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Incidence and morphometry of sellar bridges and related foramina in dry skulls: Their significance in middle cranial fossa surgery☆

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ABSTRACT

Purpose: The current study investigated the incidence, morphology and morphometry of the ossified ligaments expanding between petrous bone and posterior clinoid processes and in between the anterior, middle and posterior clinoid processes. Side symmetry, gender dimorphism and age influence were also studied.
Materials and Methods: A total of 123 adult Greek dry skulls were observed.
Results: A caroticoclinoid bar (CCB) was found in 60.2%. Partial CCBs appeared more commonly (36.6%) than complete (23.6%). The caroticoclinoid foramen (CCF) was symmetrical on both sides and genders. An anterior interclinoid, a posterior petroclinoid and a partial posterior interclinoid bar appeared in 19.5%, 6.5% and 2.4%, respectively. Osseous spurs posterolateral to the posterior clinoid process were present in 5.7%.
Conclusion: The study highlights important morphometric details about osseous bars of the sella region and the related CCF in Greek skulls. Notable differences in the incidence of these bars in Greek individuals compared with findings from other populations highlight the growing awareness of ethnic differences in skull base landmarks. Variations and surgically oriented measurements provided by this study may benefit clinicians involved in the treatment of the middle cranial fossa pathology, enriching understanding of the complicated regional anatomy. Preoperative sellar area mapping is essential, by using computed tomography images, since modification of the surgical approach may be required in cases of severe ossification.

1. Introduction

In-depth knowledge of the complicated and variable anatomy of the sellar region, and particularly the presence of partially or completely ossified ligaments between the anterior (ACP) and middle (MCP) clinoid processes, the ACP and posterior clinoid processes (PCP), the MCP and PCP and between the petrous bone and PCP, is of paramount importance to skull base procedures. In the middle cranial fossa, the ossified ligaments comprise the caroticoclinoid bar (CCB), the anterior interclinoid bar (AIB), the posterior interclinoid bar (PIB) and the posterior petroclinoid bar (PPB). Their significance was pointed out by Dolenc (1985), who focused on different surgical approaches of the internal carotid artery (ICA). The caroticoclinoid (CCF) or anterior interclinoid foramen is the outcome of the ligament ossification connecting the ACP and MCP, thus giving passage to the clinoidal ICA segment. The CCF occurrence may complicate anterior clinoidectomy procedures (Inoue et al., 1990), especially in cases of aneurysmal ICA branches (Ota et al., 2015). The posterior interclinoid (venous) foramen ensues from the ligament ossification connecting the

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MCP and PCP, transmitting the ICA anteriorly and the lateral part of the circular sinus posteriorly. The PPB is the ossified posterior petroclinoid ligament (PPL), the so-called ligament of Grüber, extending from petrous bone apex to the PCP. The PPB forms Dorello's canal, through which the abducent nerve advances to the middle cranial fossa (Tekdemir et al., 1996; Liu et al., 2009; Inal et al., 2016), posing an area of possible nerve compression (Inal et al., 2016). Attention should be paid in cases of complete petroclinoid fold ossification bringing up symptoms of trigeminal neuralgia (Komminoth and Woringer, 1964).

Clinical and cadaveric studies among different populations have investigated the variable sellar anatomy, aiming for safer and uneventful procedures. Variably ossified ligaments of sellar region may interfere with magnetic resonance imaging (MRI) or computed tomography (CT) evaluation and in the regional surgery planning as well. In order to achieve a better surgical outcome and to avoid complications, skull base surgeons should preoperatively consider racial differences, gender dimorphism and aging, especially when applying novel techniques or modifying the surgical approach in tumor resection or aneurysm repair cases in the sellar region (Boyan et al., 2011; Dagtekin et al., 2014). Focusing on the operative and diagnostic importance of the sellar anatomy, the current study highlights the ligament ossification type (partial, complete or mixed), their incidence and morphometry in skulls of Greek individuals, taking into consideration laterality, gender and age. Morphometric details of the CCF are also provided.

2. Materials and Methods

A total of 123 (62 male and 61 female) Greek adult dry skulls (246 sides) from the osteological collection of the Department of Anatomy and Surgical Anatomy of the Aristotle University of Thessaloniki were investigated. Their age ranged from 20 to 91 years. The examined skulls were classified into the following age groups: 20–39 years (19 skulls), 40–59 years (31 skulls) and 60–79 years (73 skulls), to further investigate the impact of age on the ossification process. The calvaria of all skulls was removed, thus exposing the skull base. Regarding the sellar region, only intact skulls free of erosion, trauma or any other pathological or taphonomic process were included. The incidence of partial or complete ossification of the caroticoclinoid, interclinoid and posterior petroclinoid ligament (CCL, ICL and PPL) were tabulated according to side, gender and age. Complete ossification occurred when the tips of the clinoid processes were fused. The ossification was characterized partial, if an osseous spicule extended from a clinoid process towards the other counterpart. In such cases, the distance between the tips of the ACP, MCP and PCP was also measured. The PPL is considered as a dura mater fold stretching between the petrous apex and PCP (Inal et al., 2016). The completely ossified PPL was defined as a bony extension from the PCP to the petrous ridge, while in partially ossified cases, the bony part of the ligament extends more than half the distance from the petrous ridge to the PCP (Kimball et al., 2015). The anteroposterior (APD) and transverse (TD) diameters of the CCF and the osseous spikes arising from the PCP (posteroinferior or posterolateral) were also recorded. The ACP length was measured between the optic canal roof and the ACP tip. The ACP maximum width was measured from the lateral margin of the optic foramen to the lateral margin of the ACP. The ACP thickness was measured at its base (Fig. 1). The distances between the tips of ACP and MCP, ACP and MCP, MCP and PCP were also included (Fig. 1). All measurements were performed independently by two researchers using a digital sliding caliper (Mitutoyo ABSOLUTE 500-196-20) accurate to 0.01 mm.

