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ORIGINAL ARTICLE

Diploic veins of the cranial base: an anatomical study using magnetic resonance imaging

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Abstract

Purpose The anatomy and distribution of the diploic veins (DVs) of the cranial base have not been fully documented. The aim of this study was to characterize these veins using contrast magnetic resonance imaging (MRI).

Methods In total, 95 patients underwent thin-sliced, contrast MRI. Coronal and sagittal images were used for the analysis. The cranial base was divided into the anterior, middle, and posterior bases. Then, each base was further subdivided into three equal parts in the anteroposterior and lateromedial directions. The anteroposterior parts were evaluated on coronal images, while the lateromedial parts were evaluated on sagittal images.

Results The DVs were identified over the entire cranial base. However, they were more frequent in the posterior-third of the lateral-third region of the anterior, middle-third of the lateral and middle-third regions of the middle, and middle-third region of the posterior cranial base, and sparse in the posterior and medial-third regions of the middle cranial base. The DVs showed marked morphological variability. For instance, the DVs of the pterional area were generally well defined, as pivotal channels connecting the lateral parts of the anterior and middle cranial base, but were highly varied in appearance.

Conclusions The DVs of the cranial base are distinct structures characterized by morphological variability and topographical predilection. Contrast MRI is useful for delineating these veins.

Keywords Anatomy · Cranial base · Diploic vein · MRI

Introduction

The diploic veins (DVs) are venous channels formed within the diploë of the skull. In humans, the DVs—along with the emissary veins—are established by the age of 5 years and assumed to play a role in brain cooling [7]. However, the physiological role of DVs is not fully understood. A recent study with measuring blood biomarkers suggested that DVs of the cranial base may function as alternative drainage pathways for the intracranial cerebrospinal fluid [15]. Under physiological conditions, the DVs are inconsistently visualized on computed tomography (CT) and magnetic resonance imaging (MRI). Therefore, they are infrequently paid attention in the clinical setting but can become obvious at traumatic and spontaneous dural arteriovenous fistulae, where they function as drainage routes [5, 10]. The DVs have been investigated mainly in the calvarial convexity using cadaveric specimens [3], animal experiments [12, 13], radiography [4], CT [2, 11], and MRI [6, 14]. Although there have been several studies describing the anatomy of the DVs of the cranial base [1, 8, 9, 16], only a limited area of the cranial base has been explored.

The present investigation aimed to characterize the morphology and distribution of the human DVs in the entire cranial base by using contrast MRI.

Materials and methods

The present retrospective study included 95 outpatients who underwent MRI examinations at our hospital between April 2010 and November 2015. They presented with headaches, dizziness, tinnitus, hearing loss, hemisensory disturbances, and seizures. Patients with a history of brain tumors, traumatic

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head injuries accompanying cranial base fractures, and vascular lesions affecting the dura mater and bony structures of the cranial base were excluded from the study. The patient population consisted of 44 men and 51 women aged 50 ± 16.3 years (mean ± standard deviation; range 13–78 years). Initial examinations using axial T1- and T2-weighted imaging, T2 gradient echo, fluid-attenuated inversion recovery, and diffusion-weighted sequences confirmed that none of the patients had any signs of the aforementioned pathological conditions. The patients then underwent a volumetric imaging examination with intravenous gadolinium infusion (0.1 mmol/kg) in the axial, coronal, and sagittal planes, involving the whole cranial vault. The following parameters were adopted: repetition time, 4.1 ms; echo time, 1.92 ms; slice thickness, 1 mm; interslice gap, 0 mm; matrix, 320 × 320; field of view, 250 mm; flip angle, 13°; and scan duration, 7 min 25 s. All imaging sequences were performed using a 3.0-T MRI scanner (Achieva R2.6; Philips Medical Systems, Best, The Netherlands). Imaging data were transferred to a workstation (Virtual Place Lexus 64, 64th edition; AZE, Tokyo, Japan) and independently analyzed by two of the authors (S.T. and H.I.). Coronal and sagittal images were used for the analysis. Due to low depiction performance of the DVs of the cranial base, confirmed during the preliminary observations, axial images were not used in the study. The DVs of the cranial base were assessed according to the following steps. Initially, the entire area of the cranial base was arbitrarily divided into three-thirds: the anterior, middle, and posterior cranial base. The posterior limit of the anterior cranial base was determined to comprise the sphenoid ridge, anterior clinoid process, and tuberculum sellae. The crista galli, a midline bony structure protruding upward from the floor of the anterior cranial base, was excluded from the area for analysis. The posterior limit of the middle cranial base was determined as the petrous ridge and dorsum sellae. Then, each of the three cranial bases was further subdivided into three equal parts in anteroposterior and lateromedial directions. The anteroposterior parts were evaluated on coronal images, while the lateromedial parts were evaluated on sagittal images (Fig. 1). For each subpart, the morphology and distribution of the DVs confirmed to course in the cranial base, just below the lining dura mater, were recorded. At the posterior cranial base, only the morphology and distribution of the DVs lying below the lower margins of the transverse sinuses were recorded. The emissary veins found in the diploë of the cranial base were excluded from the analysis.

