Original Article

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Evaluation of the Parietal Foramen and its Surgical Importance in Dry Skulls: A Cross-Sectional Morphometric Study

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Abstract

Aim: Few studies have analyzed the possible association between parietal foramen (PF), sagittal suture (SS), and lambdoid suture (LS). The relationship between the SS, LS, and PF might play a role in identifying various ethnicities or essential in surgery. The study examined the location, type, incidence, diameter of PF, and the relationship between SS and LS in Turkish adult dry skulls.

Methods: A cross-sectional morphological and morphometrical study of PF was conducted with one hundred and sixty-six Turkish adult dry skulls in 2018-2020. The numbers, frequency, diameters, and types of PF were measured by a digital caliper. For morphometric analyses, the shortest distances between PF-SS, median PF (MPF), Lamba, and PF-LS were measured.

Results: The incidence of PF was 74.6% (right) and 74.7% (left). The incidence of PF was 63.3 in males, it was 36.7 in females. Bilateral PF was found in 74.65%, and unilateral PF was present in 55.75% of Turkish dry skulls. The MPF was found on the SS in 33.7% of the skull. The PF-LS was 39.88±1.99 mm (2.91-104.11 mm) on the left side and 40.69±1.67 mm (6.03-101.24 mm) on the right side. The PF-SS was 12.87±1.25 mm (0.26-85.03 mm) on the left side and it was 11.95±1.21 mm (0.40-83.36 mm) on the right side (p=0.01).

Conclusion: The significant differences in the PF-SS on the left side according to sex should be considered in surgery. Other findings of the study are the presence of more than one PF and its asymmetric distribution in the skull. This might be due to the delayed ossification process or differences in ethnicity.

Keywords: Parietal foramen, suture, incidence, ossification, ethnicity

Introduction

The parietal foramen (PF) is located on both sides of the sagittal suture (SS), near the juncture of the parietal bone's middle and posterior thirds (1). It transmits parietal emissary veins (EV), arteries to the superior sagittal sinus (SSS), one branch of the occipital artery, and an anastomotic artery from the scalp (2-4). Emissary veins connects the SSS to the veins of the scalp. The EV has no valves, allowing blood to flow in both directions and performing crucial tasks, including balancing the internal pressure and providing cerebral congestion (5). A skull's diploic veins have a significant association with PF, which may serve as a route for spreading infections from the superficial veins of the skull to the dural venous sinuses (1). The ossification of the parietal bone starts in the 7-8th fetal week at ossification centers and lasts until the seventh fetal month. The parietal notch forms as the ossification decelerates significantly along the midline, and the delayed closure of the parietal notch results in several abnormalities (6). The delayed or incomplete ossification process and closed the third fontanel, frequently leave behind variations like obeliac bones, PF, or parietal fissures (7). Therefore, the neurosurgeon must know the location, number, and size of the PF to avoid inadvertent hemorrhage from injury to the parietal EV (5).

However, few studies have analyzed the possible association between PF, SS, and LS (7). The relationship between the SS, LS, and PF might play a role in identifying various ethnicities or populations. Therefore, the current study examined the location, type incidence, diameter of PF, and the relationship between SS and LS in Turkish adult dry skulls.

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Materials and Methods

A cross-sectional morphological and morphometrical study of PF was conducted with 166 Turkish adult dry skulls in 2018-2020. The skulls were obtained from the Department of Anatomy, Akdeniz University Faculty of Medicine.

Compliance with Ethical Standards

The current study was approved by the Ethics Committee of the Akdeniz University Faculty of Medicine (approval date: 26.08.2020 and decision number: 596).

Study Design

The numbers (n), incidences (%), diameters (mm), and types of PF were measured bilaterally by an LCD digital caliper (0-150 mm) (Mitutoyo, Japan). The sex and morphology of the skulls were noted. Twenty-one deformed skulls with pathology and fractures were excluded from the study. The current study comprised skulls with precise SS and LS without parietal bone injury. For morphometric analyses, the shortest distances between the PF-SS, PF-LS, inferior border of median PF (MPF) and Lambda were measured (Figure 1). These measurements were repeated twice to provide a precision estimation. The three used precision estimates were calculated as follows to provide intraobserver precision.

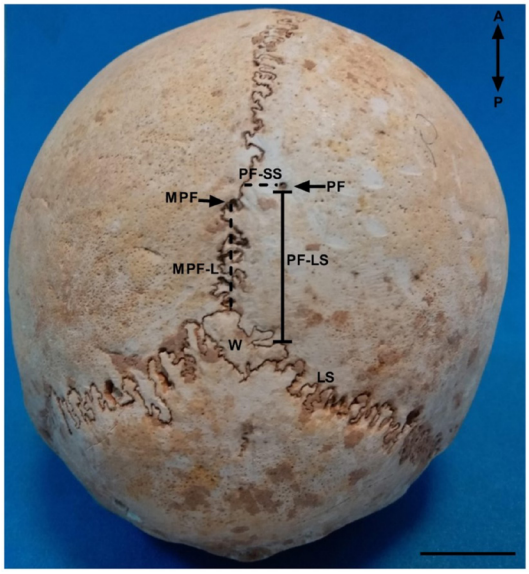

Figure 1. The morphometric measurements were taken as follows: the shortest transverse distance between the margin of the PF and the sagittal suture (PF-SS) (mm), the shortest vertical distance between the margin of the PF and the lambdoid suture (PF-LS) (mm), and the shortest vertical distance between the inferior margin of median PF (MPF) in the midline (over the SS) and Lambda (PF-L) (mm) were measured