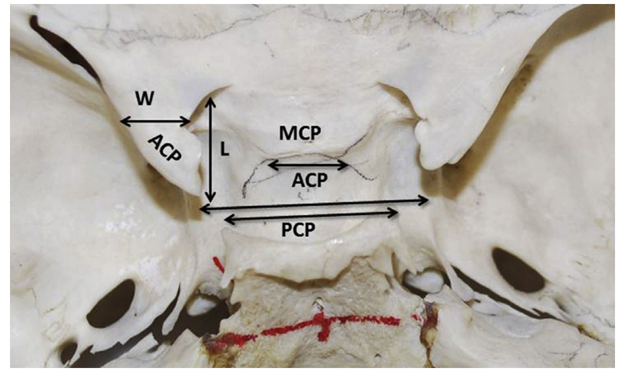

Fig. 1. Distances between anterior (ACP), middle (MCP) and posterior (PCP) clinoid process. ACP width (W) and length (L).

2.1. Statistical analysis

All values are expressed as mean ± standard deviation (SD). Statistical analysis, side asymmetry, gender dimorphism and age influence were investigated using the independent samples t-test and one-way analysis of variance. Non-parametric tests (Mann–Whitney and Kruskal–Wallis tests) were applied for findings lacking normal distribution. Statistical analysis performed using IBM SPSS Statistics version 21.0, and a p value of 0.05 was considered statistically significant.

3. Results

3.1. Incidence of ossified sellar bars

The CCB was the most commonly found (74 skulls, 60.16%). A partial CCB was found in 45 (29 male and 16 female) skulls (36.6%), in 23 of them (18.7%) unilaterally (18 on the right and 5 on the left side) and in 22 skulls (17.9%) bilaterally (Fig. 2). A complete CCB was detected in 29 skulls (23.6%), in 16 skulls unilaterally (Fig. 3A) and in 13 skulls bilaterally (Fig. 3B–C) (Table 1). The incidence of complete CCB represents the percentage of CCF existence. The ICB was detected in 27 (16 male and 11 female) skulls (21.95%). The AIB was found in 24 (16 male and 8 female) skulls (19.5%). The partial type occurred more commonly (14.6%) (Figs. 4A and 7C) than the complete (4.9%) (Figs. 3C, 4B,C,E, 5B–D, 6A–D and 7B). Partial AIBs were found in 18 (10 male and 8 female) skulls unilaterally only, predominantly on the right side (16 skulls). Complete AIBs were detected in 6 skulls (5 male and 1 female), in 4 skulls unilaterally (3 skulls on the right and 1 skull on the left side) and in 2 skulls bilaterally. An incomplete PIB was found in 3 skulls (2 female and 1 male) (2.4%), in 2 skulls unilaterally (1 skull on the right and in 1 skull on the left side) and in 1 skull bilaterally. No skull showed a complete PIB, i.e. no posterior interclinoid foramen was observed. The PPB was ossified in 8 skulls (3 male and 5 female) (6.5%), in 6 skulls it was partially ossified and in 2 skulls completely ossified unilaterally (Figs. 5D and 7A–D). No anterior petroclinoid bar (APB) was found. A combination of the above-ossified bars, i.e. a mixed type of ossification appeared in 22 skulls (17.8%) (in 13 skulls a CCB and an ICB, in 4 skulls a partial and a complete CCB, in 1 skull an ICB and a PPB, in another skull a CCB and PPB, in another a CCB, an ICB and a PPB and in another a partial and a complete ICB) (Figs. 3C, 4E, 5B–D, 6A,C,D and 7C). Osseous spurs posterolateral to the PCP were detected in 7 (6 male and 1 female) skulls (5.7%), among them in 1 skull on the right, in 2 skulls on the left and in 4 skulls bilaterally (Figs. 4D and 5A, D, 6B, 7B).

