description of the arrangement of vertebral veins. The authors suggest providing clinicians as well as anatomists with a well-detailed description of components essential to the understanding of this organization.

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KEY WORDS anatomy; histology; magnetic resonance imaging; transverse foramen; vertebral veins; vascular disorders
Methods

Cadaveric Study
Ten specimens (6 from women and 4 from men) were studied.

Vascular Injection Preparation
The right internal jugular vein and the right internal carotid artery were injected with a 30% diluted ammoniac solution. Thereafter, these vessels were injected, respectively, with a blue- and red-colored latex solution diluted with a 5% aqueous ammonia solution.

Microdissection of Vertebral Veins
After bilateral cervical dissection and laryngectomy, the vertebral veins and arteries were exposed at the transverse foramen for C-6 and C-7. Then, the ventral parts of the C-1 and C-7 cervical spine were exposed, and the transverse processes were dissected (Fig. 1A). Under a high-power microscope (×7 to ×36, model M360; Wild Heerbrugg) the transverse foramen was opened to expose the ventrolateral part of the vertebral veins as well as the spinal venous rami (Fig. 1B). Then, the C-7 and C-3 vertebral bodies were removed to expose the dorsomedial part of the vertebral veins and their anastomoses with the ventral longitudinal veins (Figs. 2B and 3). Pictures were taken through the lens of the microscope (digital Nikon D 100).

Data Collection
For each specimen the following data were collected: the general description of the vertebral veins within the transverse canal (plexiform arrangement, veins, and major location side); the detailed description of the vertebral veins (ventral, dorsal, medial, or lateral location, segmental arrangement, and level of the related vertebrae); the description of the longitudinal ventral veins (a single vein or a venous plexus, major location side, presence of left/right anastomoses and their levels); the description of the anastomoses between vertebral and longitudinal veins (levels, ascendancy from C-2 to C-6 and at the transverse canal outflow); and the description of the cervical segment of the vertebral artery.

Histological Study

Sampling Technique
Tissue fragments were collected from 3 of 10 specimens. Care was taken to include all contents of the transverse canal at C2–3 and C5–6 in this sampling block.

Analysis Technique
Tissue fragments were embedded in paraffin after formalin fixation. Blocks were cut by microtome perpendicularly to the vertebral axis, allowing 3-μm tissue sections stained with hematin-eosin-safran. The following antibodies were used for immunohistochemical analysis: smooth muscle actin (monoclonal mouse, clone 1A4 [Sigma], dilution 1:50) against soft muscular fibers, and CD31 (monoclonal mouse, clone IC/70A [Dako], dilution 1:20) against vascular endothelium. Tissue samples used as positive controls for immunohistochemical techniques were included in the same way: myometrium for smooth muscle actin and cutaneous angiosarcoma for CD31. Images were taken through the lens of the microscope (magnifying power ×25 to ×200; Zeiss AX10 Imager.A2), with an AxioCam ICc3 camera.

High-Resolution MRI Study

Controls
Ten healthy volunteers participated in this study. None reported a history of vascular or neurological disease. All volunteers were informed of the study’s objective, written consent was obtained from the patients, and all data were anonymized.

Data Acquisition
Images were obtained using a Philips Achieva 3-T TX MRI system (Philips Medical Systems), using a 16-channel head coil and parallel imaging sensitivity encoding (SENSE). Images were acquired in the axial plane using a 2D time-of-flight (TOF) venography sequence. The acquisition protocol was based on the following parameters: TE 3.45 msec, TR 18 msec, flip angle 25°, FOV 200 mm, and voxel size 0.5 mm³. The scan time for this protocol was 9 minutes, 17 seconds.

Data Collection and Analysis
Double-blinded data collection was done by 2 neurovascular radiologists into a database in accordance with the same guidelines used for dissection. All computed results were compared. Any discrepancy in the interpretation of results was solved through an additional reading for interreader consensus.

Results

Cadaveric Study
General description of the vertebral venous system within the transverse foramen showed a plexus arrange-
ment (Figs. 1B, 2A, 2C, and 3) in 80% of the cases, and a single vein in the other cases. We noted an exclusive ventrolateral position and a segmental arrangement of the venous system at each vertebra. An inverse relationship between arterial and venous predominance was noted in most of the cases. Presence of anastomoses was observed between transverse and ventral longitudinal veins in some cases (Fig. 2B). The anastomoses (Figs. 2B and 3) between ventral longitudinal and vertebral veins were bilateral and segmental at each vertebra. The vertebral and longitudinal veins running through the transverse canal were similar in size up to drainage, where the former were wider. A symmetrical organization in regard to the plexus and segmental arrangement of vertebral veins at each vertebra was reported in 80% of the cases. The rise of vertebral veins along with the vertebral artery below the transverse foramina of C-6 was confirmed through dissection. These vertebral veins then receive the plexus of the C-7 transverse foramina (Fig. 2D). These results are displayed in Table 1.