The study was conducted in accordance with the guidelines of our institution regarding human research. Written informed consent was obtained from all patients prior to their participation in the study.

Results

Coronal images

On coronal images, the DVs of the anterior, middle, and posterior cranial base were assessed at the level of the anterior-, middle-, and posterior-third regions, respectively.

Anterior cranial base The DVs were identified in the anterior-third region in 50 (53%) patients on the right side and in 40 (42%) patients on the left side. The DVs of the middle-third region were identified in 67 (71%) patients on the right side and in 61 (64%) patients on the left side, while the DVs of the posterior-third region were found in 85 (89%) patients on both sides. The DVs of the anterior-third region arose commonly from the supraorbital area, coursing upward

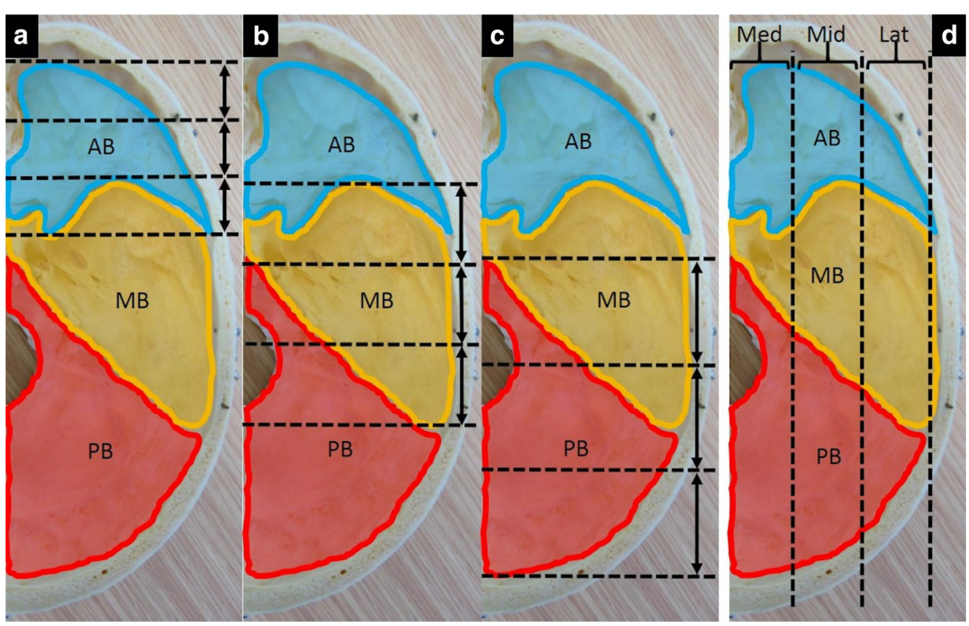


Fig. 1 The right half of an axially sectioned human dry skull, viewed from above, showing three subdivisions in the anteroposterior direction (**a**–**c**, dotted lines) of the anterior (**a**, colored in blue), middle (**b**, colored in yellow), and posterior cranial base (**c**, colored in red), which were evaluated on coronal images, and three subdivisions in the lateromedial direction of the cranial base (**d**, dotted arrows), which were evaluated on sagittal images. *AB* anterior cranial base, *Lat* lateral-third, *MB* middle cranial base, *Med* medial-third, *Mid* middle-third, *PB* posterior cranial base (color figure online)