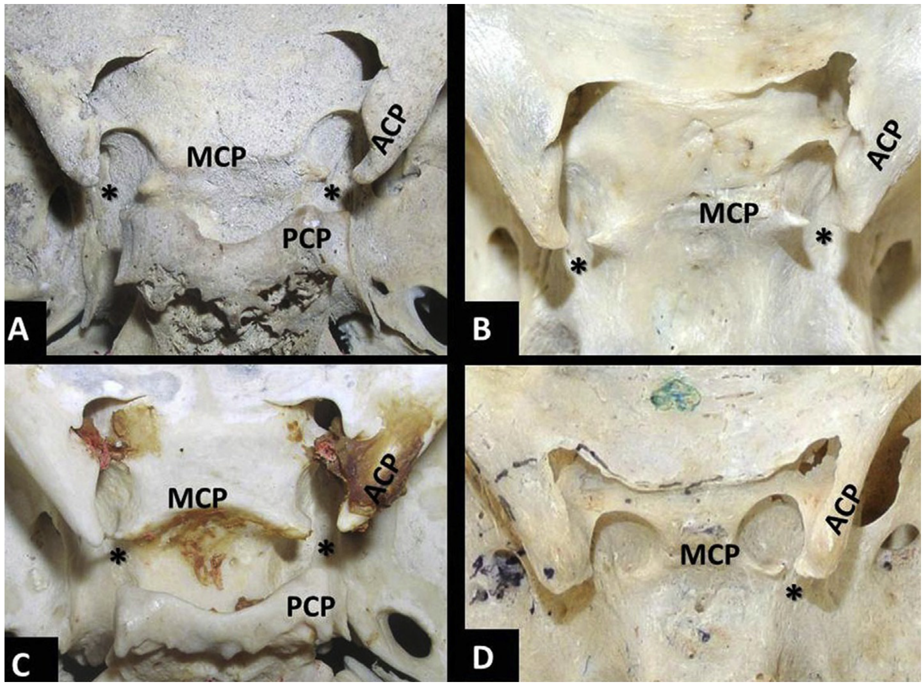

Fig. 2. Variable degree of partial ossification between anterior and middle clinoid process (ACP and MCP) (*). (A, B, C) Partial caroticoclinoid bar (CCB) bilaterally. (D) Partial CCB on the right side.

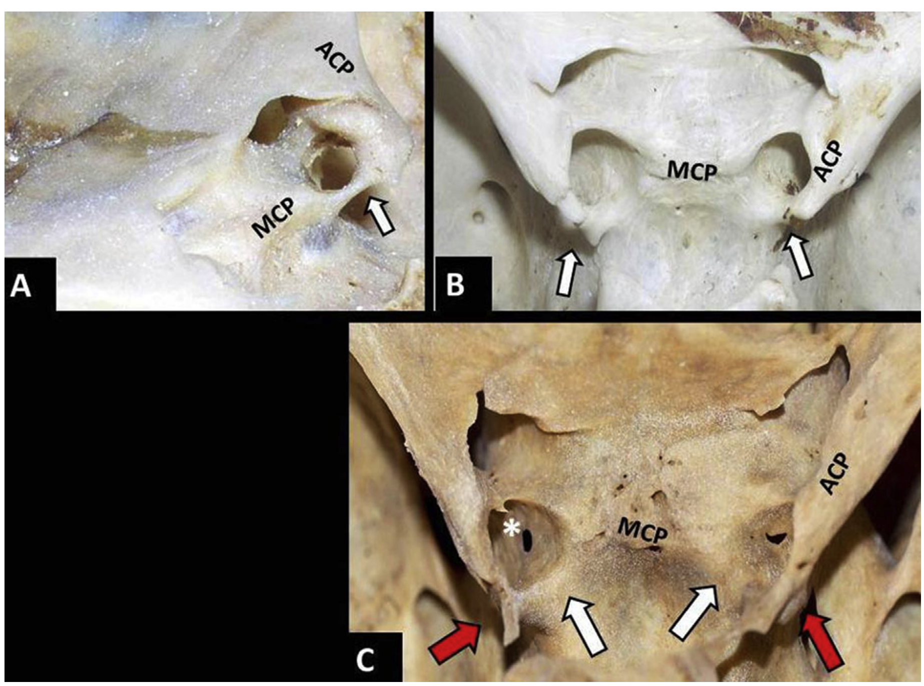

Fig. 3. Complete ossification between anterior and middle clinoid process (ACP and MCP) (arrows) and the caroticoclinoid foramina (A) on the right side (B, C) Bilateral complete caroticoclinoid bar (white arrows). (C) Coexistence of a complete right anterior interclinoid bar and an osseous spikule posterolaterally to the left caroticoclinoid foramen (red arrows). Asterisk (*) indicates an osseous spicule on the superior inner surface of the caroticoclinoid foramen.

3.2. Spearman's correlation rho coefficient test results

Spearman's correlation revealed a male predominance, concerning the partial CCB presence ($p = 0.030$ and $r = 0.324$). It also revealed that the age impact is statistically significant in the complete AIL ($p = 0.041$ and $r = 0.830$) and the complete CCL ($p = 0.021$ and $r = 0.426$) ossification. Aging showed a stronger correlation with the AIL complete ossification.

3.3. Morphometry of the ossified sellar bars

The mean distance of a partial CCB was 3.66 ± 1.54 mm (range 1.43–8.37) on the right, and 3.65 ± 1.33 mm (1.81–6.39) on the left side, and side symmetry existed. No gender dimorphism was observed, since male values (3.75 ± 1.85 mm on the right and 3.95 ± 1.48 mm on the left) were similar to female values (3.56 ± 1.13 mm on the right and 3.28 ± 1.09 mm on the left). The

Table 1
Ossification type (complete, partial) of the caroticoclinoid, anterior interclinoid, posterior interclinoid and posterior petroclinoid ligament and the resulting caroticoclinoid bar (CCB), anterior interclinoid bar (AIB), posterior interclinoid bar (PIB) and posterior petroclinoid bar (PPB) according to the observed (right and left) side.

