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Cranial diploic channels and their veins — a review of literature

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Abstract: The current paper is a review of the results attained in the past and current anatomical studies, aimed at understanding the variability and function of the diploic venous system of the human skull. The diploic veins can serve as transit for infections from the scalp to the structures contained within the cranial cavity via the emissary veins, due to their interconnections with the pericranial veins, meningeal veins and dural sinuses. Thereby this clinical aspect has also been discussed.

Keywords: diploic veins, diploic channels, diploe.

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Introduction

The inner structure of the cranial bones has been known since the time of Hippocrates who already pointed out that the middle layer of the cranial bones contains peculiar channels accommodating veins. Hippocrates noted that the diploe is the cavernous and porous part of the cranium having slender, hollow spaces filled with blood vessels [1–3].

Nonetheless, the first known description of the diploic channels is attributed to a French anatomist and surgeon Guillaume Dupuytren. He presented his own observations of the diploic channels, performed on dry and fresh bones in the monograph *"Propositions sur quelques points d'anatomie, de physiologie, et d'anatomie pathologique,"* published in 1803. In the chapter entitled *"Canaus veineux des os,"* Dupuytren described appearance and way of communication between the channels that contain veins and traverse the diploic space of different bones, paying particular attention to their shapes (flat, short, long) and location in the skeleton (the vertebral column, skull) [4]. It should be accentuated that before Dupuytren performed his study of the diploic channels, there had been earlier reports given by Fleury who worked as a prosector at the School of Medicine in Paris in the XIXth century [1]. Thus, these intraosseous channels were formerly named the "canals of Fleury" or "sinuses of Fleury." However, the aforementioned terms indicating existence of venous canals inside the diploe can rarely be found in anatomical textbooks [5, 6].

The anatomical studies of the diploic channels lodging the veins conducted by Dupuytren were further developed by Chaussier [7] around the year of 1807, and Breschet who presented evidence on their anatomy and topography (later known as Breschet's canals). The latter author's own observation was published in 1819 in the *"Recherches anatomiques, physiologiques et pathologiques sur le système veineux, et spécialement sur les canaux veineux des os"* [8].

Recent studies performed on dry skulls with the aid of radiographic techniques applied *in vivo* have confirmed, developed, detailed and systematized the previous data on the diploic venous system, obtained in the studies conducted in the XIXth–XXth centuries. Since that time, researchers started to pay closer attention to the practical value of roentgenographic images of the cranial diploic vascular channels which could help with diagnosing neurological diseases and intracranial tumors [9–12].

In the middle of the XXth century, Hewes *et al.* [13] recommended X-ray microscope technique for studying the injected channels of dry skulls for a better demonstration of small tributaries with diameters in the order of 1 mm or even less.

The radiographs allowed to trace intravital vascular communication, evaluate how the diploic channels and veins react to various pathologic conditions, and thus helped to elucidate the concept of typical variations of these vascular channels in juxtaposition to their pathological variants [10–11, 14–15]. Moreover, these methods permitted to observe age-related changes of the diploic space, including their vascular channels.

Hershkovitz *et al.* [16] found radiological examination of the skulls to be an accurate method to study the diploic channels. With the aid of the Hewlett Packard Faxitron Cabinet X-ray system, the referenced authors managed to visualize the developing diploic veins in the cranium of a seven-month-old fetus. They also displayed successfully the diploic veins of older subjects (children and adults) on X-ray images. Radiographic data was clear enough to assess in details the morphological pattern of the diploic veins, their distribution in the skull, and moreover to quantify the intensity of the veins depending on their length, width, and the area they occupied. Their study significantly expanded knowledge on the cranial diploic system in humans and its relationship to age, sex and ethnicity.

The venous diploic channels have been radiographically assessed in adult human dry skulls by Nikolova *et al.* [17]. The authors pointed out the difficulty in differentiating the diploic channels from the grooves for the middle meningeal vessels due to superimposition of their shadows, depending on imaging projection used in plain radiography, as well as positioning of the skull during its examination. Besides, they considered effectiveness of applying contrast agents to obtain a better visual effect, but also the possibilities of utilizing other imaging modalities like magnetic resonance imaging (MRI) or micro-computed tomography to obtain higher resolution data displaying the channels in 2D and 3D modes.