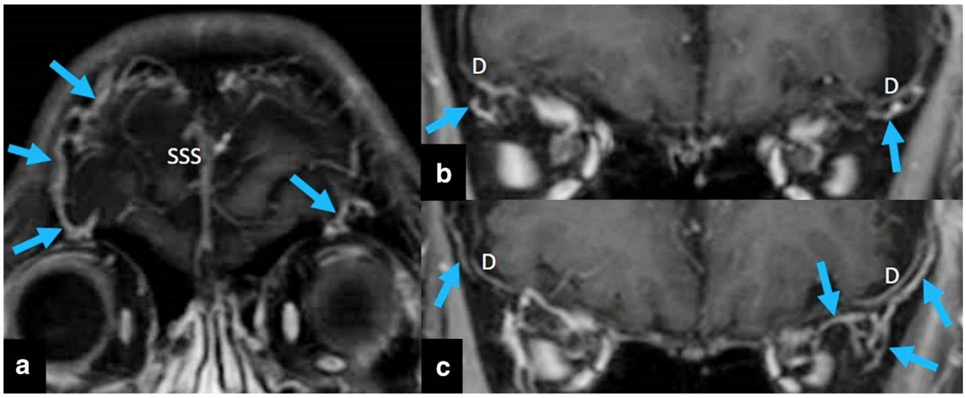


Fig. 2 Post-contrast coronal magnetic resonance images of a patient showing the diploic veins of the anterior cranial base, at the level of the anterior- (**a**, arrows), middle- (**b**, arrows), and posterior-third region (**c**, arrows). Note that the diploic veins of the anterior-third region arise from the supraorbital area, course upward in the frontal bone, and finally connect to the anterior part of the superior sagittal sinus (SSS) (**a**), while those of the middle- and posterior-third regions arise from the pterional area and course upward in the frontotemporal calvarial convexity (**b**, **c**). In this patient, the diploic veins form a multicircuit channel at the left pterional area (**c**). *D* dura mater

in the frontal bone as a single trunk, and finally connecting to the anterior part of the superior sagittal sinus (Fig. 2a). In contrast, the DVs of the middle- and posterior-third regions arose from the pterional area as a single channel or multiple channels and coursed upward in the frontotemporal calvarial convexity. In five sides, the DVs of the posterior-third region arose from a multicircuit channel (Fig. 2b, c).

Middle cranial base The DVs were identified in the anterior-third region in 56 (59%) patients on the right side and in 50 (53%) patients on the left side. The DVs of the middle-third region were identified in 62 (65%) patients on the right side and in 74 (78%) patients on the left side, while those of the posterior-third region were found in 4 (4%) patients on both sides. These DVs were delineated as linear or dashed line-like structures lying below the floor of the middle cranial base (Fig. 3).

Posterior cranial base The DVs were identified in the anterior-third region in 57 (60%) patients on the right side and in 78 (82%) patients on the left side. The DVs of the

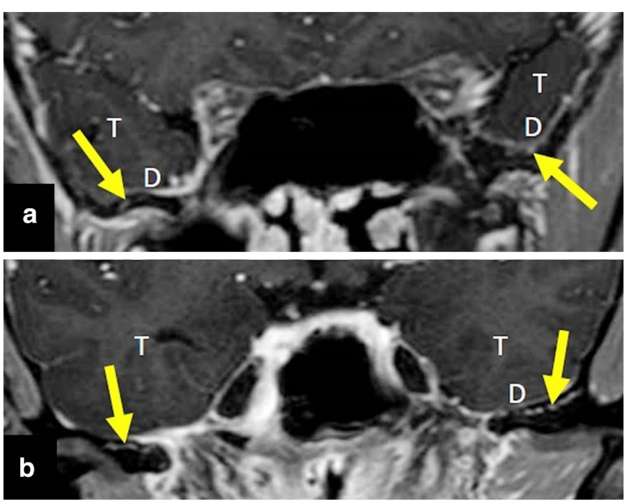


Fig. 3 Post-contrast coronal magnetic resonance images of a patient showing the diploic veins of the middle cranial base, at the level of the anterior- (**a**, arrows) and middle-third regions (**b**, arrows), coursing below the temporal dura. *T* temporal lobe