Bridge formation		Complete CCB		Partial CCB		Complete AIB		Partial AIB		Partial PIB		Complete PIB		Partial PPB	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
Unilaterally	R	9	7.3	18	14.6	3	2.4	16	13.0	1	0.8	1	0.8	3	2.4
	L	7	5.7	5	4.1	1	0.8	2	10.6	1	0.8	1	0.8	3	2.4
Bilaterally		13	10.6	22	17.9	2	1.6	0	0.0	1	0.0	0	0.0	0	0.0
Total		29	23.6	45	36.6	6	4.9	18	14.6	3	2.4	2	1.6	6	4.9
Bridge absence		94	76.4	78	63.4	117	95.1	105	85.4	120	97.6	121	98.4	117	95.1
Total skulls		123	100.0	123	100.0	123	100.0	123	100.0	123	100.0	123	100.0	123	100.0

N = number of cases; % = percentage of incidence of occurrence; R = right side; L = left side.

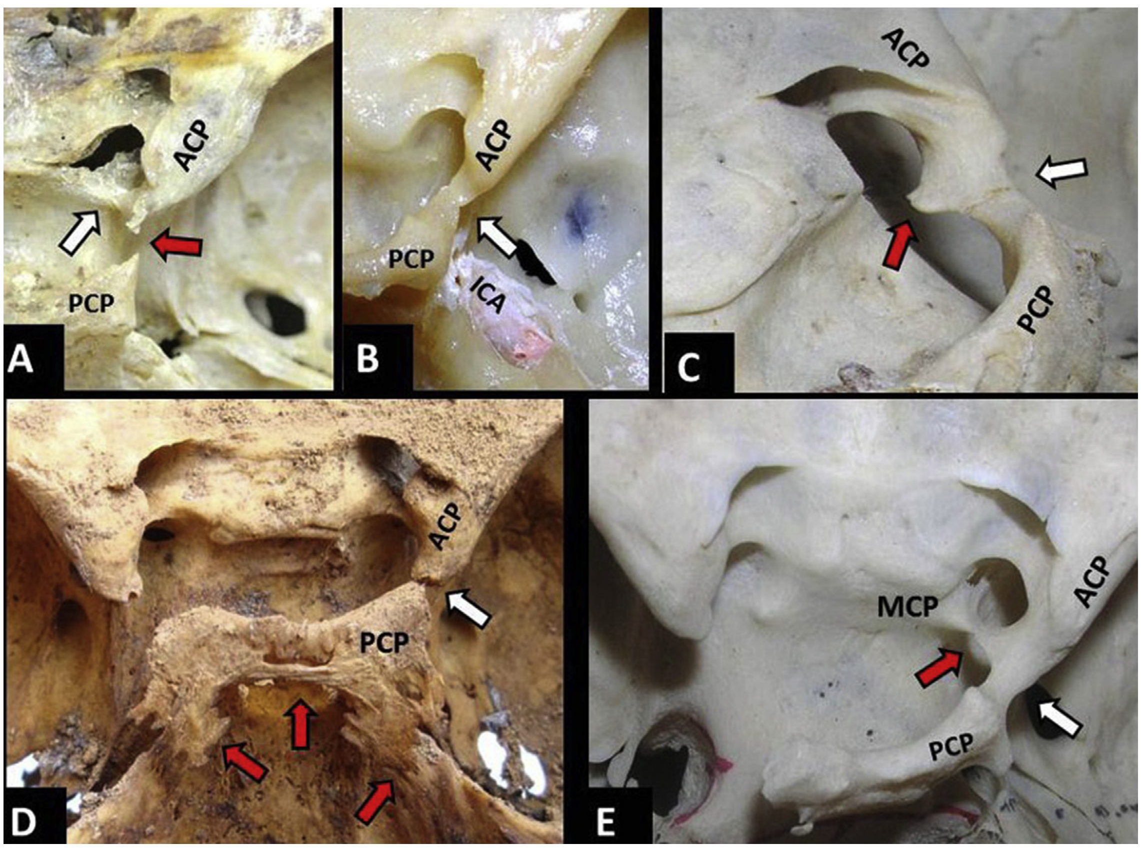

Fig. 4. (A) Complete ossification between anterior and middle clinoid process (ACP and MCP) on the right side (white arrow) in coexistence with a partial anterior interclinoid bar (AIB) on the ipsilateral side (red arrow) (B) Complete AIB on the right side (white arrow), ICA-internal carotid artery (C) Complete AIB on the right side (white arrow) and an osseous spikule towards the MCP (D) Tips of the ACP and PCP in contact (white arrow) and osseous spikules at the dorsum sella (red arrows) (E) A complete AIB (white arrow) combined with a complete caroticoclinoid bar (red arrow) on the right side. PCP = posterior clinoid process.

mean APD of the CCF was 5.19 ± 0.74 mm (range 4.30–6.66 mm) on the right and 5.44 ± 1.08 mm (3.32–6.86 mm) on the left side, and the mean TD was 5.32 ± 0.54 mm on the right (range 4.71–6.21 mm) and 5.56 ± 0.94 mm (4.30–7.74 mm) on the left side, and side symmetry existed. The CCF diameters did not differ between male and female skulls. The mean distance of a partial AIB was 4.99 ± 1.60 mm (range 2.73–9.04 mm) on the right and 4.92 ± 1.31 mm (2.38–8.26 mm) on the left side, and side symmetry existed. No gender dimorphism existed between male and female skulls (Table 2).