A: Anterior, L: Lambda, LS: Lambdoid suture, MPF: Median parietal foramen, P: Posterior, PF: Parietal foramen, SS: Sagittal suture, W: Wormian bone

The technical error of measurement (TEM), the relative TEM (rTEM), and the coefficient of reliability (R) were all used in this research (8-11).

Statistical Analysis

SPSS 25 (IBM, United States) was used for analysis, and $p<0.05$ was deemed statistically significant for all comparisons. For continuous variables, descriptive statistics included mean standard deviation, standard error of the mean, minimum, and maximum, and for categorical variables, percentages (%). Multiple t-tests were used to compare groups with normal distributions.

Results

The R-values of the variables were close to one, indicating that measurements were achieved with an adequate degree of intra-observer accuracy.

Incidence

The incidence of PF was detected at a rate of 74.6% (right) and 74.7% (left). The incidence of PF was 63.3 in males, this rate was 36.7 in females. The incidences of PF on both sides are presented in Figure 2. Bilateral PF was found in 74.65%, and unilateral PF was present in 55.75% of Turkish dry skulls. The MPF was found on the SS in 33.7% of the skull. Five types of PF (absence, single, double, triple, quadruple, and quintet) were recorded (Figure 3).

Distance

The PF-LS was 39.88±1.99 mm (2.91-104.11 mm) on the left side, while the mean distance between PF-LS was 40.69±1.67 mm (6.03-101.24 mm) on the right side. The mean values of PF-LS and the differences between the sexes are presented in Table 1. Their differences were not significant on both sides ($p>0.05$). The PF-SS was 12.87±1.25 mm (0.26-85.03 mm) on the left side, and it was 11.95±1.21 mm (0.40-83.36 mm) on the right side. PF-SS values on the left side differ significantly according to sex. This value indicates that PF has an asymmetrical distribution ($p=0.010$, $p<0.05$). MPF-L was 45.64±3.34 mm. The MPF also differed significantly by sex ($p=0.04$, $p<0.05$). The number of PF and PF-LS values do not differ significantly according to the sex on both sides (Table 2).

Discussion

The incidence of bilateral PF (74.65%) was higher than unilateral PF (55.75%) in Turkish adult dry skulls. The incidence of the MPF (33.7%) was found to be higher than in other studies. A comparison of the findings of our study with other studies in the literature is presented in (Table 3). The incidence of PF varies from 50-80% in various populations (3,5,12). Several variants, including PF, may have a different occurrence according to the demographic, origin, and sex (13).

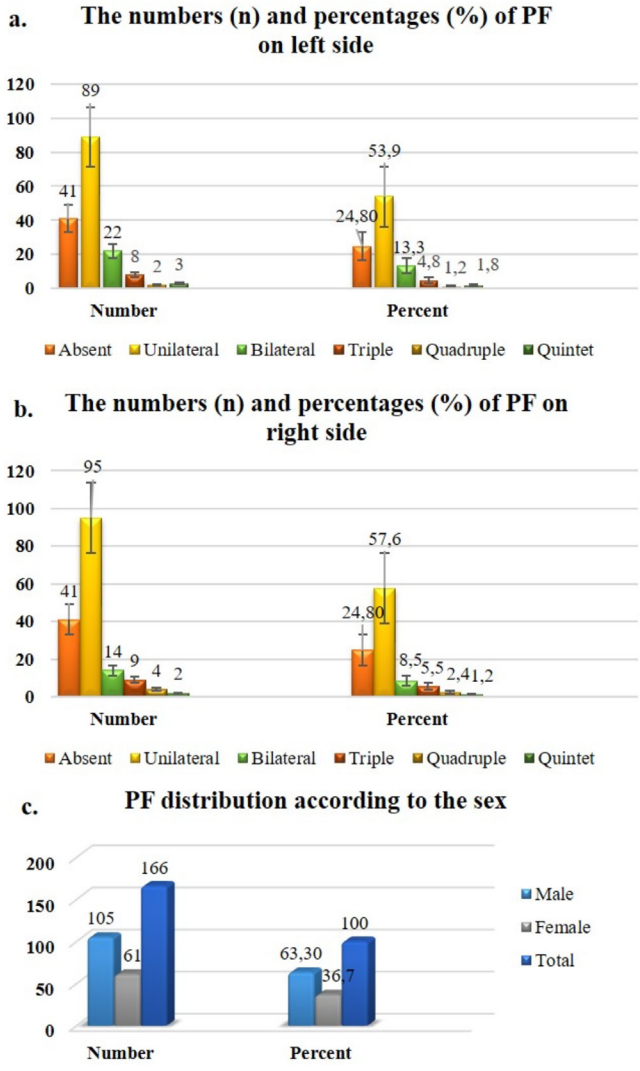

Figure 2. The numbers (n) and percentages (%) of the PF on both sides and PF distribution according to the sex. **a.** The incidence of PF on the left side was as follows; 24.8% were absent, 53.9% had a single PF, 13.3% had double, 4.8% had a triple, 1.2% had quadruple, and 1.8% had a quintet PF **b.** Incidence on the right side was absent in 24.8%, 57.6% had single PF, 8.5% had double, 5.5% had a triple, 2.4% had 4, and 1.2% had 5 PF **c.** The incidence of PF was 63.3 in males, this rate was 36.7 in females