Histological Study

The venous system observed at the C-3 sampling displayed a circumferential periartrial vascular network (Fig. 4A). The latter was regarded as a venous sinus with its endothelium placed directly on the neighboring fibrous tissue (periosteum) without muscularis interposition (Fig. 4C). At the drainage of vertebral artery of the C-6 transverse foramina, the vertebral artery was associated with a satellite vein (Fig. 4B), which has, by definition, a muscular layer (Fig. 4D). The CD31 revealed only scattered endothelial cells at the vertebral artery and the neighboring venous system (regardless of the segment level). This aspect could be explained by endothelium abrasion due to latex removal done before paraffin embedding. Thus, noninjected capillaries located remotely within the periosteum displayed a continuous endothelium.

FIG. 2. Photographs of cadaveric spines showing right ventrolateral view before (A) and after (B) vertebral bodies and discs were removed. Photographs showing ventral view after dissecting the transverse canal (D), and ventral view of the vertebral vessels exiting the transverse canal (D). The numbers designate the following anatomical structures: 1 = vertebral venous plexus; 2 = vertebral artery; 3 (panels A and B), 5 (panel B), and 6 (panel C) = ventral ramus of C-5; 4 = right ventral ramus of C-4; 7 = C-4 right transverse process resection; 8 = intervertebral disc C4–5; 9 = intervertebral disc C5–6; 10 = right anterior longitudinal vein; 11 = transverse plexuses; 12 = C-2 vertebral body; 13 = C-7 transverse venous plexus; 14 = ascending cervical artery; 15 = extraspinal ventral plexus; 16 = right longus colli. Figure is available in color online only.

FIG. 3. Right ventrolateral view of the left transverse canal after dissection and removal of vertebral bodies. The numbers designate the following anatomical structures: 1 = left vertebral venous plexus surrounding the vertebral artery; 2 and 3 = left ventral ramus of C-5; 4 = C-4 left transverse process resection; 5 = C-4 pedicle; 6 = left ventral ramus of C-4; 7 = venous plexus surrounding the left C-4 nerve; 8 = anastomosis between vertebral and anterior longitudinal venous systems. Figure is available in color online only.
Venous organization in the transverse foramen

A plexus arrangement of the vertebral veins was observed (Fig. 5A). We observed an exclusive ventrolateral position of the venous system within the transverse foraminal canal (Fig. 5) and a segmental arrangement at each vertebra (Fig. 5B). Left predominance of the cervical vertebral artery (V2) and absence of predominance were observed in 3 and 5 of the 10 cases, respectively. On the one hand, an inverse correlation between arterial and venous predominance was noted. On the other hand, both arterial and venous predominance were observed in the same 5 cases. Longitudinal ventral veins were described as a single isolated vein in most of the cases, and as venous plexus with a single vein in the remaining cases. Transverse plexuses were observed in a few cases (Fig. 5C). Bilateral, segmental, and constant anastomoses were observed between the vertebral and anterior longitudinal plexus at each vertebra (Fig. 5B). At the drainage of the transverse canal, a predominance of size of vertebral veins compared with ventral longitudinal veins was noted. In all cases, the following were observed: a symmetrical plexus arrangement of the vertebral veins, the ventral longitudinal veins, and the anastomoses between the ventral longitudinal veins and the vertebral veins.

Radiological and Anatomical Comparison

As shown in Table 2, the MRI findings as well as the dissection results revealed a plexus organization within the transverse canal (90%), with a predominant vein being involved in 75% of the cases. The findings through dissection and MRI were consistent in regard to size of the vertebral veins and arteries. A ventrolateral position of the vertebral veins was noted in 84% of the cases. The arrangement was segmental at each vertebra in all the cases evaluated using MRI and in 62% of the cases examined using dissection. Neither MRI nor dissection revealed a correlation between the predominance of size of ventral longitudinal veins and that of the vertebral veins and arteries. The anastomoses between the vertebral and the ventral longitudinal veins were observed in 95% of the cases. On the one hand, through dissection, on the transverse canal, a global predominance of the size of the ventral longitudinal veins compared with the vertebral veins was observed. However, no such predominance was observed through MRI. On the other hand, at the drainage of the canal, such a predominance of the size of the vertebral veins was observed through both MRI and dissection.