3.4. Morphometry of the clinoid processes

The mean distance between the ACP, MCP and PCP tips was 25.51 ± 2.4 2 mm (range 18.82–31.55 mm), 11.06 ± 2.07 mm (6.74–17.81 mm) and 16.25 ± 2.29 mm (10.38–21.35 mm), respectively. No gender dimorphism existed. Although distance between ACP right-ACP left, MCP right-MCP left, PCP right-PCP left decreased with aging due to the ossification progress, no statistically significant difference was observed. The mean ACP length was 11.43 ± 2.33 mm on the right and 11.66 ± 1.70 mm on the left side with side symmetry ($p = 0.321$). No gender dimorphism and age influence were found. The third age group had higher ACP length values. The mean ACP maximum width was 9.02 ± 1.67 mm on the right and 9.63 ± 1.71 mm on the left side, and side asymmetry existed ($p = 0.002$). Gender dimorphism was observed only on the right side ($p = 0.009$). The mean ACP thickness was 5.91 ± 1.63 mm (range 3.14–9.65 mm) on the right and 5.92 ± 1.48 mm (2.60–10.44 mm) on the left side, and side symmetry existed. No gender dimorphism and age influence were detected for both sides (Table 2).

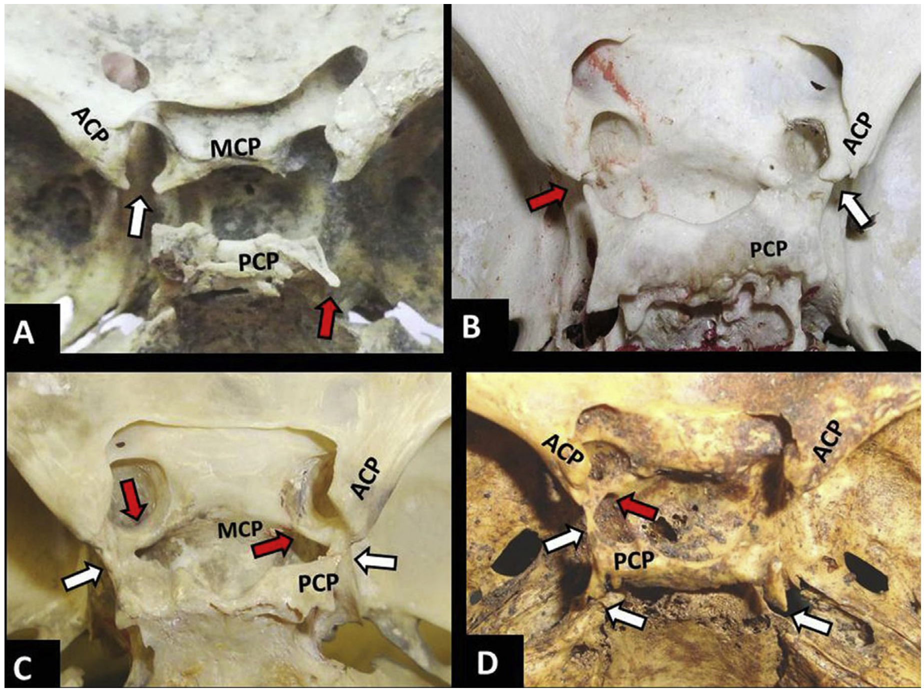

Fig. 5. (A) Partial ossification between anterior and middle clinoid process (ACP and MCP) on the left side (white arrow) in coexistence with an osseous spikule on the posterior clinoid process (PCP) on the contralateral side (red arrow) (B) Complete (white arrow) and partial (red arrow) anterior interclinoid bars (AIB) (C) Complete AIB bilaterally (white arrows) in coexistence with complete caroticoclinoid bars (CCB) (red arrows) (D) Complete AIB on the left side (white arrow) coexisting with an ipsilateral complete CCB (red arrow) and ossified petroclinoid ligaments (partial on the right and complete on the left side), MCP = middle clinoid process.