Rangel-de Lázaro *et al.* [18] applied digital segmentation of the computed tomography (CT) scans to visualize the diploic channels and performed a quantitative description of their variation. They found that most of the diploic channels could have been observed with an isometric voxel size of 0.21 mm, however the resolution significantly contributed to the quality and reliability of the final reconstruction rendered in the 3D display. Not only did their research confirm that the diploic channels are highly variable among human individuals, but also provided quantitative data on their volume and correlation between the two hemicrania.

In turn, Jivraj *et al.* [19] used volumetric and digital subtraction methods as a way for accurate 3D visualization of the diploic veins acquired with MRI. The proposed technique allowed for an *in vivo* investigation of the probability of the diploic veins' existence, their distribution in the skull, and concentration, defined as the amount of space occupied by the veins in subsequent cranial regions. Tsutsuni *et al.* [20] found that thin-sliced, contrast-enhanced MRI appeared to be useful in depicting the diploic veins, whereas the maximum intensity projection images showed their course and 3D architecture. Moreover, these imaging methods allowed to detect fenestrations that may occur in the diploic venous channels. Clinical importance of having detailed data on the distribution of diploic veins in the human skull was further highlighted by Alarfaj *et al.* [21] who also used MRI to examine the diploic venous system. They verified how the blood is drained from the cranial diploic space in pediatric and adult patients, hence they established optimal sites for insertion of tools used to treat hydrocephalus.

Application of various radiographic techniques to visualize the venous diploic channels allowed to perceive their specific anatomical details, which in turn enabled to quantify their morphological features, and to assess the relationship between parameters of the diploic channels and the cranial dimensions or morphometric features of particular cranial bones.

Development of the diploic venous channels

The diploic venous channels of the human skull show age-dependent development. This means that their morphological features like size, shape and distribution across the cranium correlate with growth of the skull, and remain in correlation with the amount of the diploe interposed between the outer and inner tables of the compact bone forming the cranial vault. Thicker diploe creates better conditions for intensive development of the intraosseous venous vasculature, accommodated within the diploic channels [22–23]. Arrangement of these channels also depends on individual character of the skull shape, and is moreover related to the number of emissary veins present. The diameter of the venous diploic channels is directly proportional to age and inversely related to the number of their branches. Nevertheless, their formation pattern does not follow the rules of mathematical regularity, as postulated originally by Breschet, but rather reveal unlimited variety of patterns, classified and described in the later reports [24].

Therefore, mathematically speaking the diploic channels should be regarded as structures having fractal properties, similarly to the branching pattern of the middle meningeal artery or other blood vessels which subsequent divisions follow the rules of fractal scaling [25–28]. However, this issue requires further and careful studies aimed at estimation whether the diploic venous channels actually form fractal patterns, and whether the fractal dimension would be a reliable measure of the complexity of the diploic vascular network in the light of current concept on the fractal properties of vascular networks [29–30].

Previously, it was believed that the diploic veins do not exist in fetuses, are absent at birth, and begin to develop at the age of about 2 years [23]. Later studies delivered radiographic images showing the diploic channels in the late fetal period and in the newborns. Hershkovitz *et al.* [16] found them in fetuses aged 7–9 months, and Rangel-de-Lazaro *et al.* [31] observed them in children at the age of 1–2 years and older, as well. In the infants, the diploic veins are usually small and follow a relatively straight course, contrasting to large and branched patterns characteristic for the adulthood. However, prominent diploic channels have been observed on radiographs of healthy children 10 years of age [10].

Ontogenetic changes of the diploic channels were thoroughly analyzed by Rangel-de-Lazaro *et al.* [31], who confirmed that complexity of the vascular diploic channels increases with age. Initially, singular, short, isolated diploic channels transform into to numerous branches that form interconnected networks. Notwithstanding, their growth is discontinuous and practically occurs during the period between the adolescence and the adulthood. Subsequently, lumen of the diploic channels increases considerably, so do their length and number. The diploic channels of both hemicrania develop similarly, however bone thickness appears to be the major determinant affecting their parameters [31].

The diploic veins interlace through the diploic space. Nonetheless, they are confined to the particular cranial bones at birth and remain as separate, intraosseous venous systems until the cranial sutures are obliterated. Thereafter, the diploic veins can communicate bilaterally, increasing the number of anastomoses observed in the adults. In the elderly, the diploic channels are relatively large. Besides, the cranial diploe may disappear or become thinner with age, what is usually best noticeable in the parietal bones. Thereby, the wall of the diploic channels erodes and vanishes, leaving only the grooves lodging the diploic veins which are not well protected and become prone to destruction. Thus, the risk of complications increases if the skull injuries occur at the old age, what has been already noted in the books and reports of the XIXth century clinical anatomy [32–34].