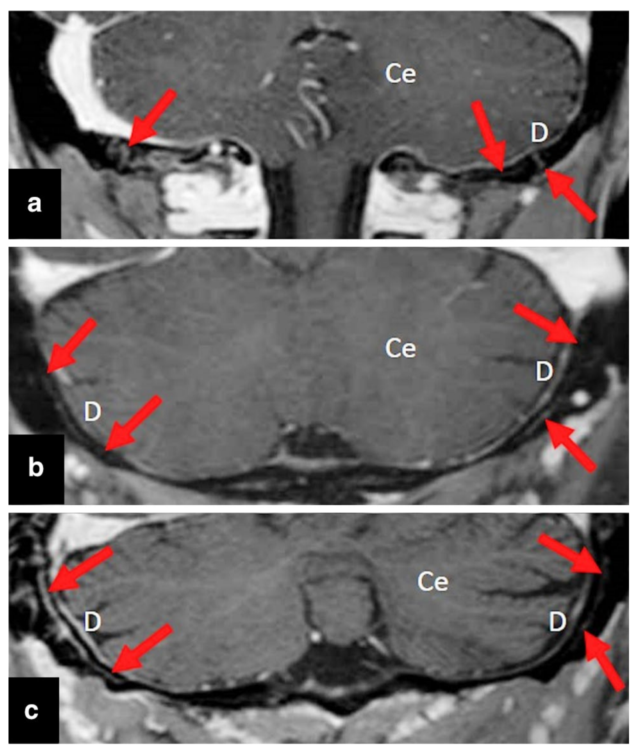


Fig. 4 Post-contrast coronal magnetic resonance images of a patient showing the diploic veins of the posterior cranial base, at the level of the anterior- (**a**, arrows), middle- (**b**, arrows), and posterior-third regions (**c**, arrows), coursing in the occipital bone along with the suboccipital surface of the cerebellum. *Ce* cerebellum

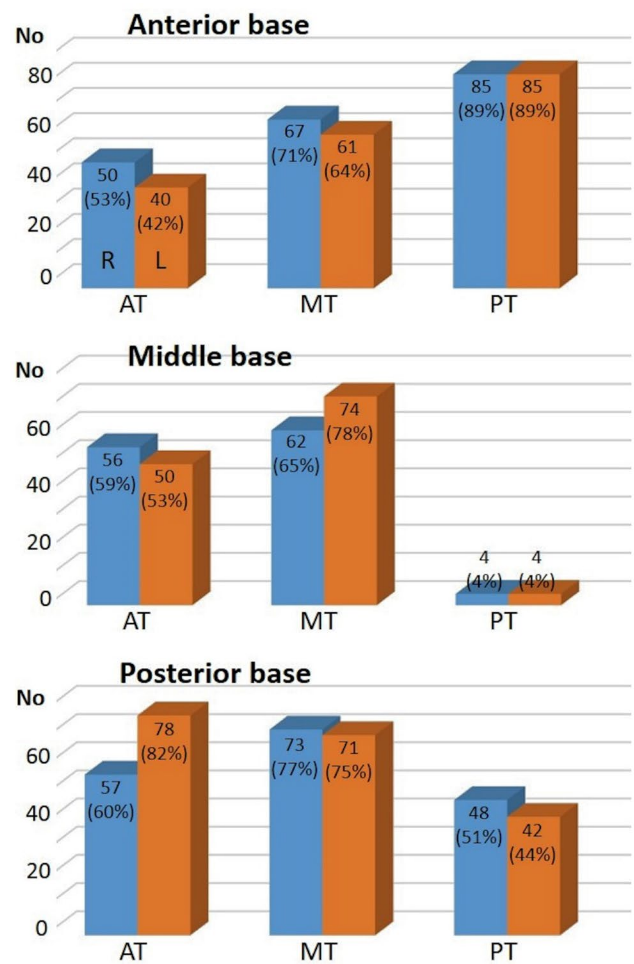


Fig. 5 Distributions and identification rates of the diploic veins in nine subparts of the cranial base: coronal images. *AT* anterior-third, *L* left, *MT* middle-third, *PT* posterior-third, *R* right

