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ORIGINAL ARTICLE

The parietal foramen anatomy: studies using dry skulls, cadaver and in vivo MRI

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Abstract

Objective The aim of this study was to describe the anatomical features encountered in the parietal foramen in a series of 178 human bones and 123 head MRI examinations. A cadaveric specimen was also dissected to demonstrate the trajectory of a superficial scalp vein through the parietal foramen as far as the dura mater. A literature review was performed regarding prevalence of parietal foramen in different populations.

Methods Totally, 178 paired adult bones were used to investigate the presence, shape and number of the parietal foramina. In addition, 123 brain MRI examinations were also studied.

Results The parietal foramina were encountered in 75/89 (84.3%) skulls [32/38 (84.2%) in women vs. 43/51 (84.3%) in men, $p > 0.05$]. The parietal foramen was present bilaterally in 44.73% of females and 54.9% of males. Regarding unilaterality of the parietal foramen, a right or left laterality was observed in female 21% right versus 18% left; and 16% versus 14% (left) in males ($p > 0.05$). The accessory parietal foramen was present in the right parietal in 2.6% and in 7.9% on the left side of the females, while 5.9% and 3.9% of the males on the right or left sides, respectively. The parietal foramina located in the proximity of the sagittal suture (male 7.1 ± 2.5 mm vs. female, 7.4 ± 2.7 mm). There was a positive correlation between the right and left parietal foramina regarding the distance from the median line. The distance from a foramen to the contralateral one was 16 ± 4 mm in men and 18 ± 5 mm in women, respectively ($p > 0.05$).

Conclusion No major differences were encountered between sexes regarding the anatomical features of parietal foramen.

Keywords Human skull · Parietal foramen · Morphology · Sex difference

Introduction

Very little attention has been paid to the parietal foramen, an often symmetrical bilateral anatomical structures with a function of extreme importance in controlling intracranial temperature and maintaining intracranial pressure in the various positions of the head in relation to the body during daily activities. Often during different approaches to reach intracranial structures, used in neurosurgery procedures, the surgeon has to observe the parietal foramen and the respective nerve and vessels that pass through it, to preserve functions. As there are several other communication routes between the intracranial cavity and the outer part of the head, e.g., scalp, damage to the foramen usually does not cause significant disturbances (or clinically noticeable) in the functions linked with vessels (venous and arterial) and nerve that travel through it.

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Regarding the venous anastomosis, with a venous blood flow that may occur in opposite directions, depending on the pressure gradient between these two compartments, venous vessels establish its physiological role through the parietal foramina.

Although rarely mentioned, it is a fact that arterial vessels and nerves may also use this foramen to reach the intracranial structures, which were observed during several cadaveric specimens [15, 41]. Yoshioka and coworkers [41], in the Laboratory of Rhoton, studied 20 parietal foramina in adult cadaveric specimens, and in all, they identified anastomoses between middle meningeal and scalp arteries. These authors and reviewers also mentioned the following conditions as possible causes of vascular changes or exerting a role in the pathophysiology linked to the parietal foramen: air embolism, Moya–Moya disease, dural arteriovenous malformation, traumatic subdural or epidural hematomas and defects in the cranial revascularization during reconstructive procedures [41].

In non-physiological conditions, the presence of a parietal foramen can facilitate the passage of tumors cells from the intracranial compartment to the outer part of the head, as reported by Nawashiro [29] in a patient with meningioma. In addition, the parietal foramen was, inclusive, used in endovascular procedures in the treatment of a patient with dural fistula [7]. Thus, a quantitative anatomical study of the morphological characteristics of this foramen is of vital importance for those who deal with surgical procedures on the skull.

The parietal foramina, frequently located bilaterally, are usually symmetrical rounded or oval structures, positioned side by side a few millimeters from the sagittal suture [27]. They are orifices observed on the postero-medial surface of the parietal bones connecting a complex network of veins between the extracranial tissues and the intracranial venous vessels, directly or indirectly connecting with the superior sagittal sinus [4]. This venous system is also interconnected with an extensive diploic venous structure [4, 12].

The parietal foramina vary widely in topography, shape, number and size and may occur unilaterally in isolation or even be absent [40, 41]. One early study [10] showed that the parietal foramen was present in 60–70% of adults and was unilateral in roughly half of them.

Regarding phylogeny, the parietal foramen may be found in various animals with a skull, including species in an early phase of the evolutionary process [2].

In humans, the formation of the parietal foramen occurs from a single membranous center between the seventh and eighth weeks of fetal development [10]. Other authors [33], however, consider that the ossification involves two or more membranous centers that merge to form a tunnel through the parietal bone.