The placement of the PF concerning the SS is crucial for neurosurgeons since the EV might rupture during surgery and result in spontaneous bleeding (5,14). The significant differences in the PF-SS on the left side according to sex should be considered in surgery. It was reported that 32% (calvaria) bilateral, and 35% (calvaria) of them unilateral (1). It has been reported that PF is more often unilateral than bilateral, and it was hardly ever multiple or MPF (15). PF was present on the SS in 5% calvaria (1). The mean incidence of bilateral PF was 41.2%, and unilateral PF was 29.9%, as reported in the literature (1). The data of our study was found to be lower than the de Souza et al. (16) (84.3%, Brazil), Mann et al. (7) (85%, Japan), Liu et al. (17) (82.86%, China), Shmarhalov et al. (18) (85.7%, Ukraine); however, it was higher than Boyd (13) (60%, Scotland), Wysocki et al. (12) (60%, Poland), Murlimanju et al. (19) (55.2%, India), Yoshioko et al. (3) (50%, USA) and Berge and Bergman (20) (30%, unilateral, USA). The incidence of MPF was noted by Mann et al. (7) (0.7%) and Naidoo et al. (1) (3.4%), which were conducted in Japanese, and South African populations. It has been reported that PF is greater in the Australian and New Zealand populations than in other ethnicities (13). There were no age or sex differences between the populations according to the distribution, frequency, and size of PF (13). However, this study revealed that the incidence of MPF was higher (33.7%) than in other studies. This difference between findings may be impacted by shifts in ethnicity, population, location, or intervariability in the same population, or by using criteria for determining the PF (18,20).

The relationship between the PF-SS is crucial for neurosurgical approaches because of the possibility of EV rupture during surgery (19). The shortest distance between PF and SS was 12.87±1.25 mm (0.26-85.03 mm) on the left side, and PF-SS was 11.95±1.21 mm (0.40-83.36 mm) on the right side in the current study. However, our findings were higher than those of Naidoo et al. (1) (4.44-18.2 mm; mean: 9.02 mm), Yoshioko et al. (3) (3-12 mm), and Murlimanju et al. (19) (0.5-15 mm), Halagatti and Sagar (2) (6.6 mm) and Shantharam and Manjunath (5) (2-36 mm). Piagkou et al. (21) asserted that PF-SS was 13.5 mm (right) and 14.6 mm (left) and PF-LS was 36.5 mm (right) and 40.8 mm (left). Similarly, it was found to be 39.88±1.99 mm on the left side and 40.69±1.67 mm on the right side in our study. Shantharam and Manjunath (5) reported that PF was located 7-56.1 mm from the Lambda. It was found to be 45.64±3.34 mm (range: 9-100.28 mm), and the MPF also differs significantly by sex ($p=0.04$, $p<0.05$). It might be due to the mechanical stresses in the vicinity of the PF over the SS and Lambda (7). The size and symmetry of the PF are significant because they may aid radiologists in diagnosing several pathological impairments (20). Safe radical surgery requires a thorough understanding of the morphological differences in the PF and skull vault (20). Failure to recognize this variance might injure the branches of EV and related arteries that have formed around the PF, leading to excessive intraoperative bleeding and sinus thrombosis (21). The mean size of PF was recorded by Yoshioka et al. (3) (0.4-4.3 mm), Shantharam and Manjunath (5) (0.86-5.57 mm), Mann et al. (7) (1.8-2 mm), Naidoo et al. (1) (0.74-3.08 mm), Berge and Bergman (20) (0.67 mm). Similarly, the mean diameter was 1.7 mm (0.6-2.9 mm) in our study. In the

literature, the size of the PF less than 0.5 mm or above 1.5 mm has been reported as a rare condition (7). Boyd (13) reported that PF was equal in size on both sides. In about half the cases mean diameter of PF was ≤0.5 mm, PF was >1-5 mm (7%), and their rest were 1 mm. A large PF was typically not linked to a larger EV and most likely resulted from an ossification deficiency in the parietal bones (13). Moreover, a large PF greater than 5 mm likely suggests an abnormal development of the fetal vascular system that may affect both skull and brain development (22).