Anatomy and topography of the diploic channels and diploic veins

The diploic channels run in the cancellous tissue, located between the compact outer and inner tables of the cranial bones (Fig. 1), and accommodate veins, thereby are also referred to as the diploic venous channels. The diploic channels usually run closer to the inner than the outer table of the compact bone of the cranial vault. They traverse the diploe of the frontal, parietal and occipital bones, however the most complex mesh occurs in the parietal bone [4, 9, 16, 18].

Fig. 1. The diploe of the right parietal bone exposed by excising the outer table of the compact bone, presented at top and lateral views. Below, a close-up of the diploic channels traversing the diploe. The skull is derived from the Anatomical Museum of the Department of Anatomy, Jagiellonian University, Medical College, Kraków, Poland.

According to the original observations performed by Dupuytren [4], the number of the diploic veins varies a little in the skull, and there usually exist three or four diploic veins lodged in the osseous channels on each side. They run from its top, along the lateral walls towards the cranial base where they terminate in three ways: 1) in the external veins of the skull; 2) in the internal veins which accompany the meningeal arteries; or 3) in the dural sinuses.

Dupuytren defined the diploic channels and veins as voluminous structures that are constantly isolated from the corresponding arteries [4]. By injecting their lumen, he noticed that the channels penetrated into the center of the diploe and spread inside the diploic space. Hence, Dupuytren noticed that the diameters of the diploic channels are smaller in childhood than in adulthood, and their total capacity decreases from the original canaliculi towards the terminal branches, forming distal parts of the diploic venous system. He also observed that the diploic channels in infant skulls were less pronounced than in the skulls of the elderly, where they were dilated or swollen (resembling varicose veins). Dupuytren found that diploic channels begin in the spongy bone by very fine tubular tributaries, which unite under acute angles and form a branched system which terminates in a few collective trunks [4].

Nowadays, it is known that the diploic veins commence by thin capillary tubes from the diploic space's membranous lining, and even these of a bigger caliber are still thin-walled vessels. Wall of the diploic veins is lined by a single layer of endothelium that rests upon a layer of elastic tissue. The wall of the diploic veins can be imperfect, thereby they can transform to intradiploic venous lakes or form pouch-like dilations located at irregular intervals. These pouch-like dilatations or cul-de-sacs of the venous vessels may serve as reservoirs for blood [35].

The diploic veins are valveless blood vessels. Nonetheless, in the XIXth century Dupuytren indicated the presence of valves in the diploic veins, and so did Langer asserting that valves may exist at the openings of the diploic veins which prevent blood to flow from the cranial surface towards the sinuses of the dura mater [36]. These views are contradictory to Trolard's experimental studies of the diploic venous system who injected the vessels running from the top to bottom and from the bottom to top of the skull, and did not find any obstacles (i.e., valves) that would have stopped the flow of the injected medium. Therefore, Trolard concluded that the diploic veins are devoid of valves. Moreover, he perceived the diploic channels as a complex, ramified network, being of variable morphology [37].

Passing through the numerous channels and foramina that penetrate the cranial bones, the diploic veins communicate among themselves, and further with veins of the scalp, orbit, meninges, and the dural sinuses. The diploic veins can also open directly into the lacunae in which the arachnoid granulations lie (they are responsible for absorption the cerebrospinal fluid into the venous sinuses). In this way, the cerebrosp-inal fluid can be drained from the subarachnoid space through the diploic veins, and hence flow into the blood stream [38]. Especially in the elderly, the lateral lacunae communicating with the superior sagittal sinus can join together and form plexiform venous structures that receive the arachnoid granulations and the diploic veins [39]. According to Tsutsumi, the veins of the cranial diploe and the spinal epidural veins may function together as an alternative drainage system for the cerebrospinal fluid outflow to the blood stream [40]. Further analyses of the diploic channels and veins revealed the extent of their morphological variation, namely their size, shape and unilateral or bilateral position in the skull.

The diploic channels traverse the diploe in various directions, thus shaping the diploic space in diverse ways to provide effective encapsulation of the venous vessels. Based on their appearance, Hershkovitz *et al.* [16] termed the diploic venous patterns as the: bonsai, serpentine, coronal, spider, thousand lakes, mixed, or otherwise undetermined. In turn, the most constant diploic channel seems to be present in the frontal bone, whereas the most variable and complex channels are confined to the parietal bones, particularly in the region of the parietal eminence. Conversely, the largest channel of the cranium accommodates the occipital diploic vein.