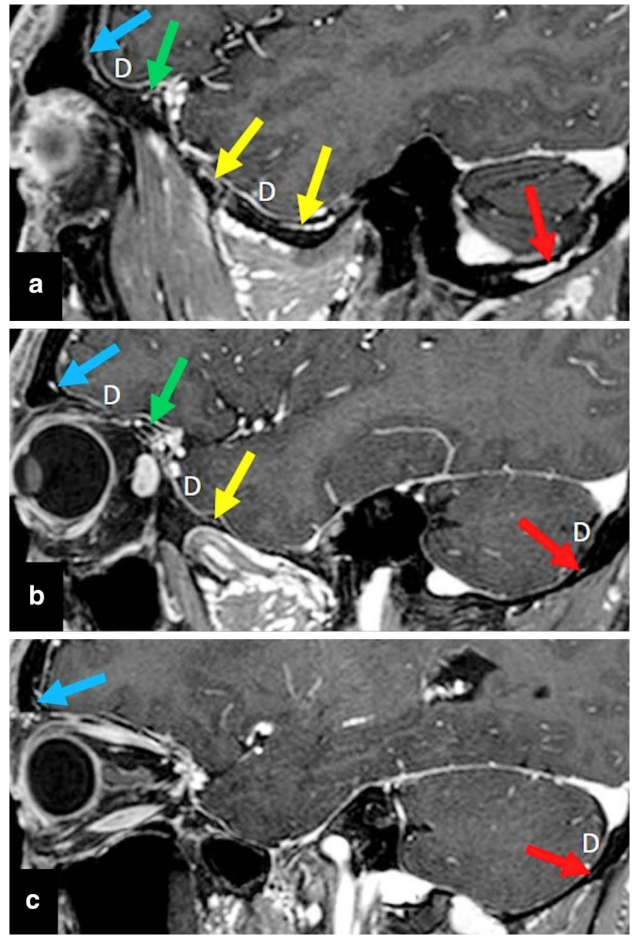


Fig. 6 Post-contrast sagittal magnetic resonance images of a patient, at the level of the lateral- (**a**), middle- (**b**), and medial-third regions (**c**), right side, showing the diploic veins of the anterior cranial base (**a–c**, blue arrow), pterional area (**a** and **b** green arrow), middle cranial base (**a** and **b**, yellow arrows), and posterior cranial base (**a–c**, red arrow) (color figure online)

middle-third region were identified in 73 (77%) patients on the right side and in 71 (75%) patients on the left side, while those of the posterior-third region were found in 48 (51%) patients on the right side and in 42 (44%) patients on the left side. These DVs were delineated commonly as linear structures coursing in the occipital bone along the suboccipital surface of the cerebellum (Fig. 4). The distributions and identification rates of the DVs in nine subparts of the cranial base are summarized in Fig. 5. The DVs were more frequently distributed on the left side in the middle-third region of the middle cranial base and anterior-third region of the posterior cranial base.

Sagittal images

On sagittal images, the DVs of the cranial base were assessed at the level of the lateral-, middle-, and medial-third regions in each hemicranium. These DVs were delineated as linear structures with variable length and thickness (Fig. 6).

Lateral-third region The DVs were identified in 50 (84%) patients in the right anterior base, 78 (82%) patients in the middle base, and 80 (84%) patients in the posterior cranial base; and in 78 (82%) patients in the left anterior base, 80 (84%) patients in the middle base, and 84 (88%) patients in the posterior cranial base.

Middle-third region The DVs were identified in 61 (64%) patients in the right anterior base, 70 (74%) patients in the middle base, and 75 (79%) patients in the posterior cranial base; and in 80 (84%) patients in the left anterior base, 77 (81%) patients in the middle base, and 75 (79%) patients in the posterior cranial base.

Medial-third region The DVs were identified in 39 (41%) patients in the right anterior base, 6 (6%) patients in the middle, and 81 (85%) patients in the posterior cranial base; and in 48 (51%) patients in the anterior base, 10 (11%) patients in the middle base, and 71 (75%) patients in the posterior