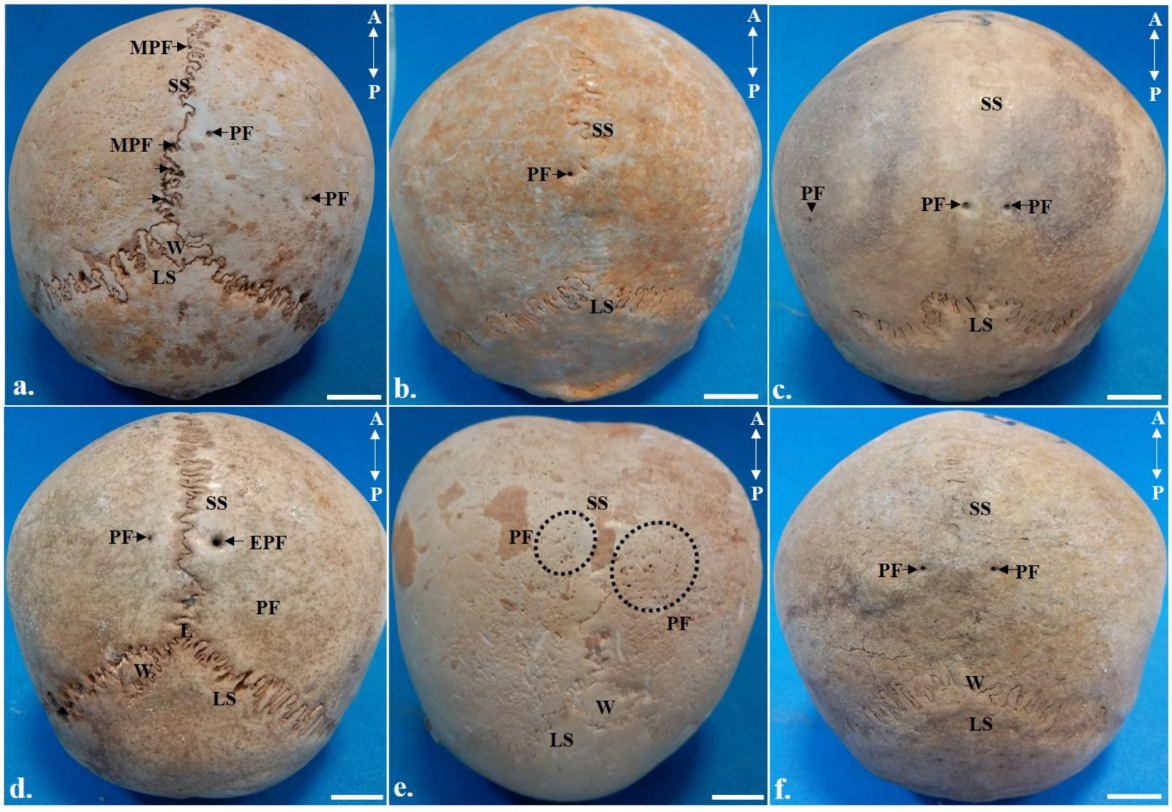

Figure 3. The types of PF according to the location and shape. **a.** Absent (on the left side), double round and oval PF (on the right side), median parietal foramen (MPF). Numerous MPFs were seen at the SS line along with Wormian bone (W) **b.** Unilateral single round PF (on the left side), **c.** A bilateral double round PF was detected on the left side and a single round PF on the right side **d.** Small round PF on the left side. Round Enlarged Parietal Foramen (EPF) on the right side along with W. **e.** There was more than one round, circle, oval, slit like PF on both sides; triple and quadruple (left), quintet (right). The PFs were located within the area indicated by the dashed lines. W was observed along with several PF, **f.** Bilateral single round PF was detected on either side of the SS

A: Anterior, EPF: Enlarged parietal foramen, L: Lambda, LS: Lambdoid suture, MPF: Median parietal foramen, P: Posterior, PF: Parietal foramen, SS: Sagittal suture, W: Wormian bone

Table 1. The descriptive statistics of PF

	Sex	PF-LS (Left)	PF-LS (Right)	PF-SS (Left)	PF-SS (Right)	MPF-L	PF (n) (Left)	PF (n) (Right)
Total number (n)*	166	123	116	123	117	56	165	165
Mean	1.3675	39.8890	40.6946	12.8705	11.9590	45.6430	1.0909	1.0667
Std. error of mean	0.03753	1.99672	1.67698	1.25931	1.21590	3.34121	0.07681	0.07648
Median	1.0000	35.0700	38.2950	9.1300	8.2500	41.9400	1.0000	1.0000
Std. deviation	0.48357	22.14467	18.06168	13.96642	13.15199	25.00333	0.98661	0.98236
Variance	0.234	490.386	326.224	195.061	172.975	625.166	0.973	0.965
Range	1.00	101.20	95.21	84.77	82.96	91.28	5.00	5.00
Minimum	1.00	2.91	6.03	0.26	0.40	9.00	-	-
Maximum	2.00	104.11	101.24	85.03	83.36	100.28	5.00	5.00

*The n numbers indicate the number of skulls observed in PF. L: Lambda, LS: Lambdoid suture, MPF: Median parietal foramen, PF: Parietal foramen, SS: Sagittal suture