Discussion

Major Findings of This Study According to Each Methodology

These study results were consistent between MRI and dissection findings, both revealing a ventrolateral plexus.
arrangement of the venous system within the transverse canal. The presence of ventral longitudinal veins (89%), sometimes with a plexus arrangement (27%), implied the absence of a single description of these veins. Moreover, several anastomoses were observed between the plexus transverse veins and the vertebral veins. The transverse plexuses, which connect the left and right ventral longitudinal veins, were not seen at any vertebra. Chaynes et al.\textsuperscript{2} described these anastomoses as being posteriorly placed, often within a branch of the superficial layer of the dorsal longitudinal ligament (DLL). François et al.\textsuperscript{9} proposed an interperiosteo-dural concept of the dura mater consisting of 2 layers at the encephalic and spinal levels (i.e., the spinal dura mater layer and the periosteal layer including the DLL). Given the failure of the MR venography (MRV) TOF sequence in revealing the dura mater and detecting enough

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<th>Table 2. Comparison of major results of radiological and anatomical investigations of the venous system within the transverse foramen</th>
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* Venous anastomosis between vertebral and ventral longitudinal veins.
circulating flow in the transverse direction, the MRI did not allow clarification of the precise relation between these transverse anastomoses and the 2 dura mater layers. In this study, the MRV TOF sequence was chosen to optimize the collection of venous signals within the canal.

The dissections confirmed the drainage of vertebral veins along with vertebral arteries via the transverse foramen of C-6. This is in contrast with the conventional description found in the literature. Finally, this study showed that the vertebral veins receive flow from the plexus rising from the transverse foramen of C-7.

The already well-known variation in venous system arrangement in the human body conveys the absence of a common description of vertebral veins. However, a general description is possible. In this manner, the transverse canal venous system was arranged symmetrically: in the plexus, segmental and preferably placed ventrolaterally to the artery. This plexus arrangement evolves in a craniocaudal direction toward an isolated vein exiting the transverse foramen of C-6. This venous system shows segmental anastomoses with ventral longitudinal veins at each vertebral level.

Comparison With the Literature

The embryology of the venous system helps with understanding of the vertebral vein segmental development that was shown in this study. In this manner, it seems that the whole encephalic venous system shows a primitive plexus arrangement. This plexus arrangement is also true for the suboccipital venous system from which the vertebral veins rise. Furthermore, according to Poirier, ventral longitudinal veins are sinusoidal at the neck, half sinusoidal at the dorsal region, and veins at the lumbar region and the sacrum. This description suggests a craniocaudal organization of the vertebral venous system. Our results confirm those of Walther, Poirier, and Patuert, as well as those of Gérard, who described a collective vein with a lower common trunk, a single vein branched in some places, and several trunks encircling the artery in plexus.

Our study results are consistent with those described by Rouvière and Delmas, who described the vertebral venous system as a single vein. All of these anatomical descriptions put forward a lateral localization of vertebral veins to the artery. This was confirmed by our study. According to Dubreuil-Chambardel, in 38% of the cases, the cervical vertebralveae have 2 foramina instead of the transverse canal: a venous canal located outside of another canal within which the vertebral artery runs along with a small vein and nerve. Some authors such as Laux et al. and Chopard et al. revealed a fibrous sheath encircling the vertebral artery and constrained by connective tracts at the opening of the transverse canal. Our results were consistent with this description.

In contrast, according to Lu et al., ventral vertebral veins were classified into the following categories: 1) 1 or 2 veins; 2) 1 plexus; or 3) absence of veins. They furthermore gave an equal ventrolateral or ventromedial positioning of these veins. These results (i.e., the presence of a single vein within the transverse canal as well as the position of the vein) are not consistent with our results. The Trolard description of the transverse vertebral vein (i.e., a sinus) was confirmed by Palombi et al. The following findings were confirmed by Jovanovic and Palombi: the transverse foramen vertebral veins exiting from the C-6, and the venous drainage of intraspinal plexuses of the C-7 transverse foramen toward the vertebral vein. Our results were in line with those of Zhao et al. via tomodensitometry, revealing the medial positioning of the vertebral artery within the transverse canal (i.e., occupying only half of the canal). According to Chaynes et al., ventral longitudinal veins are positioned at the ventrolateral part of the vertebral canal, within a branch of the DLL superficial layer. Despite the limited number of subjects, our observations of an intradural positioning of the abovementioned anastomoses were not consistent with the descriptions by Chaynes et al.

According to Zouaoui and Hidden, intra- and extraspinal cervical vertebral venous plexuses play a role in the venous drainage of the brain. This role was explained by the presence of numerous anastomoses with the intracranial venous system. Histological studies are quite rare. On the one hand, a periarterial venous system, histologically similar to a sinus and in line with the theory of a transverse vertebral sinus, was defined by Laux et al. and Palombi. On the other hand, the presence of a connective blade unifying the artery to the periosteum and the presence of a venous confluence positioned in the plexus encircling the artery were described by Chopard et al. Our histological study confirmed the above descriptions, supporting the formation of a transverse vertebral venous sinus.