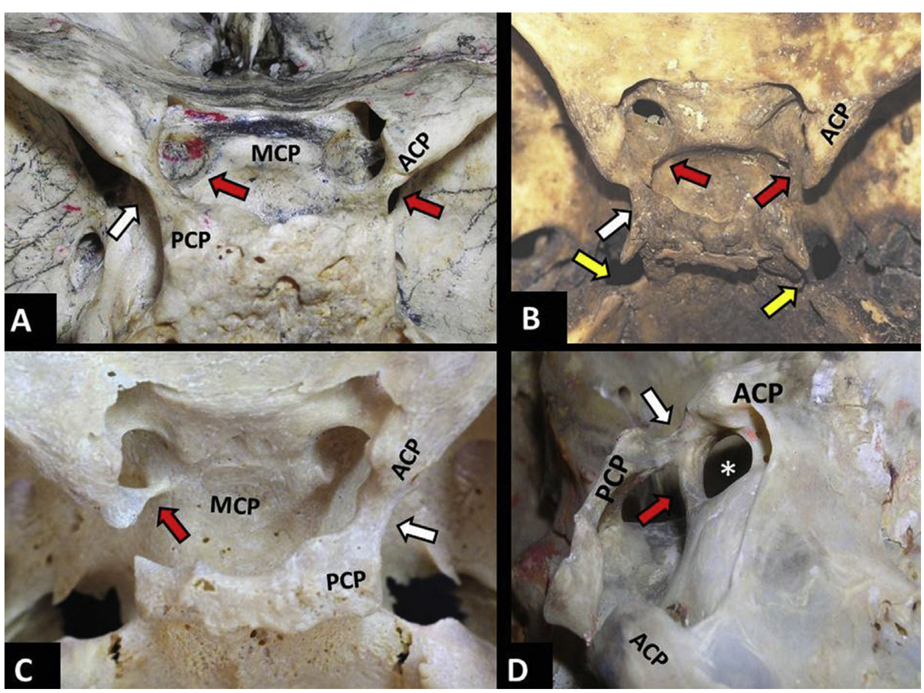

Fig. 6. (A) Complete ossification between anterior and posterior clinoid process (ACP and PCP) on the left side (white arrow) in coexistence with a complete caroticoclinoid bar (CCB) bilaterally (red arrows) (B) Anterior interclinoid bar (AIB) on the left side (white arrow) in coexistence with a complete CCB (red arrow) on the ipsilateral side and a partial CCB (red arrow) on the contralateral side and osseous spikules on PCP on both sides (yellow arrows) (C) Complete AIB (white arrow) on the right side in coexistence with a contralateral complete CCB (red arrow) (D) Ccomplete AIB (white arrow) in coexistence with a complete CCB (red arrow) on the left side. *Caroticoclinoid foramen.

4. Discussion

Intracranial ossification in the sellar region (Skrzat et al., 2006) produces the CCB, AIB (so-called sellar bridge), PIB, APB and PPB (Galdames et al., 2008). The etiology of these ligamentous ossifications remains uncertain. Changes in calcium metabolism, phosphorus and vitamin D suggested as a predisposing factor to calcium deposition and ossification (Gokce et al., 2008). Some proteins

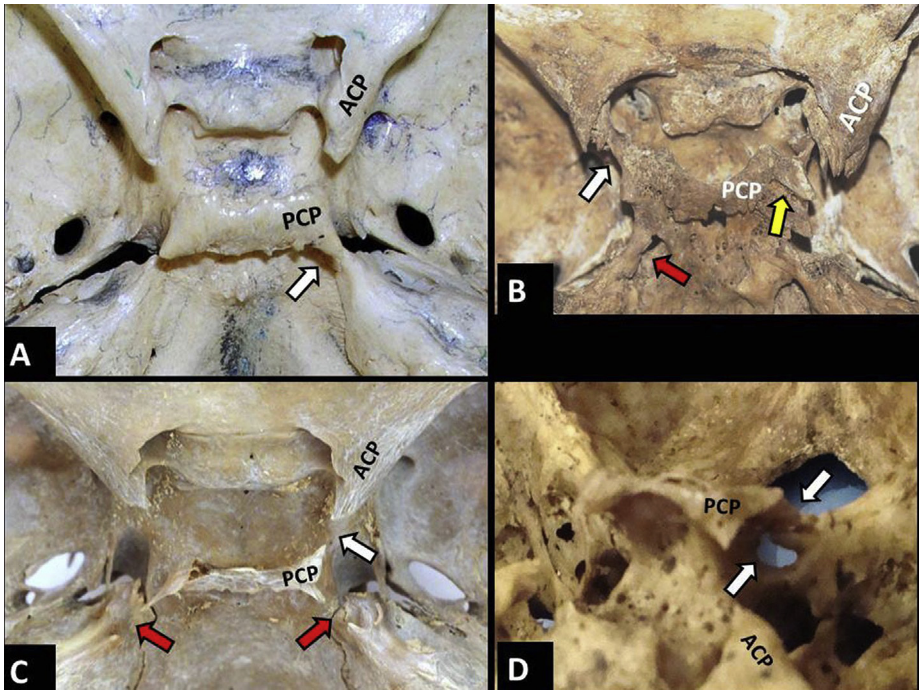

Fig. 7. (A) Completely ossified petroclinoid ligament on the right side (white arrow), the so-called Dorello's canal (B) Asymmetric anterior clinoid processes (ACP) on both sides, complete anterior interclinoid bar (AIB) on the left side (white arrow) in coexistence with complete posterior petroclinoid bar (PPB) (red arrow) and osseous spikule on the posterior clinoid process (PCP) (yellow arrow) (C) Partial PPB on both sides (red arrows) in coexistence with a partial anterior interclinoid ligament (white arrow) on the right side (**D**) Complete PPB–Dorello's canal (white arrows).

Table 2
Measured distances (in millimeters [mm]) according to side and gender.