It is believed that the parietal foramen with its emissary vein (valveless) plays an important role in regulating intracranial pressure and brain temperature in view of its ability to modify the direction of blood from the intracranial space to the extracranial one or vice versa [6, 9, 18]. In the scalp, the temperature is, most of the time, lower than in the intracranial compartment and the exchange of blood may regulate the intracranial temperature, depending on the metabolic demand of the individual and the temperature of the environment [6, 23]. For its part, the venous system plays a pivotal role in controlling intracranial pressure, particularly during changes in the position of the head and Valsalva manoeuvers during daily physical activities [25].

Although it is known that there are significant differences between the size of the skull between the sexes in humans, almost nothing has been published about possible differences between the sexes concerning the parietal foramen.

The aim of this article is to compare the sexes in relation to anatomical features encountered in the parietal foramen in a series of parietal bones and MRI head examinations. In addition, a cadaveric specimen was dissected in order to illustrate the trajectory of a superficial scalp vein through the parietal foramen until the dura mater. A literature review was performed regarding prevalence of parietal foramen in different populations.

Method

The study was approved by the Ethics in Research Involving Human Subjects Committee at the Federal University of Pernambuco, Brazil (CAAE: 79464917.6.0000.5208).

In order to better illustrate the passage of an anastomitic vein and artery through the parietal foramen, an adult male cadaveric specimen was dissected.

In this study, 178 paired parietal bones (right and left) belonging to the Human Adult Bone Collection of the Academic Center of Vitoria, Federal University of Pernambuco, Brazil, were used in order to investigate the presence and number of the parietal foramina, from March 2017 to December 2017. With the help of a pachymeter, the respective distance between the sagittal suture (midline) and the foramen (Fig. 1) and the distance between the parietal foramen and the *euryon* were determined. Possible differences between sexes were also verified.

Considering that an emissary foramen connects the extracranial and the intracranial compartments, a 0.5-mm (outer diameter) needle was employed, thereby demonstrating its total passage from the outer to the inner compartments or, alternatively, the passage of light from a lantern though the foramen, in order to confirm a complete communication between the extra- and intracranial content.

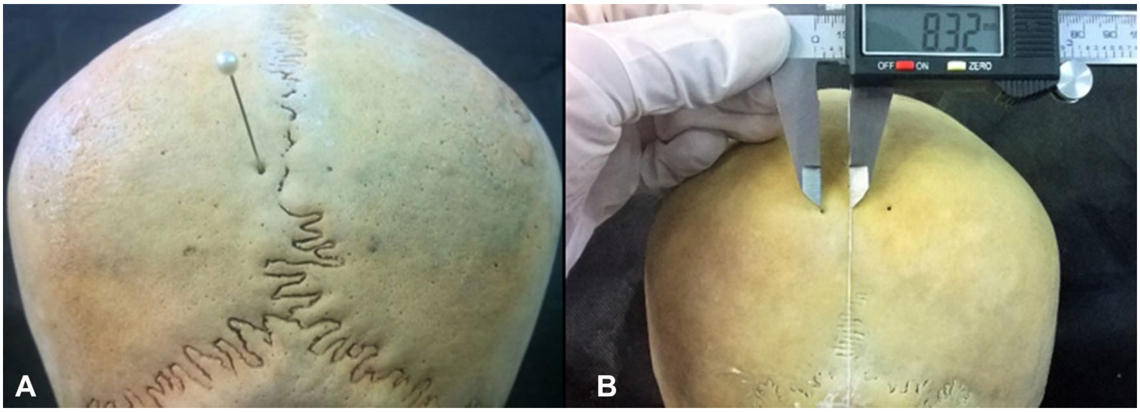

Fig. 1 **a** Penetrability of the pin in the foramen. **b** Measure the distance between the parietal foramen and the sagittal suture

Table 1 Prevalence of the parietal foramen in men and women

	Men	Women	p^a
Bilateral	28/51 (55%)	17/38 (45%)	0.395
Unilateral right	8/51 (16%)	8/38 (21%)	0.583
Unilateral left	7/51 (14%)	7/38 (18%)	0.570
Absent	8/51 (16%)	6/38 (16%)	> 0.999

[a] X^2 test

To determine the median sagittal line, a line from the bregma to the lambda was created using a #10 cotton thread and the distance from the lateral edge of the orifice of the parietal foramen to the median sagittal line was measured with the aid of a 150-mm digital stainless steel pachymeter (Lee Tools).