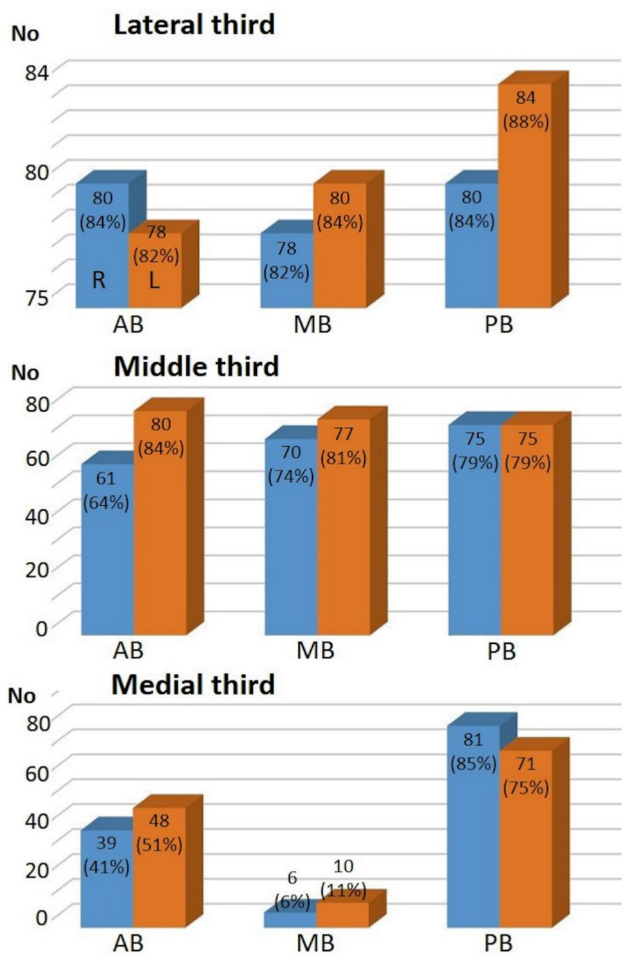


Fig. 7 Distributions and identification rates of the diploic veins in nine subparts of the cranial base: sagittal images. *AB* anterior cranial base, *MB* middle cranial base, *PB* posterior cranial base

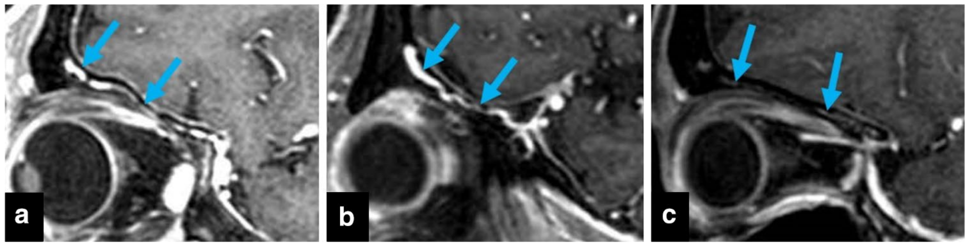
Fig. 8 The right half of an axially sectioned human dry skull, viewed from above, showing three predilection sites of the diploic veins in the cranial base as elliptical areas colored in purple and two regions with sparse diploic veins indicated as elliptical areas colored in green (color figure online)

cranial base. The distributions and identification rates of the DVs in nine subparts of the cranial base are summarized in Fig. 7. The DVs were more frequently distributed on the left side in the middle-third region of the anterior cranial base.

In summary, the DVs of the cranial base were more frequently distributed in three areas: the posterior-third of the lateral-third region of the anterior cranial base, middle-third of the lateral and middle-third regions of the middle cranial base, and middle-third region of the posterior cranial base. In contrast, these veins were sparse in two sites: the posterior and medial-third regions of the middle cranial base (Fig. 8). Concerning the laterality, the DVs were more frequently distributed on the left side in the middle-third regions of the anterior and middle cranial bases and anterior-third region of the posterior cranial base. Furthermore, the coronal images were, compared to the sagittal images, more sensitive in detecting the DVs of the anterior base, while sagittal images were more sensitive in detecting the DVs of the middle and posterior cranial bases (Figs. 5, 7).

Then, the lateral orbital roof, pterional region, lateral-third region of the middle cranial base, and posterior cranial base were further explored. The lateral part of the orbital roof contained the DVs with variable morphologies and connecting between the pterional and supraorbital region (Fig. 9). The DVs of the pterional area were generally well developed, while showing highly variable appearance. On coronal images, these DVs were delineated as a single channel, a confluent channel of multiple tributaries, a confluent channel of groups supplied by aggregation of small tributaries, or a multicircuit channel forming a network structure (Fig. 10). On sagittal images, the DVs of the region were delineated as pivotal DV channels connecting the lateral parts of the anterior and middle cranial base, and were varied in appearance (Fig. 11). The DVs of the lateral-third region of the middle cranial base showed variable morphologies, lying in the diploë of the floor. In 20 (11%) sites, these DVs of the middle cranial base were found

Fig. 9 Post-contrast sagittal magnetic resonance images of different patients showing the diploic veins with variable morphologies, coursing in the lateral orbital roof, and connecting between the pterional and supraorbital area (**a**–**c**, arrows). **a**–**c** Right side