Measured distances	Right side	Left side	Right side		Left side	
			Males	Females	Males	Females
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
ACP-MCP	3.66 ± 1.54	3.65 ± 1.33	3.75 ± 1.85	3.56 ± 1.13	3.95 ± 1.48	3.28 ± 1.09
	Symmetry, p = 0.480 T-test		p = 0.764, T-test		p = 0.272, T-test	
ACP-PCP	4.99 ± 1.60	4.92 ± 1.31	4.98 ± 1.83	5.01 ± 1.43	4.52 ± 1.11	5.38 ± 1.45
	Symmetry, p = 0.391 T-test		p = 0.971, T-test		p = 0.189, T-test	
MCP-PCP	5.66	-	-	-	-	-
Inter-ACP	25.51 ± 2.42		25.41 ± 2.24 (males), 25.62 ± 2.62 (females), p = 0.717, T-test			
Inter- MCP	11.06 ± 2.071		11.18 ± 2.39 (males), 10.92 ± 1.61 (females), p = 0.592 one-way ANOVA			
Inter-PCP	16.25 ± 2.29		16.68 ± 2.54 (males), 15.69 ± 1.85 (females), p = 0.247 T-test			
ACP length	11.43 ± 2.33	11.66 ± 1.70	11.11 ± 2.01	11.79 ± 2.63	11.54 ± 1.79	11.79 ± 1.61
	Symmetry, p = 0.321 T-test		p = 0.482, T-test		p = 0.885, T-test	
ACP width	9.02 ± 1.67	9.63 ± 1.71	9.54 ± 1.56	8.41 ± 1.61	9.80 ± 1.81	9.43 ± 1.61
	Asymmetry, p=0.002, T-test		**p=0.013 gender dimorphism Mann–Whitney Test**		p = 0.470, T-test	
ACP thickness	5.91 ± 1.63	5.92 ± 1.48	5.88 ± 1.79	5.93 ± 1.49	5.83 ± 1.39	6.02 ± 1.59
	Symmetry, p = 0.861 T-test		p = 0.922, T-test		p = 0.660, T-test	
CCF anteroposterior diameter	5.41 ± 0.74	5.35 ± 1.26	5.76 ± 0.69	4.83 ± 0.69	5.62 ± 1.42	4.89 ± 1.02
	Symmetry, p = 0.859 T-test		p = 0.111, Mann–Whitney Test		p = 0.402, T-test	
CCF transverse diameter	5.31 ± 0.54	5.48 ± 1.00	5.24 ± 0.57	5.44 ± 0.59	5.76 ± 1.14	5.02 ± 0.62
	Symmetry, p = 0.692 T-test		p = 0.687, T-test		p = 0.124, T-test	

ACP = anterior clinoid process; MCP = middle clinoid process; PCP = posterior clinoid process; CCF = caroticoclinoid foramen.
Bold letters indicate asymmetry and gender dimorphism. The other variables are symmetrical and no gender dimorphism exist.

promote hardening of the ossifying structures (Steitz et al., 2002), while others inhibit calcification (Murshed et al., 2004). The theory of reactive metaplasia suggests that a previous trauma in the sellar region may cause multiple metaplastic changes to ligaments, stimulating complete or partial ossification. The occurrence of metaplasia might be attributable to the presence of osseous centers within these fibrous formations (Steinmann, 1970).

Osseous bridging is a frequent age-related process representing the ossification outcome of fibrous structures. Fibers within the ligaments undergo degenerative changes and become hypertrophied. The presence of chondrocytes around the ossified area defines the enthesopathy phenomenon (Natsis et al., 2007), explaining the higher incidence of bony bridges with aging. Our study supports and confirms this view. Insertion sites are subject to tensile and compressive forces due to their fibrocartilaginous origin (Natsis et al., 2007). Regarding skull ligaments, the age impact on the ossification process is controversial, since some investigators reported that aging affects CCB and sellar bridges morphology, while others highlighted that CCB and sellar bridges occurrence is not age related (Ozdogmus et al., 2003) and develops due to the complex sphenoid bone embryology. Lang (1977) reported CCF and sellar bridge presence in embryos and newborn infants, suggesting that the ossification process derives from the cartilaginous tissue and not from the dura mater. Kiroglu et al. (2010) mentioned that the PPL calcification is age related, and Skrzat et al. (2014) referred to the highest mineralization process in the marginal part of the PCP osseous extensions. The CCB and sellar bridge prevalence in our study was higher in the older age group. Spearman's correlation revealed that the age impact holds statistical significance only in the complete CCL and ICL ossified ligaments. Aging was more strongly correlated with the complete AIL ossification than CCL.

In our sample, the CCB was the most commonly detected (60.15%). Its incidence presents a wide variability among different populations (Table 3). Unilateral CCBs were more frequently detected (31.7%) in the current study, compared to bilateral CCBs (28.45%). The majority of studies reported a higher frequency of unilateral CCBs in comparison to the bilateral ones, except for the studies by Azeredo et al. (1988-1989), Deda et al. (1992), Boyan et al. (2011) and Sanobar et al. (2012), who reported that bilateral CCBs were more prominent. The prevalence of side predominance regarding partial CCB differs significantly among populations. We agree with the right side predominance reported by Erturk et al. (2004), and Kapur and Mehic (2012). In contrast, Boyan et al. (2011) detected left-sided predominance. The findings in Turkish (Erturk et al., 2004; Boyan et al., 2011; Dagtekin et al., 2014) and Indian (Archana et al., 2010; Kolagi et al., 2011; Aggarwal et al., 2012; Kanjiya et al., 2012; Archana et al., 2013; Raveendranath et al., 2013) populations are notably different, with significant variation in frequency, type of ossification and laterality. Variations among similar populations suggest that excluding racial/ethnic differences, other parameters such as gender, age, geographical distribution, genetic and molecular factors could play an important role in ligament ossification and foramina morphometry (Boyan et al., 2011; Dagtekin et al., 2014).