Table 2. The p-values of parameters according to the PF on both sides

	F	Sig.	t	df	p-values	Mean	Std. error		
								Lower	Upper
PF-LS (Left)	0.230	0.632	1.388	121	0.168	5.59095	4.02667	2.38090	13.56279
		1.395	111.833	0.166	5.59095	4.00833	2.35117	13.53306	
PF-LS (Right)	0.727	0.396	0.318	114	0.751	1.09957	3.45506	5.74487	7.94401
			0.331	105.397	0.741	1.09957	3.32023	5.48355	7.68269
PF-SS (Left)	13.956	0.000	2.604	121	0.010	6.48566	2.49090	1.55427	11.41705
			2.911	98.593	0.004	6.48566	2.22825	2.06411	10.90721
PF-SS (Right)	7.148	0.009	1.627	115	0.106	4.03808	2.48170	0.87769	8.95385
			1.904	105.957	0.060	4.03808	2.12137	0.16775	8.24392
MPF-L	2.463	0.122	1.922	54	0.060	13.88088	7.22128	0.59693	28.35868
			2.134	35.174	0.040	13.88088	6.50392	0.67955	27.08220
PF (n) (Left)	0.013	0.910	0.580	163	0.562	0.09286	0.15999	0.40878	0.22307
			0.594	131.587	0.554	0.09286	0.15636	0.40217	0.21645
PF (n) (Right)	3.192	0.076	0.493	163	0.623	0.07857	0.15935	0.39323	0.23608
			0.528	148.412	0.598	0.07857	0.14881	0.37262	0.21548

Independent samples test was performed. L: Lambda, LS: Lambdoid suture, MPF: Median parietal foramen, PF: Parietal foramen, SS: Sagittal suture. PF-SS values on the left side differ significantly according to sex. This value indicates that PF has an asymmetrical distribution

Reddy et al. (14) claimed that aberrant vascular evolution with enlarged PF (>5 mm) during the fetal development might affect the development of the brain and skull. It has been reported that enlarged PF (foramina parietal permagna, Catlin marks) coexists with a benign calvarial deficiency with a prevalence of 1 in 15,000 to 1 in 50,000 individuals and numerous Wormian bones (14,21,23). Several reports of enlarged PF have been in conjunction with clinical diseases such as cerebral venous and cortical abnormalities, perineural tumors, and skull fractures (5,13,14). It has been reported that enlarged PF reveals a genetic background and carries an autosomal dominant inheritance (21). Although they are asymptomatic, they have been linked to nausea, multiple exostoses, mental retardation, cleft palate, headaches, encephaloceles, vomiting, myelomeningocele, Duane's syndrome, straight sinus hypoplasia, the persistence of the median prosencephalic vein and falcine sinus, a dilated vein, vascular or cortical malformations of the brain (14,21). In contrast, it has been claimed that small PF had only a minor hemodynamic role. Moreover, the persistence of the lateral margin of the parietal notch may cause a small PF during the development (21). Wysocki et al. (12) stated that sexual dimorphism in PF according to the size of the PF.

Halagatti and Sagar (2) reported that the frequency and situation of PF help in knowing the relationship between sinuses and extracranial veins. Their situation is essential for analyzing the injuries of the scalp and surgery (2). It has been reported that PF is positioned at the posterior one-third of the parietal bone (7). It is situated 83 mm anterior to the Inion, 2 cm in front of the Lambda in newborns, and 2-5 cm in front of the Lambda in adults (3,7). It has been reported that PF is found 3.5 cm anterior to the Lambda and on either side of the SS (2). In our study, similar to the others, PF was present on both sides of the SS or unilaterally and it was located in front of Lambda and LS. Yoshioka et al. (3) reported that PF occurred between the middle meningeal and scalp arteries. They reported scalp anastomosis that gives off a small artery via PF to communicate with the same branches of the middle meningeal artery (55%), and 45% had an anastomosis with pericranial artery through PF (3). It has been indicated that the PF and the skull's diploic veins had a direct relation (13). This association is likely to be crucial in transmitting the infection to the extracranial part of the skull (13). The risk of injury to the SSS or intraoperative blood loss can be reduced by precisely localizing the PF on radiological evaluation and then carefully obstructing the EV (24). The current findings may aid in safe movements around PF that transmit an arterial channel across the scalp and dura mater covering the SSS.

The PF can show variations concerning its type, number, size, and shape (2,3). Circular, oval, slit-like, and enlarged PFs have been described in the literature (7,15).