A literature review was performed using MeSH Database (NCBI) and the terms "parietal foramen." After the literature search, 138 articles were found. One hundred and twelve articles were excluded after reading the title and other 2221 after reading the abstract. In the end, only five articles reporting the prevalence of parietal foramen in the human skull in different populations were used to make Tables 1 and 2.

Quantitative data are shown as mean ± SD and the qualitative variables are expressed through relative frequency (percentage) and absolute number. Chi-square test or Fischer's exact test, when applicable, was used to compare groups in relation to their qualitative variables. Student's *t* test or Mann–Whitney test was performed to the numeric variables, depending on the normality of data. A significant difference in the statistical test was considered when $p < 0.05$.

In addition, 142 brain MRI examinations were also studied. Only subjects without expansive intracranial processes (tumor, acute/subacute ischemia or hemorrhage) were reviewed. After excluding 19 anatomically disrupted patients, 123 adult patients were suitable for morphometric measurements, examined independently of their right and left halves. The mean age was 58.9 years (range, 18–80 years). Examinations were performed using a 1.5 T MR scanner equipped with an 8-channel head coil (Achieva02; Philips Medical Systems, Recife, Brazil). Contrast examination with intravenous infusion of gadolinium (0.1 mmol/kg) on T1-weighted sequence and obtained in sagittal sections of the whole cranial vault was performed with the following parameters: pulse repetition time 6.983 ms, echo delay time 3.162 ms, slice thickness 1.00 mm, interslice gap 0.5 mm, matrix 0 256 256 0, flip angle 8 and scan duration 5 min 19 s. All imaging data in the contrast examinations were transferred to the software OsiriX 10.0.1 in order to be analyzed.

Results

Figure 2 shows the examples of different anatomical variations encountered in parietal bones regarding the presence or absence of the parietal foramina. Figure 3 shows the external and internal aspects of a skull with bilateral parietal foramina. Also, the interior of a parietal foramen can be seen. The trajectory of the superficial temporal vein (Fig. 4a) until the emissary vein of the parietal foramen (Fig. 4b) in direction to the dura mater is shown in Fig. 4. Artery and vein through the parietal foramen can be seen in Fig. 4c and d.

The parietal foramina were encountered in 75 of the 89 (84.3%) studied dry skulls [32/38 (84.2%) in women vs. 43/51 (84.3%) in men]. While in MRI examinations, it was found in 87 of 123 (70.7%) [61/81 male (75.3%) and 26/42 female (61.9%); $p = 0.145$] (Fig. 5).

Table 1 shows the data referring to parietal foramen, such as bilateral or unilateral (right or left) presence, or its absence in both sexes. The parietal foramen was present