Classification of the diploic veins

Both original and reissued editions of popular textbooks of human anatomy, as well as contemporary books oriented towards clinical anatomy, used to present four main trunks of the diploic veins that were termed as: the frontal, anterior temporal, posterior temporal, and occipital veins due to their position in the skull [23, 33, 35, 41–45].

- The frontal diploic vein (also referred to as the anterior diploic vein) arises in the diploe of the frontal bone, and at the level of the supraorbital notch opens into the supraorbital or ophthalmic vein. The frontal diploic vein may also communicate with the anterior temporal veins, hence can be a tributary of the superior sagittal sinus of the dura mater.
- The anterior temporal diploic vein traverses chiefly the frontal bone and/or the anterior portion of the parietal bone. This vein may communicate with meningeal veins, and opens into the deep temporal vein or terminates in the cavernous or spheno-parietal sinuses of the dura mater.
- The posterior temporal diploic vein (confined to the parietal bone) runs downwards inside the posterior part of the parietal bone, towards the mastoid process. In its proximity it opens into the mastoid emissary vein, thereby communicating with the transverse sinus of the dura mater. Occasionally, the posterior temporal diploic vein might terminate in the posterior auricular vein.
- The occipital diploic vein (confined to the occipital bone) runs downwards in the occipital squama, usually near the midsagittal line, and opens either into the occipital vein, or the occipital emissary vein. Henceforth, it provides a commu-

nication with the dural sinuses: occipital and transverse, or directly to the confluence of sinuses.

The abovementioned classification of the diploic veins was presented by Breschet who noticed a considerable variation in the pattern of the diploic channels accommodating the veins in human skulls. He noted that few of the channels, as well as their veins, branched more than the others, depending on the cranial region evaluated. Hence, few of them were dilated or formed venous lakes, and bays [8].

Bifurcations of the end of the diploic channels terminate near the cranial sutures or communicate with the channels of the contralateral side of the skull. Breschet found that divisions and subdivisions of the veins traversing the diploe form numerous anastomoses among themselves and veins of the intra- and extracranial circulation. Breschet's intention was also to show the arrangement of the venous system of the cranial bones not only in the adults, but in the fetuses and the infants, as well [8]. However, this task appeared problematic owing to the techniques which he and the other anatomists could use at the time. In fact, demonstration of the diploic channels was restricted to the manual chiseling of the compact bone forming the external surface of the cranium, and injection of various liquid dies (e.g., Prussian blue) via the emissary foramina of the skull, what improved visibility of the venous network and enhanced tracing of their communications.

Later investigations of the diploic veins performed with the aid of more sophisticated methods, including radiographic imaging, allowed to precisely assess their anatomical variation, estimate occurrence of various patterns of the diploic veins, and attribute their clinical character. Thereby, four main pathways of the diploic venous system have been established based on their clinical considerations: the pteriofrontoparietal, frontoorbital, occipitoparietal and occipitocervical [46].

Clinical relevance

The diploic veins form a delicate, but at the same time intricate venous plexus, localized within the diploic space. The wall of the diploic vein lacks effective elastic layer, which could contract spontaneously in case of the vein's rupture. Henceforth, these veins can easily bleed due to an accidental injury, resulting from a trauma or surgery performed on the cranial vault. The bleeding may result in formation of epidural or subdural hematomas. Thus, the diploic veins may be involved in formation of arteriovenous fistulas between them and branches of the meningeal arteries that were lacerated [47–50].

Multiple communicating diploic channels facilitate interconnections between the diploic veins and the intra- and extracranial veins, by the means of the emissary veins. Such arrangement of the cranial vasculature favors spread of bacterial infections across the skull, as well as facilitates cancer metastases. Therefore, a scalp inflammatory process can spread into the cranial cavity, invading structures of the central nervous system. This problem has already been recognized in the XIXth century medicine and regarded as a serious problem for former cranial surgery [32, 51–52]. Holden in his book dedicated to the anatomy of the human bones treated about the clinical significance of the diploic veins, and accentuated that their inflammation resulting from head injuries may lead to suppuration in the diploe, which might be fatal in consequences [53].

Moreover, Morris in his textbook of human anatomy mentioned that a meningeal infection can be a consequence of scalping (either due to industrial accidents prominent in the XIXth/XXth century or otherwise tribal rituals), as the infectious process can spread through the diploic veins [42].