Table 3. The comparison of the PF by years

Author et al.	PF	Year	Study design	Total number	Incidence (%)	Place	Location	Average size (mm)	Clinical significance	Distance
Berge and Bergman (20)	Absent, Single, Double	2001	Dry skull	100	80% (bilaterally 50%; unilaterally 30%)	USA	Bilateral or unilateral side of the parietal bone	(0.30-1.67 mm) 0.67 mm	-The differences according to the incidence (unilateral, bilateral) may result from the populations or criteria used for determining if a foramen exists.	Unknown
Yoshioka et al. (3)	Absent, Single, Double, Triple	2006	Cadaver	Forty parietal regions from 20 adult cadavers	40 (Bilateral) 20 (Unilateral) Posterior 1/3 of the parietal bone.	Florida, USA	It lies 2 cm anterior to the Lambda in newborns and 20.5 cm anterior to the Lambda in adults	External 1.8 mm (range, 0.4-4.3 mm) internal 0.9 mm (range, 0.2-1.9 mm)	-The PF transmits an anastomosis between the middle meningeal and scalp arteries. -Anastomosis may be involved in several pathologies. -Symptoms include epidural hematoma, moyamoya disease, arteriovenous malfunctions	8 mm (3-12 mm) from the midline, 83 mm (range 55-95 mm) from the inion
Wysocki et al. (12)	Absent, Single, Double	2006	Dry skull	100 (50M, 50F)	60%	Poland The 13th century (Kielce)	Bilateral or unilateral side of the parietal bone	11.9 mm^2 (left), 16.8 mm^2 (right)	-There was a correlation between the total surface area of hypoglossal and condylar canals, oval foramen, mastoid and PF on both sides. -There was asymmetry among the PF	Unknown
Mann et al. (7)	Absent, Single, Double	2009	Dry skull	137 (79M, 58F)	67M (85%), 43F (74%) 47 unilateral (28M, 19F) 62 bilateral (39M, 23F)	Japan	2.05 cm anterior to the Lambda and Obelion	0.50-1.5 mm	-It reflects redirected bone stresses around a circular opening, resulting in reduced tensile stresses and increased compressive stresses adjacent to the PF.	PF-L: 3.8 cm
Collipal et al. (22)	Absent, Single, Double	2009	Dry skull	39	Bilaterally 23 (58.97%) Unilaterally 10 (10.25%) Right (15.38%) Left (10.25%)	Chile	The junction of the SS with the Lambda	0.37-2.65 mm	The contribution of these morphometric data of the PF allows increasing anatomical knowledge and serves as a basis for future anatomical clinical studies.	6.29 mm 33.25 mm PF-L
Murlimanju et al. (19)	Absent, Single, Double, Triple	2015	Dry skull	58	83 (71.5%)	South India	The junction of middle 1/3 and posterior 1/3 of the parietal bone.	Unknown	-It's critical to identify the parietal EV and accessory veins to reduce the loss of blood during surgery. -The most of the PF were situated about 4–8 mm from the sagittal suture.	PF-SS: 6.7±2.9 mm right 6.8±2.8 mm left
Tsutsumi et al. (24)	Absent, Single, Double, Triple	2016	MRI	104 (52M, 52F)	78/104 (75%) 116 PF (68% single, 30% double, 2% triple, 9.5% symetry)	Japan	Coursed above the SSS	Unknown	-EV demonstrated a relatively uniform sagittal path, despite perforating the skull at varying angles. -The PF and EV can be used as markers for the SSS that is directly below.	Unknown
Shantharam and Manjunath (5)	Absent, Single, Double	2018	Dry skull	78	87 (55.77%) (bilaterally 37.18%; unilaterally 18.59%)	South India	Middle and posterior 1/3 of parietal bones	01.99±0.78 (0.86-5.57)	-An important relationship between the emissary foramina and the diploic veins of the skull, which are involved in the spread of infection from the extra cranial veins to intracranial sinuses -The EV may be ruptured during the surgical procedure and cause spontaneous bleeding	PF-SS: 07.34±4.12 PF-L: 37.95±8.75