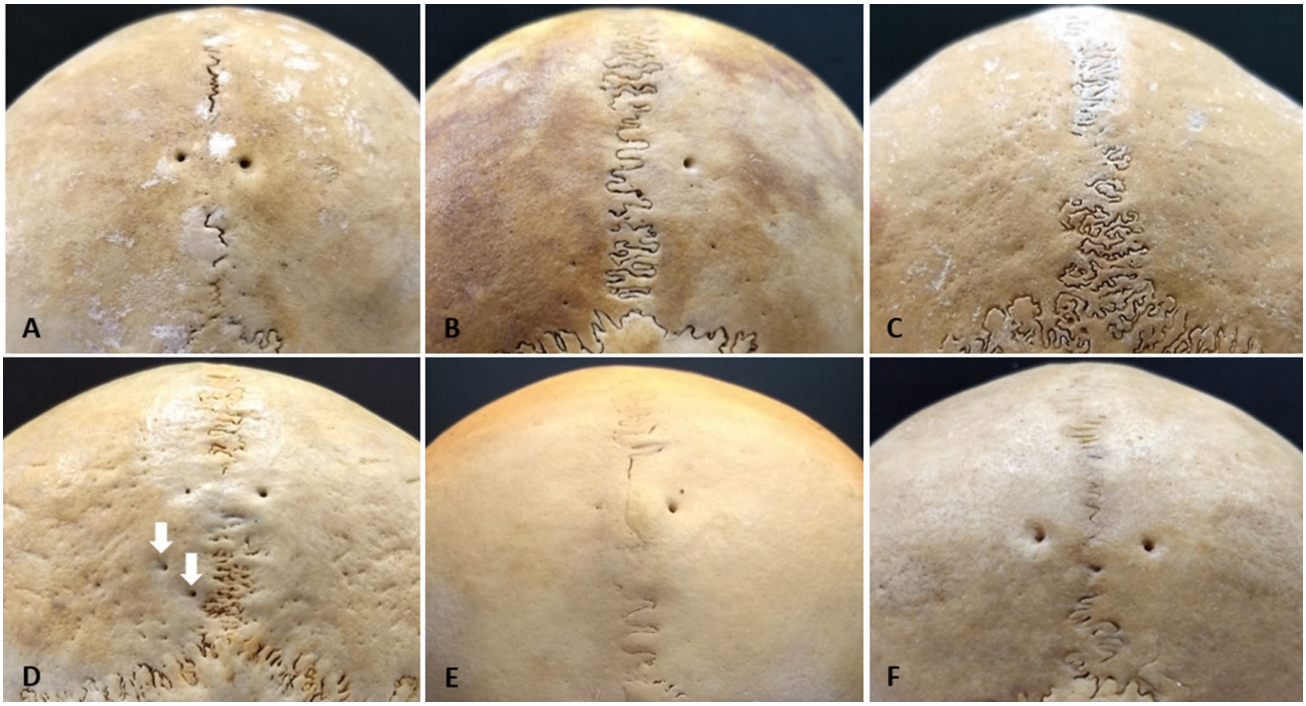

Fig. 2 Presence/absence of the parietal emissary foramen. **a** Present bilaterally. **b** Present unilaterally. **c** Absent. **d** Presence of multiple foramina (arrows). **e** Oval foramen. **f** Presence of a foramen in the sagittal suture

bilaterally in 44.7% of females and 54.9% of males in dry skull and in 53.8% of females and 45.9% of males in MRI, respectively.

A slight asymmetry was encountered between sides regarding unilaterality. In dry skull, the right parietal bone presented parietal foramina in 21% versus 18% (left) in females and 16% versus 14% (left) in males, without statistical significance ($p > 0.05$, X^2). Conversely, in MRI, females with 34.6% (right) and 11.5% (left), while males with 21.3% (right) and 32.7% (left).

In all hemicrania with a parietal foramen examined, the parietal foramina located in the posterior part of the parietal bone (male 84 ± 8 mm from bregma and 33 ± 8 mm from lambda; female 84 ± 6 mm from bregma, 30 ± 6 mm from lambda), in the proximity of the sagittal suture [male 7.1 ± 2.5 (min 1.9–max 13.4) mm vs. female, 7.4 ± 2.7 (min 2.2–max 13.2) mm; Fig. 6b]. There was a positive correlation ($p < 0.001$, linear regression) between the right and left parietal foramina regarding the distance from the median line in the skulls with bilateral parietal foramina (slope 0.4265 ± 0.108, 95%CI 0.2133 to 0.6397, R^2 0.2610; Fig. 6a).

As for the existence of more than one parietal foramen in each parietal bone, some individuals presented an extra foramen (accessory foramen), and of the 178 parietal bones (dry skulls) studied only one individual presented two accessory foramina on the same side.

The accessory parietal foramen was present in the right parietal in 2.6% and in 7.9% on the left side of the females, while 5.9% and 3.9% of the males presented an accessory parietal foramen on the right or left sides, respectively. There was a second left parietal foramen (accessory) in one of the two (4%) parietal bones in male.

The distance from a foramen to the contralateral one was 16 ± 4 mm in men and 18 ± 5 mm in women, respectively ($p > 0.05$ Student's *t* test). No statistical differences were found between sexes in the distance between the foramen and the ipsilateral *euryon* (female 5.8 ± 0.1 mm vs. male 6.0 ± 0.1, $p = 0.076$ unpaired Student t-test).

There were no statistically significant differences when comparing the distance between the right and left foramina, in men and women.

The external appearance of the parietal foramina was a round shape in all except four foramina [1/49, 2.0% in women vs. 3/71, 4.2% in men; $p = 0.644$ Fisher´s exact test] which the contour was oval [one woman (unilateral) and two men (unilateral and bilateral, respectively)].