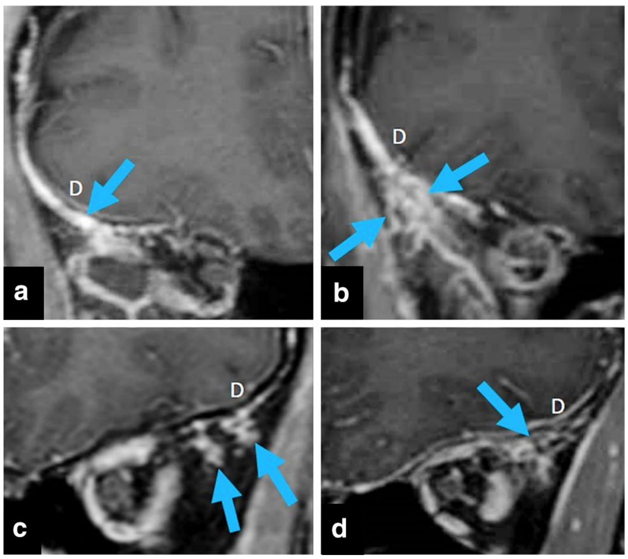


Fig. 10 Post-contrast coronal magnetic resonance images of different patients showing variable morphologies of the diploic veins lying in the pterional area (**a**–**d**, arrows). **a** Single channel; **b** channel formed by confluence of multiple tributaries; **c** channel formed by groups of venous aggregation supplied by small tributaries; **d** multicircuit channel forming network structure. **a**, **b** Right side; **c**, **d** left side

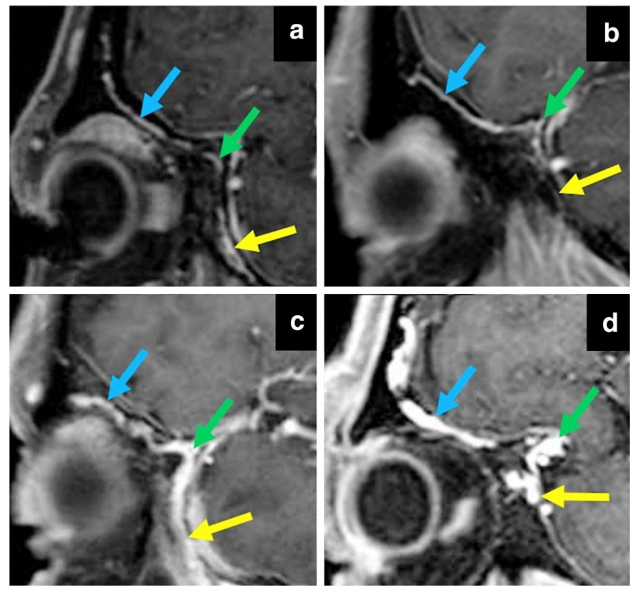


Fig. 11 Post-contrast sagittal magnetic resonance images of different patients showing variable diploic veins of the pterional area (**a**–**d**, green arrow), functioning as pivotal channels connecting the diploic veins of the lateral parts of the anterior (**a**–**d**, blue arrow) and middle (**a**–**d**, yellow arrow) cranial base. **a**–**d** Right side (color figure online)

to pass through the floor and join the pterygoid venous plexus. Furthermore, the DVs of the posterior cranial base showed variable morphologies coursing in the rostro-caudal direction, parallel to the sagittal planes. In 14 (7%) sites, these DVs communicated with the dura mater or the extracranial, suboccipital venous system (Fig. 12).

Discussion

In this study, the DVs were identified in all areas of the cranial base. However, they were more frequently identified in three different parts of the anterior, middle, and posterior cranial base, and sparser in two parts of the middle cranial base. In addition, the DVs were more frequently distributed on the left side in three parts of the cranial base. The DVs showed marked morphological variability. For instance, the DVs of the pterional area were generally well developed, functioning as pivotal DV channels of the lateral parts of the anterior and middle cranial bases. The topographical predilection of the DVs needs further investigation for probable anatomical and functional implications. Previous studies also suggested that the major DV channels course through specific sites of the calvarial convexity [3, 14].