Table 3. Continued

Author et al.	PF	Year	Study design	Total number	Incidence (%)	Place	Location	Average size (mm)	Clinical significance	Distance
Halagatti and Sagar (2)	Absent, Single, Double, Triple	2018	Dry skull	215	326 (75.6%) Single 283, Double 35, Triple 8	India	The junction of the middle and posterior 1/3rd of the parietal bone.	N/A	-The number and location of PF helps in knowing the communications between dural venous sinuses and scalp veins. -Their location is also important for analysing the avulsion injuries of scalp and neurological surgeries.	PF-SS: 6.4±2.6 mm
Naidoo et al. (1)	Absent, Single, Double	2021	Dry skull	100	68% (bilaterally 32%; unilaterally 35%)	South Africa	Bilateral: 32 Unilateral: 35 SS: 5	1.55 mm (0.74 0 3.08 mm)	-The high incidence of the PF and EV of the cranium will be encountered by the Neurosurgeon, therefore knowledge of the anatomy of the emissary PF is imperative.	9.02 mm
De Souza et al. (16)	Absent, Single, Double, Triple, Quadruple	2021	Dry skull + MRI	89 dry skul 51 M 38 F 123 (MRI) 81 M, 42 F	Male: 43/51 (84.3%) Female: 32/38 (84.2%) Bilaterally 54.9% male 44.73% female Unilaterally M R 8/51 (16%) L 7/51 (14%) F R 8/38 (21%) L 7/38 (18%)	Brazil	The proximity of the SS and posterior part of the parietal bone	61 (75.3%) M, 26 (61.9%) F Bilaterally 45.9% M 53.8% F Unilaterally M R 21.3% L 32.7% F R 34.6% L 11.5%	-No major differences were encountered between the sexes regarding the anatomical features of PF	Male: 7.1±2.5 mm Female: 7.4±2.7 mm
Liu et al. (17)	Single	2021	Dry skull	280	82.86%	China	Most PFs were anteromedial direction	1.02±0.72 mm (left) 1.07±0.67 mm (right) 1.77±0.44 mm (on SS)	-The intracranial and extracranial communication was 39.97% and the incidence,location,diameter of PF were important for imaging diagnosis and neurosurgery	PF-SS: 5.90±2.78 mm (left), 5.85±2.75 mm (right)
Shmarhalov et al. (18)	Absent Single Double	2022	Fixed skull	42	85.7% (n=36) 54.8% (n=23) bilateral 30.9% (n=13) unilateral 14.3% (n=6) absence	Ukraine	The most frequent location of the PF was at the side of the SS, mid of the distance between the vertex and L	0.5-2.7 mm 1.7±0.6 mm (right) 2.7±0.5 (left)	To assist surgical and radiological procedures, it is essential to have in-depth knowledge of the anatomical differences of PF across various ethnicity	PF-L: 22.5-62.0 mm PF-bregma: 62.0-99.0 mm
Present study	Absent, Single, Double, Triple, Quadruple Quintet	2022	Dry skull	166	74.6% (right side) 74.7% (left side) M: 63.3 F: 36.7	Turkey	Bilateral or unilateral side of the parietal bone	Bilateral: 74.65%, unilateral: 55.75%, median: 33.7%	-Although the incidence of PF was 74% in our study, it was higher in males than in females -The significant differences in the PF-SS on the left side according to sex should be considered in surgery. -The current study revealed that PF has an asymmetrical distribution in the skull. -It may aid in safe movements around the PF during the surgery.	PF-LS: 39.88±1.99 (left) 40.69±1.67 mm (right). PF-SS:12.87±1.25 mm (left) 11.95±1.21 mm (right)

CN: Cranial nerve, EV: Emissary vein, F: Female, L: Lambda, LS: Lambdoid suture M: Male, MPF: Median parietal foramen, MRI: Magnetic resonance imaging, PF: Parietal foramen, SS: Sagittal suture, SSS: Superior sagittal sinus

Circular, oval, slit-like, and enlarged PFs were also detected in our study. The size of the PF and how far away it is from the midline affect the shape of the PF, and differences may be caused by alterations in the ossification process (18). A slit or V-shaped notch caused by a prolonged ossification process behind the parietal bone and especially in the obelion is known as the sub-sagittal suture or third fontonel (6). According to reports, heterozygous mutations of MSX2, an autosomal dominant gene, cause the enlarged PF and contiguous gene deletion syndrome (Potocki-Shaffer syndrome) with oval deformities of parietal bone (25). The PF often has a well-defined border, which aids the radiologist in distinguishing it from other clinical situations such as lytic lesions and burr holes during surgery (5,14). However, in a study, the margins of PF were not regular due to the presence of a small groove close to the PF (21). The variations in PF might be related to the changes in the embryological development of the parietal bone (3).

It has been revealed that knowledge about the prevalence and location of PF may help neurosurgeons modify the procedures to reduce the injury risk of EV and related arteries (1,26). The early fusion of the SS, excessive bone growth, and aberrant fibroblast growth factor (FGF) might cause craniofacial deformity and osteogenic differentiation (7). More than one PF could be explained by a delayed or incomplete ossification process of the parietal bone or third fontanel. In our study, the presence of more than one PF was detected (n=1-5), this indicates a delayed ossification process. PF has implications for bone biomechanics, suture development, reduced tensile stresses, increased compressive stresses, and transfer of infection to the cerebral cavity (2,7). The other hypothesis that ALX_4 is a specific gene for the formation of PF in the deletion syndrome is supported by individuals with 11p11.2 deletion who also have bilateral PF (25).

Additionally, enlarged PF has been recorded in Chinese populations; however, only 16% have a potential third locus on 4q21-q23, which are caused by these mutations (21). We can compare the allometric patterns in various populations thanks to epigenetic variants such as PF, which serve as indicators of embryological processes (4). The variations in PF might provide significant insights into the structure of the human genome and advance our knowledge of the causes of congenital diseases.

Study Limitations

The causes of death, pathology, and neurological or congenital disorders of the measured skulls were unclear. Therefore, we could not establish a correlation between our findings and clinical impairments. Despite these limitations, the study has strengths in emphasizing the possible association between PF, SS, and LS in dry skulls and the differences between the sexes. This relationship between them might play a role in identifying various ethnicities and reducing the surgical complications surrounding the PF.

Conclusion

The significant differences in the PF-SS on the left side according to sex should be considered in surgery. Other findings of the study are the presence of more than one PF and its asymmetric distribution in the skull. This might be due to the delayed ossification process or differences in ethnicity.

Ethics

Ethics Committee Approval: The current study was approved by the Ethics Committee of the Akdeniz University Faculty of Medicine (approval date: 26.08.2020 and decision number: 596).

Informed Consent: Not required.

Peer-review: Internally peer-reviewed.