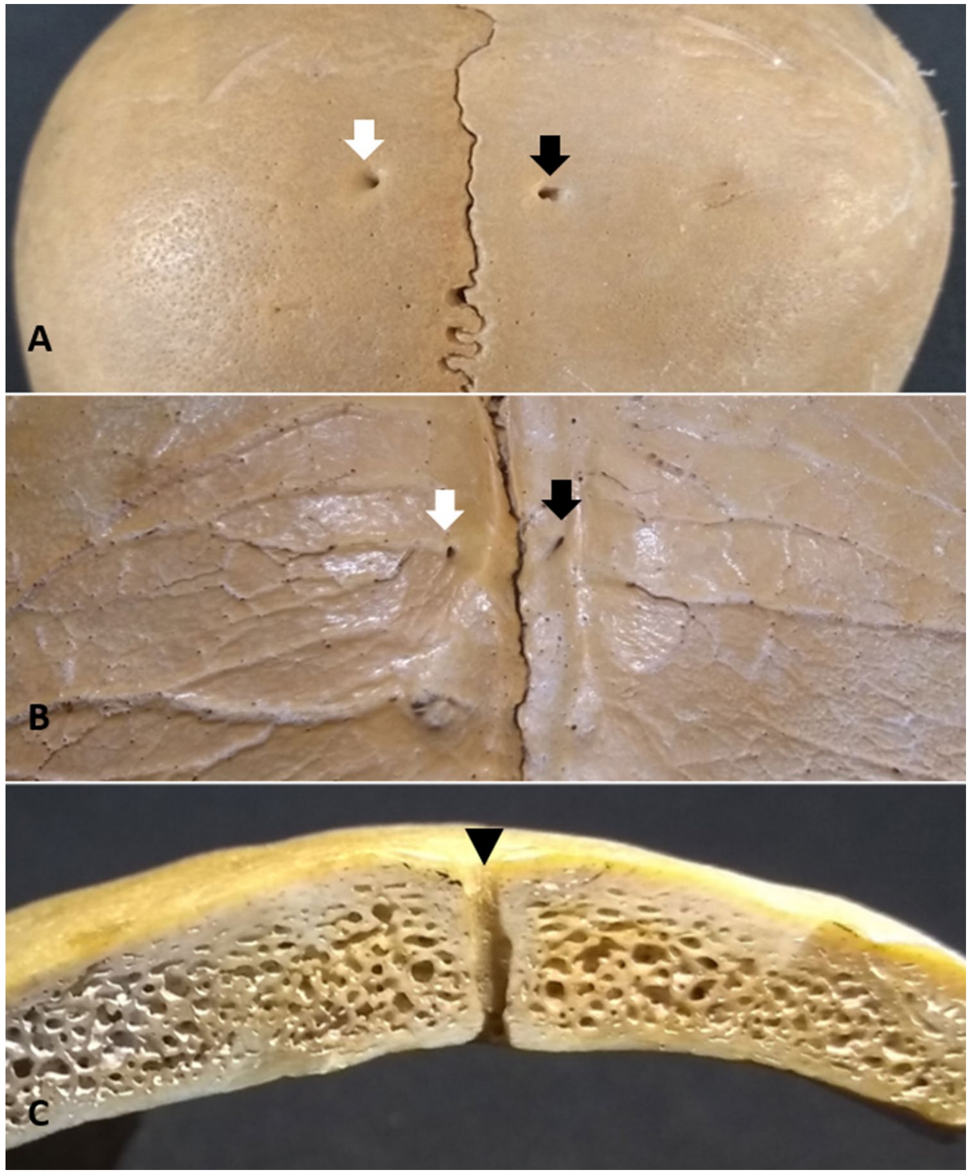

Fig. 3 **a** External view of the parietal emissary foramen, right foramen (black arrow), left foramen (white arrow). **b** Internal view of the parietal emissary foramen, right foramen (black arrow), left foramen (white arrow). **c** Sagittal section in the foramen canal

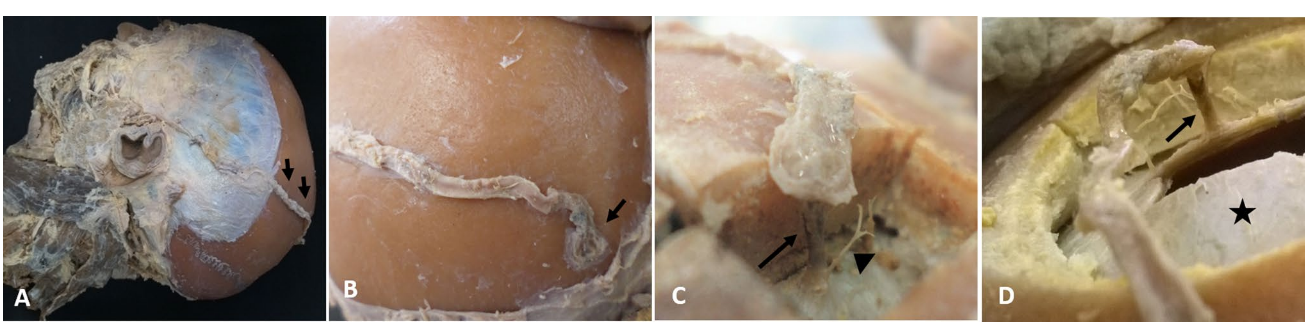

Fig. 4 **a** Superficial temporal vein (arrows). **b** Emissary vein passing through the parietal foramen (arrow). **c** Path of the outgoing vein that passes through the foramen (arrow), artery that accompanies the outgoing vein (arrow head). **d** Emissary vein (arrow) in contact with the dura mater (star)