The changes of the cranial diploic venous channels may accompany pathological alterations of the skull and its contents. An atypical enlargement of the diploic channels and dilation of their veins can be a diagnostic sign of abnormal dynamic conditions that emerged within the cranial cavity, e.g., in relation to hydrocephaly. In such case, the system of the diploic veins can be a potential, indirect way for the cerebrospinal fluid outflow to the dural venous system [15, 21, 38, 40].

Detailed experimental study of the topographic localization of the diploic veins, their morphological patterns, as well as distribution and occurrence in the skull, has been performed by García-González *et al.* [54]. The authors emphasized involvement of the diploic veins in numerous pathophysiological conditions. These namely included: head injuries and their related infections, intracranial hematomas, intracranial hypertension, hydrocephaly, craniosynostoses, air embolism, formation of the diploic fistulas, venous sinus thrombosis, meningiomas, tumor growth and cancer metastases.

In certain cases, tumors of the brain (e.g., endotheliomas), among other pathological entities, can involve directly the diploic veins, hence altered appearance of the diploic space can be a sign of an intracranial disease [55]. One of the vascular anomalies involving the diploic veins is the sinus pericrania. In such case, the diploic veins become mediatory vessels connecting the extracranial venous system with the intracranial dural sinuses. Moreover, the subepicranial varix with connections to diploic veins has been reported, and a case of venous sac expanding in the diploe which communicated the diploic venous system with the intracranial sinus [56]. It is also worth mentioning that the diploic veins may become a part of the collateral venous system if thrombosis occurs in the dural sinuses [57–58]. Otherwise, the diploic veins can convey blood clots what explains some cases of the dural sinus thrombosis that may occur after cutaneous infections of the scalp or a head trauma [59]. A subsidiary role of the diploic veins has been also noted in patients with dural venous sinus invasion caused by meningiomas [60]. This follows the natural communication between the diploic veins and the dural venous sinuses, particularly if they open to the superior sagittal sinus. Occurrence of a tumor can disturb the diploic venous circulation, and disruption of such veins during craniotomy may cause postoperative neurological deficits. However, this issue is little known and requires further studies, as also noted by Yamashiro *et al.* [60].

Therefore, clinical observations and experimental data about potential routes that can facilitate spread of pathogens via the venous vascular system and restricting risk factors related to intracranial hemorrhages is essential in making decisions about proper treatment methods.

Little is known about the blood flow through the diploic venous systems which vessels do not have valves ensuring a one-way flow. Therefore, possible bidirectional blood flow through the diploic veins may cause turbulences when the blood starts to flow in reverse direction. This physiological mechanism combined with specific regional morphology of the diploic veins (dilation, tortuosity) sometimes induces pulsative effect of the blood flow that can be audible as tinnitus, particularly if the veins of the mastoid process are involved [61–62].

Clinical significance of the diploic channels and veins is strongly accentuated in the medical literature, however one more issue related to this specific venous circulation needs attention and further studies. This refers to the possible thermoregulative function of the cranial diploic venous system that coexists and works together with the network of the middle meningeal vessels. Both systems are regarded as responsible for thermal protection for the cranial vault and brain which are supported by the interconnections existing between the endo- and ectocranial vascular system [63–65]. Evidence on communication between these cranial vascular systems via the diploic veins providing cooling effect due to the blood flow through them has been indicated in experimental studies performed on animals [66]. Therefore, future studies should be focused on investigating the potential interplay between the cranial bones, dura mater and the vascular system interposed between them, taking into the account morphological features of these vessels, cranial dimensions, bone thickness, and variety of other anatomical and physiological factors which may correlate and have a mutual effect on each other [67]. This knowledge seems to be indispensable for developing innovative reconstructive methods based on the bionic technology which could be implemented in cranial surgery [68].

To sum up, previous and contemporary experimental studies and clinical observations of the cranial diploic system accomplished in physiological and pathological conditions allow to regard the diploic veins as a very important part of the circulatory system of the human body.

Conclusions

The diploic veins play an important role in the blood drainage of the head because they allow for a communication between the intra- and extracranial vascular system. Therefore, comprehensive knowledge about topography and configuration of the diploic venous system appears to be crucial for understanding mechanisms of pathological processes that can been transmitted across the cranial bones. Further studies on anatomical variation of the diploic veins may improve therapeutic effect attained in cranial surgery, and help in preventing spread of pathogens via the cranial venous system.

Conflict of interest

The authors declare no conflict of interest nor any financial interest associated with the current study.

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