Authorship Contributions

Concept: O.G., E.O., F.B.Y., Design: O.G., E.O., F.B.Y., Data Collection or Processing: O.G., E.O., Analysis or Interpretation: O.G., E.O., Literature Search: O.G., E.O., Writing: O.G., E.O.

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References

1. Naidoo J, Luckrajh JS, Lazarus L. Parietal foramen: incidence and topography. Folia Morphol (Warsz) 2021;80:980-4.
2. Halagatti M, Sagar S. An Anatomical Study of Parietal Emissary Foramina in Dry Adult Human Skulls. IJARS 2018;7:AO20-AO2.
3. Yoshioka N, Rhoton AL Jr, Abe H. Scalp to meningeal arterial anastomosis in the parietal foramen. Neurosurgery 2006;58(1 Suppl):ONS123-6.
4. Carolineberry A, Berry RJ. Epigenetic variation in the human cranium. J Anat 1967;101:361-79.
5. Shantharam V, Manjunath KY. Anatomical Study of Parietal Emissary Foramina in Human Skulls. IJARS 2018;7:11-4.
6. Currarino G. Normal variants and congenital anomalies in the region of the obelion. AJR Am J Roentgenol 1976;127:487-94.
7. Mann R, Manabe J, Byrd J. Relationship of the Parietal Foramen and Complexity of the Human Sagittal Suture. Int. J. Morphol 2009;27:553-64.
8. Ogut E, Armagan K, Barut C. Reappraisal of the types of trigeminal porus and importance in surgical applications. SRA 2021;43:1169-78.

9. Sekerci R, Ogut E, Keles-Celik N. The influences of porus acusticus internus on ethnicity and importance in preoperative and intraoperative approaches. SRA 2021;43:1829-38.
10. Akdag UB, Ogut E, Barut C. Intraforaminal Dural Septations of the Jugular Foramen: A Cadaveric Study. World Neurosurg 2020;141:e718-e27.
11. Ogut E, Akdag UB, Kilincli MF, Barut C. Reappraisal of the types of hypoglossal canal: endocranial approach. Anat Sci Int 2022;97:399-408.
12. Wysocki J, Reymond J, Skarzyński H, Wróbel B. The size of selected human skull foramina in relation to skull capacity. Folia Morphol (Warsz) 2006;65:301-8.
13. Boyd GI. The Emissary Foramina of the Cranium in Man and the Anthropoids. J Anat 1930;65:108-21.
14. Reddy AT, Hedlund GL, Percy AK. Enlarged parietal foramina: association with cerebral venous and cortical anomalies. Neurology 2000;54:1175-8.
15. Keskil S, Gözil R, Calgüner E. Common surgical pitfalls in the skull. Surg Neurol 2003;59:228-31.
16. de Souza Ferreira MR, Galvão APO, de Queiroz Lima PTMB, de Queiroz Lima AMB, Magalhães CP, Valença MM. The parietal foramen anatomy: studies using dry skulls, cadaver and in vivo MRI. SRA 2021;43:1159-68.
17. Liu D, Yang H, Wu J, Li JH, Li YK. Anatomical observation and significance of the parietal foramen in Chinese adults. Folia Morphol (Warsz) 2022;81:998-1004.
18. Shmarhalov A, Vovk O, Ikramov V, Acharya Y, Vovk O. Anatomical Variations Of The Parietal Foramen And Its Relations To The Calvarial Landmarks: A Cross-Sectional Cadaveric Study. Wiad Lek 2022;75:1648-52.
19. Murlimanju BV, Saralaya VV, Somesh MS, et al. Morphology and topography of the parietal emissary foramina in South Indians: an anatomical study. ACB 2015;48:292-8.
20. Berge JK, Bergman RA. Variations in size and in symmetry of foramina of the human skull. Clin Anat 2001;14:406-13.
21. Piagkou M, Skotsimara G, Repousi E, Paraskevas G, Natsis K. Enlarged parietal foramina: a rare finding in a female Greek skull with unusual multiple Wormian bones and a rich parietal vascular network. Anat Sci Int 2013;88:175-80.
22. Collipal E, Silva H, Quintas F, Martínez C, Sol M. Estudio Morfométrico del Foramen Parietal. 481Int J Morphol 2009;27:481-4.
23. Chigurupati NJ, Muraleedharan A, Gunasegaran JP, Devi R. Morphometric Analysis of Accessory Sutural Bones Association With Parietal Emissary Foramina. ASJ 2022;19:33-8.
24. Tsutsumi S, Nonaka S, Ono H, Yasumoto Y. The extracranial to intracranial anastomotic channel through the parietal foramen: delineation with magnetic resonance imaging. SRA 2016;38:455-9.
25. Wu YQ, Badano JL, McCaskill C, Vogel H, Potocki L, Shaffer LG. Haploinsufficiency of ALX4 as a potential cause of parietal foramina in the 11p11.2 contiguous gene-deletion syndrome. Am J Hum Genet 2000;67:1327-32.
26. Chigurupati NJ, Sriambika K, Muraleedharan A, Gunasegaran JP, Devi R. Morphometric and topographic analysis of calvaria: A special focus on parietal emissary foramina. JCRSM 2021;7:93-6.