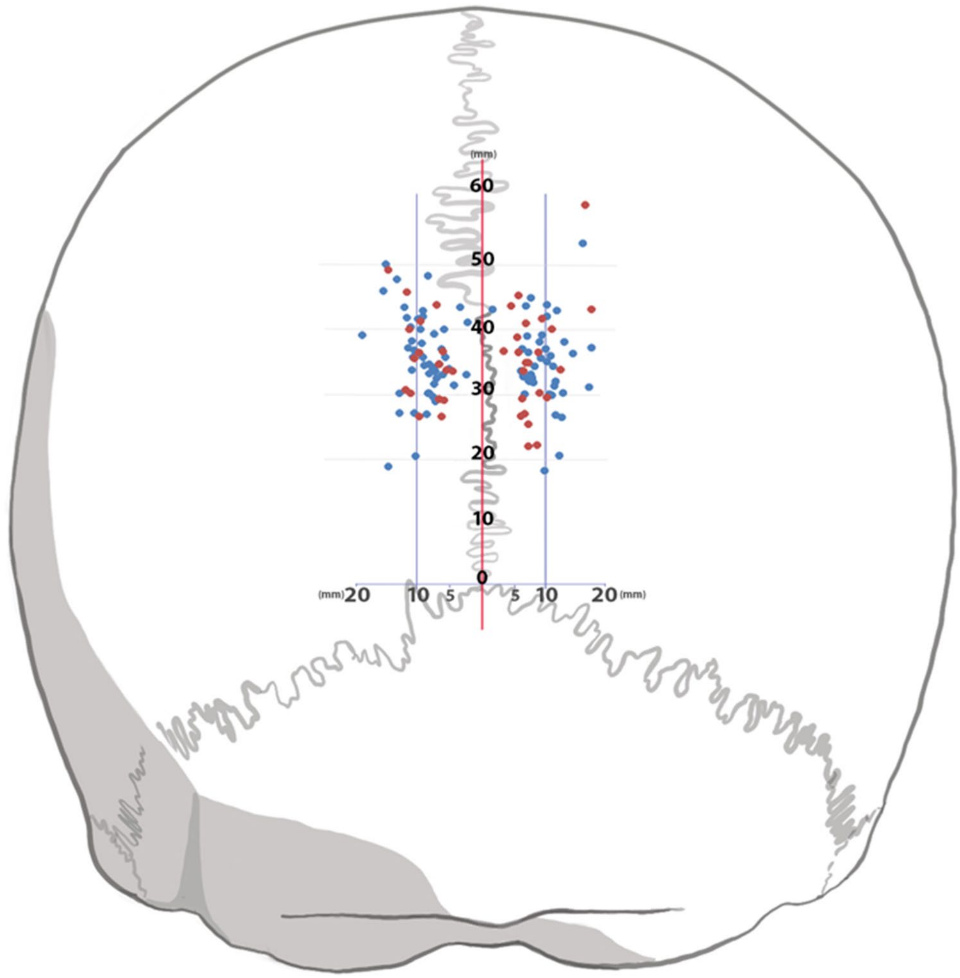

Fig. 5 Representation of the distribution of parietal foramina in resonance exams. Men in blue, women in red (color figure online)

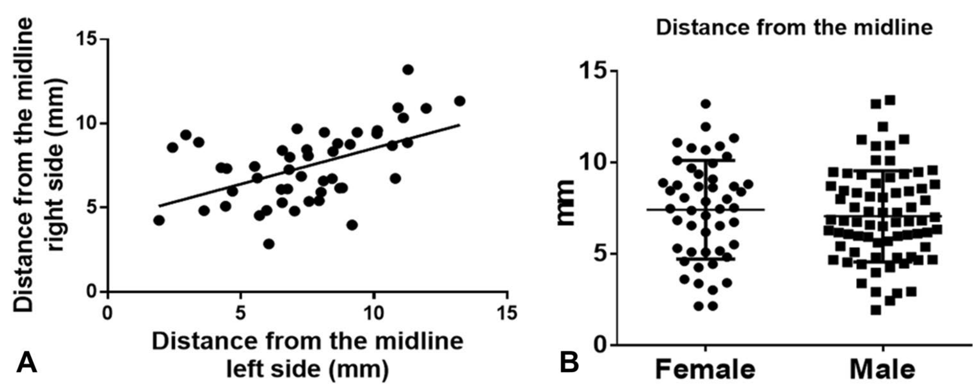

Fig. 6 **a** Distance from the right and left foramens to the median line, **b** distance from the median line in men and women

Discussion

The standard description of the parietal foramen considers it as a pathway that connects the intracranial cavity with the extracranial structures, through which vascular and neural structures may course [41]. There are many peculiarities when it comes to its location in the parietal bones and distance between the parietal foramen and two craniometric points named bregma and lambda [39].