Practical Applications

Vertebral artery dissections are the main cause of cerebral ischemic stroke and cerebral trunk stroke in young adults in particular. The clinical signs can be very mild and a clinical presentation might not be found. On diagnosis of dissection of the vertebral artery, a long-term anticoagulation treatment should be initiated. Even though the use of anticoagulation is recommended in cases of positive diagnosis of dissection, it is harmful in cases of false positives. Hence, the diagnosis of vertebral artery dissection has a direct therapeutic implication and the reduction of false positives is a major challenge. Magnetic resonance angiography (MRA) is used as a routine method to explore any suspicion of vertebral artery dissection. Nevertheless, the accuracy of conventional imaging sequences is lessened by the slow flow of the vertebral veins, thus yielding false positives. There are several imaging methods for exploring the vertebral veins: venography or CT scans, and now MRV. The results of our study increase knowledge about the arrangement of vertebral veins and provide an MRV description. Nevertheless, the observed symmetry is a main part of the venous system description because it can provide the contralateral arrangement. Then, the use of an MRV sequence associated with MRA can help to distinguish the long flows related to the veins and the hypersignal related to an intrawall hematoma of the dissection.

Furthermore, during surgery of the cervical spine via the anterior approach, significant venous bleeding can occur on reaching the lateral part of the vertebral canal. Lu et al. showed that vertebral veins began at the junction of

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the anastomoses with the ventral longitudinal veins. The understanding of the aforementioned venous anatomical descriptions is quite valuable in avoiding rare but adverse lesions of the vertebral artery. Indeed, the vertebral arteries are located medially in the transverse canal but always surrounded by a venous plexus, which is itself surrounded by periosteum. So, when venous bleeding occurs at the junction of the lateral part of the vertebral canal and the medial part of the transverse canal, the lateral resection should be stopped as a safeguard. Moreover, for anterolateral approaches for tumors and proximal brachial plexus surgery, knowledge of the anatomical relationship between the cervical nerve root and the vertebral vessel in the transverse canal is a major concept. In particular, the fact that the venous plexus is surrounded by periosteum, which is in the plane of dissection, should be respected to reduce the risk of vertebral artery injury.

In regard to the posterior approach for surgery of the cervical spine, some authors have focused on the accurate position of the artery within the transverse canal. In this manner Zhao et al., in their tomodensitometry study on the vertebral artery, revealed a medial positioning and an average 35% occupancy within the canal. The above observation may explain the reason for the lack of a systematic lesion of the artery on piercing of the canal by a sharp object (i.e., a screw). Indeed, for the posterior approach it is also important to know these anatomical details to understand that the danger lies medially in the transverse canal. Other authors such as Kawashima et al. have proposed a detailed anatomical description of the vertebral arteries in the transverse canal.

Study Limitations

Despite the use of anatomical and radiological studies, changes in the arrangements of vertebral veins, as are well known for the venous system in the human body, do not allow us to provide a modal description. The limited number of specimens dissected and data obtained using MRI is also a limitation. Since our main goal was analysis of the transverse venous system, the veins were injected prior to the arteriography and an average 35% occupancy within the canal. The limited number of specimens dissected and data obtained using MRI is also a limitation. Since our main goal was analysis of the transverse venous system, the veins were injected prior to the arteriography, which limited our confrontation at the transverse level, which would have left enough space for the veins to be visualized. However, with the injection-dissection method it was difficult to study very small caliber vessels, and moreover, in our method the freezing and defreezing process may sometimes alter the veins.

Conclusions

In light of the above observations, our study confirmed most of the descriptions found throughout the literature and invalidates others. On the anatomical level, our study revealed a plexiform organization of the vertebral veins, which allowed us to name them “vertebral plexus,” or “vertebral sinus.” This naming is not yet adopted in different nomenclatures, even though the “plexiform” terminology is already used in some old anatomy textbooks. In practice, this lack of standardized nomenclature (terminology) could bring about confusion. In regard to the segment located inside the transverse canal, the “transverse vertebral plexus” or “transverse vertebral sinus” terminology designated by Trolard seems more appropriate. Moreover, the “vertebral vein” terminology is appropriate only after the vessel exits the canal. Finally, the naming of “plexus” or “sinus” will be varied along the transverse canal height: it will be more sinusoidal on the top and plexiform on the bottom.

References


Author Contributions
Conception and design: Magro, Seizeur. Acquisition of data: Magro, Gentic, Talagas, Seizeur. Analysis and interpretation of data: Magro, Gentic, Talagas, Seizeur. Drafting the article: Magro. Critically revising the article: Gentic, Alavi, Nonent, Dam-Hieu, Seizeur. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Magro. Administrative/technical/material support: Magro, Alavi, Seizeur. Study supervision: Seizeur.

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