In the present study, contrast MRI allowed visualization of the DVs at their predilection sites both on coronal and sagittal images, with identification rates greater than 80%. Different from CT scans, contrast MRI is a simple and convenient modality that can make direct visualization of the DV segments feasible without adding technical modifications to the obtained original images [8, 9, 11, 14]. Also, the coronal sequence was, compared to the sagittal imaging, more sensitive in delineating the DVs of the anterior cranial base, while the sagittal sequence was more sensitive in detecting the DVs of the middle and posterior cranial bases. In contrast, the axial images showed low depiction performance for the DVs. These findings may mainly derive from the topographical

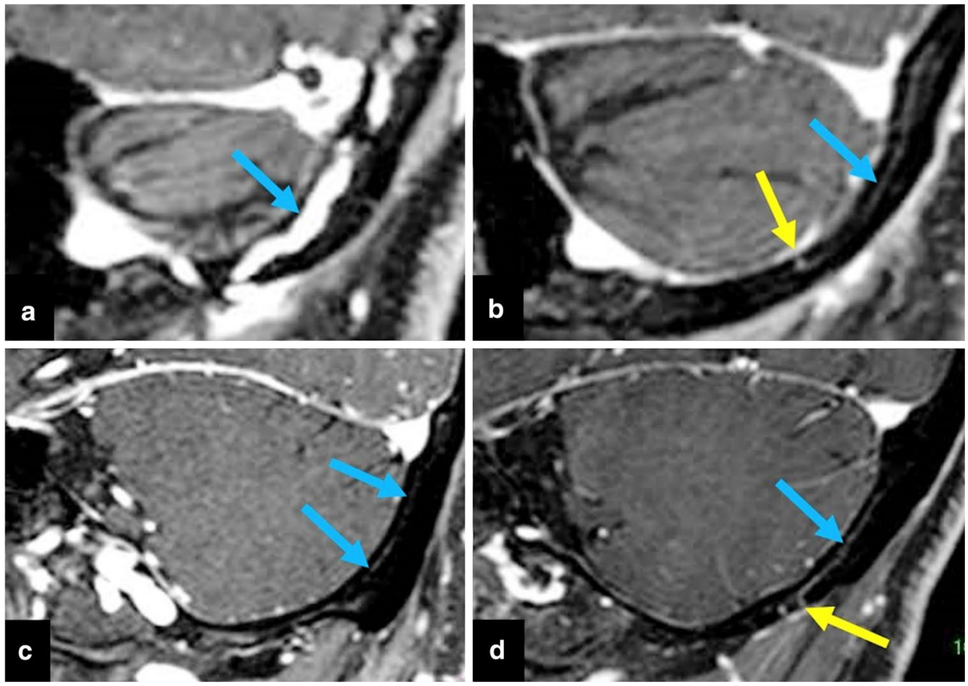


Fig. 12 Post-contrast sagittal magnetic resonance image showing variable morphologies of the diploic veins of the right posterior cranial base coursing in the rostro-caudal direction parallel to the sagittal planes (**a**–**d**, blue arrows). There are diploic veins communicating with the dura mater and the extracranial, suboccipital venous system (**b** and **d**, yellow arrow) (color figure online)

differences of the morphology of the skull base and its DVs. Continuous exploration using MRI coupled with case accumulation and technological innovations would much improve the resolution of the DVs. Investigation of the anatomical and functional connections not only between the DV system of the calvarial convexity and that of the cranial base but also between the extracranial venous system and the DV system of the cranial base would be the next steps. In addition, correlations between the topographical predilection of the DVs and occurrence of various pathologies affecting the cranial base, such as tumors, vascular lesions, and infectious diseases, warrant investigation. Settlement of these issues may bring about more reasonable strategies of surgical treatments based on the association between these pathologies and adjacent DVs.

The present study has limitations and weaknesses. The study population consisted of patients with an inhomogeneous age distribution and uneven sex ratio. They were retrospectively evaluated and not randomly assigned. Therefore, statistical analysis was not adopted. Furthermore, these DVs were assessed based only on the observations of thin-sliced, contrast MRI. In addition, in the present study, the cranial base was arbitrarily divided into nine subparts for convenience of analysis. The method might be convenient for investigating within a limited area, but unsuitable for gaining a perspective of the DVs distributing over the broad cranial base. Despite these limitations, we believe that the results of this preliminary study can provide insights to improve understanding of the DVs of the cranial base.

Conclusions

The DVs of the cranial base are distinct structures characterized by morphological variability and topographical predilection. Contrast MRI is useful for delineating these veins.

Author contributions ST conceived the study. HO and YY collected the imaging data. ST and HI analyzed the imaging data. ST wrote the manuscript.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare regarding the materials or methods used in this study or the findings presented in this paper.

Ethical approval All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all involved participants included in the study.

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