Only a few studies [8, 27, 40, 41] have examined the frequency and other anatomic aspects of the parietal foramen, but, to the best of our knowledge, none of them evaluated in detail more specific differences between the sexes. Berry [3], using four collections of dry skulls (without reporting

Table 2 Prevalence of the parietal foramen in different populations or studies

Author (reference)	*n*	Population	Unilateral	Bilateral	Absent	Men	Women
41	20	Florida	20%	40%	40%	?	?
4	?	?	40.5%	19.9%	39.6%	?	?
27	58	South Indians	32.7%	55.2%	12.1%	?	?
8	39	Chile	25.6%	59%	15.4%	?	?
3	?	London collection	?	?	?	62.7%	60.4%
	?	Mexican	?	?	?	47.7%	51.6%
	?	Americans	?	?	?	43.2%	50.0%
	?	Burmese	?	?	?	50.0%	50.0%

the number of evaluated skulls) collected from different geographic region (i.e., St Bride's, London; Burma; North West coast of America; and Mexico), did not find differences in the frequency between sexes (Table 2), but without further morphological details (e.g., if they were unilateral or bilateral).

The prevalence of a parietal foramen was higher in the present study than in previous studies [4, 41] (see Table 2). This may be due to the racial variations found among different populations [27].

In the present study, the parietal foramen was bilateral in half of the cases, unilaterally in 11.5–34.6% and absent in 16.7–38.1% of the skulls. On the other hand, Yoshioka et al. [41] studied 40 parietal bones of adult individuals and noted that parietal foramina were present bilaterally in 40%, unilaterally in 20% and absent in the remaining 40%. This trend was also found in the studies of Boyd [4].

Boyd [4] observed the presence of the accessory foramen in 2–5% of the cases. This variability in the number of parietal foramina might be due to the difference in ossification of the posterior fontanelle and/or *obelion* area, and, perhaps, the ethnic variations among the population studied [11, 13].

In a noninvasive method to study [22] geometric characteristics of living human skulls, using 3000 CT scan images studying the A-P length and breadth of the skull, the authors reported an A-P length of 175.81 mm for male versus 170.61 mm in the female; regarding breadth de size was 145.35 mm in male versus 140.11 mm in the female. They concluded that males have a wider breadth and longer A-P length when compared to females.

The metrical relations between parietal foramina and other cranial structures must have an intimate relationship with hemodynamic phenomena responsible for controlling the pressure and temperature of brain tissue within the skull. The metrical relations were similar between the sexes, and we observed little variability. This suggests a strategic role in the arterial or venous blood flow that may exist between the intracranial space and the external tissue of the head, since a difference between the sexes was expected due to the smaller size of the female skull.

When comparing the distance between the right and left foramina, in men and women, there are no statistically significant differences. This may indicate that a fixed distance from the median line, i.e., from the foramen to the superior sagittal sinus, is required in order to maintain adequate hemodynamic equilibrium to allow for blood flow between intra- and extracranial compartments, to regulate intracranial pressure and temperature during changes in head position and Valsalva maneuver [11, 25]. Studies that address sex differences suggest the importance of assessing anatomical landmarks to explore the human skull [14, 28, 35, 37]. The vein that enters the foramen may also emit collaterals connecting the diploic venous system to the superior sagittal sinus and other venous vessels in the head. Curiously, there was a positive correlation regarding the distance between the foramen and the median line in both sides, suggesting a similar role of the right and left foramina in the control of hemodynamic regulation.

During a careful examination of a dry skull specimen over the frontoparietal bone portion of the skull, several holes can be seen on both surfaces (outer and inner) of the vault, which may be small emissary foramina for veins that typically connect to the superior sagittal sinus (Fig. 4) [25, 26, 36].

In addition, the calvaria diploe contains a number of very complex interconnected venous channels, functioning as a network, probably also responsible for the regulation of the intracranial temperature [26, 31]. This aspect of the regulation of brain temperature is commonly overlooked. It may, nonetheless, be extremely important for brain function [13, 30].

The present authors believe that several morphological characteristics in the head strongly suggest an essential function as a control mechanism regulating intracranial temperature [16]. In addition to emissary foramina and diploic veins abovementioned, the air-filled space of the paranasal sinuses allow the air we breathe, whose temperature is lower than that of the human body, to cool more internal structures, including carotid arteries and the skull base [7, 30]. Particularly noteworthy is the characteristic siphon like morphology of the internal carotid artery in a close anatomical relationship with the sphenoid sinus, suggests a function of decreasing the blood temperature at this location [32]. In this regard, a study involving seven normothermic subjects during carotid arteriography showed that the temperature of the arterial blood within the circle of Willis was 0.30–0.55 °C lower than the rectal temperature [24, 25].

Early studies [1, 11] demonstrated that in cat and sheep, the temperatures of the blood of cerebral arteries and brain are different from aortic arterial temperature. In these animals, unlike a human being, the carotid rete, an arterial network, supplies the circle of Willis. Thus, the carotid siphon might be an evolutionary anatomical form to cool the cerebral blood [34, 38], which would work in collaboration with the parietal emissary vein/diploic system.

Some emissary veins use different foramina other than the parietal one, such as the foramina lacerum, ovale, vesali, spinosum, occipital, mastoid and condylar [25, 26]. In a few individuals, the Zuckerkandl's emissary vein can also be found in the adult [17, 19]. Whether other foramina would compensate the absence of the parietal foramina in some individuals is still unknown. In the present study, we could not find any correlation between the absence of both parietal foramina (in 14 studied skulls) and the existence of the nearby occipital foramen (data nor shown), which could functionally substitute an inexistent parietal foramen.

The preventive action of botulinum toxin in the migraine seems to involve intracranial dura mater. In this regard, following a peripheral application of botulinum toxin in rat [21], the botulinum toxin-cleaved synaptosomal-associated protein 25 was colocalized with CGRP in intracranial dural nerve endings. The authors explained as the toxin was taken up by the pseudounipolar neuron of the extracranial trigeminal afferent fibers and, retrogradely, transported to the trigeminal ganglion, to be transcytosed to afferent meningeal pseudounipolar neurons which anterogradely transported the botulinum toxin to dura mater, where it would inhibit neuropeptide release. However, the presence of nerves inside the parietal foramen strongly suggests that a direct, probably, bidirectional innervation take place between intradural and extradural trigeminal systems. Anatomical features made Yoshioka and coworkers [41] affirm that the arterial blood flow may be, at least in a few individuals, from outside to intracranial middle meningeal artery in the parietal foramen, and a similar pattern may also occur regarding neural innervation. In addition, Burstein and colleagues [5] reported that botulinum toxin decreases the mechanical sensitivity in rats of extracranially projecting collaterals of afferents from the dura mater exiting the cranium through the skull bone sutures. Furthermore, emissary canals in rats are passages in the calvaria where veins carry blood from dural sinuses and diploic veins, and may play a similar role as that of the parietal foramen in humans. Accordingly, in the emissary canal, peripherin- and CGRP-labeled fibers may originate from either extracranial nerve bundles (in the proximity of the periosteum) or intracranial bundles near the dura mater [20].

In conclusion, no major differences were encountered between sexes regarding the prevalence of parietal foramen. The distance of the parietal foramen from the median line appeared to be constant when the sexes were compared, suggesting that it plays a role in the hemodynamic changes between the superior sagittal sinus, emissary parietal vein and diploic venous system. In other words, major changes in the distance would significantly alter physiological function. Why the parietal foramen is absent in some individuals is a question we are still unable to explain. Probably channels (e.g., emissary veins) other than the parietal foramen are connecting the intra- and extracranial compartments, bearing in mind that a bidirectional flow of venous blood is constantly taking place during the frequent changes in the position of the body and head, intrathoracic and intra-abdominal pressures, or during the cardiac cycle.

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Author contributions MRSF, CPM and MMV conceived and designed the analysis; MRSF, AMBQL, CPM and MMV collected the data; APOG, PTMBQL and AMBQL contributed data or analysis tools; MRSF, PTMBQL and MMV performed the analysis; MRSF and MMV wrote the paper.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All stages of this study were carried out in accordance with the guidelines of the National Research Ethics Commission and were approved by the Research Ethics Committee involving human beings at the Federal University of Pernambuco through the protocol CAAE: 79464917.6.0000.5208.

Informed consent The study data were previously approved by the ethics and research committee of the Federal University of Pernambuco.

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