The TD of the CCF found in Greeks (5.32 ± 0.54 mm on the right and 5.56 ± 0.9 mm on the left side) is very close to the values reported by Erturk et al. (2004) (5.33 ± 0.3 mm on the right and 5.32 ± 0.73 mm on the left side), Freire et al. (2011) (5.18 ± 4.66 mm on the right and 5.35 ± 0.71 mm on the left side) and Kapur and Mehic (2012) (5.32 ± 0.52 mm on the right and 5.21 ± 0.73 mm on the left side) in studies performed in Turkish, Brazilian and Bosnian populations, respectively. Archana et al. (2013) found side asymmetry with right-sided predominance (6 mm) versus left-sided (5.5 mm). The incidence of CCF, in order of frequency, is reported to be 35.7% in Turks, 34.8% in Caucasian/white Americans, 23.4% in Sardinians, 17% in Alaskan Eskimos, 15.7% in Koreans, 14% in Germans, 9.9% in Japanese and 6.27% in Portuguese (Erturk et al., 2004). From a pathological point of view, the incidence of CCF is reported to be high (15%–38%) in individuals with hormonal derangement, in idiots, in criminals, and in epileptics (Lang, 1995).

The frequency of the ICBs ranges from 0.5% (Brahmbhatt et al., 2015) to 34.1% (Peker et al., 2006) (Table 2). Our study found a high incidence of 19.5%, while the highest value of 34.1% was observed in Turkish skulls (Peker et al., 2006). We agree with the view of Patnaik et al. (2003) that partial ICBs appear more frequently unilaterally, while complete ones presented more commonly bilaterally. Cederberg et al. (2003) mentioned that the extent of ICL calcification does not vary by gender. They also detected an association between the ossified ICL and PPL, attributing this condition to their common derivation from the same dural fold. Cederberg et al. (2003) reported the highest incidence of 23% for the partial and 9% for the complete PPB, projecting the familial background as a possible etiology. Stanton and Wilkinson (1949) found the PPB in 19.4% and Peker et al. (2006) detected the PPB in 7.6% of subjects on the right side and in 10.1% on the left. Sedghizadeh et al. (2012) identified the ossified petroclinoid dural folds via CT scan in 40 of 500 patients, an incidence of 8% bilaterally. A unique case of exostosis arising from the lateral aspect of the PCP was also described by Nagasawa and Ohta (1994). In our study, the mixed type of ossification in Greeks showed the high incidence of 17.8%, in contrast to findings by Archana et al. (2010), who reported the lowest incidence of 0.4% in Indians. In rare cases, all 3 clinoid processes may fuse together. In our study, a single skull (0.8%) with a combination of CCB, ICB and PPB was observed.

An increased prevalence (range 10.71%–18.6%) of sellar bridges was reported in patients with mental disorders (38%), in severe craniofacial and dentofacial deviations associated with tooth agenesis or displacement (Archana et al., 2010), in Down's, Wiliam's, Seckel's, Rieger's and Axenfeld-Rieger's syndromes (Tassoker et al., 2017) and in skeletal class III malocclusion. Jones et al. (2005) reported a higher prevalence (16.7%) of sellar bridges in patients treated with combined surgical and orthodontic procedure versus those (7.3%) treated with orthodontic method. The extent of sellar bridges' ossification might be positively associated with the ICA course (Platzer, 1957) and the ponticulus posticus occurrence (Haji-Ghadimi et al., 2017; Tassoker et al., 2017). The relationship of sellar bridging with the ponticulus posticus existence may be explained by the involvement of neural crest cells and/or homeobox genes during development (Saokar and Nawale, 2014). Pineyro et al. (2017) reported that anti-osteoporotic drug accumulation in osseous structures poses a higher risk of transsphenoidal surgery due to the spontaneous sellar re-ossification.

In cases of partial ossification, the ACP-MCP distance in our study is similar to the findings reported by Erturk et al. (2004) and Kapur and Mehic (2012). In our study, the ACP length, width and thickness (11.54 ± 2.01 mm, 9.32 ± 1.69 mm and 5.91 ± 1.55 mm respectively) are in accordance with the findings of Bozkurt and Tagil (2000) in Turks (10.05 ± 1.27 mm, 9.63 ± 1.03 mm and 5.58 ± 0.98 mm). Dagtekin et al. (2014) in a study in Turks, reported lower results of ACP, since the average length, maximum width and thickness were found to be up to 9.7 mm, 7.3 mm and 5.4 mm respectively. Similar observations were reported by Gupta et al. (2005), Hunnargi et al. (2008), Huynh-Le et al. (2004), Lee et al. (1997) in Nepalese, Indians, Japanese and Koreans, respectively. According to the above findings, the mean length of ACP is longest in Indians and the mean width is shortest in Turks.

Since the presence of osseous bridges in the sellar region can complicate the neurosurgical procedure and increase the intraoperative risk (Ozdogmus et al., 2003), their preoperative identification by using a 3-dimensional computed tomography (3D-CT) scan is of paramount importance (Erturk et al., 2004; Lee et al., 1997; Ota et al., 2015). In cases of severe ossification, modification of the surgical approach is required to ensure a safe and uneventful surgery (Ota et al., 2015).

The presence of AIB and CCB may cause compression, tightening or stretching of the ICA. Distinct morphological changes in the triangular clinoid space (Gupta et al., 2005) and ICA (Erturk et al., 2004) have been observed in cases of CCF presence. A wide CCF may provide a safety cover for the ICA, while, on the other hand, it may also confuse radiologists while performing carotid arteriograms. An encircling CCF may reduce the ICA caliber, inducing headaches and other compression symptoms owing to discrepancies between the larger arterial and the smaller bony foraminal diameter (Das et al., 2007). Presence of CCB increases the risk of rupturing or tearing the ICA, leading to fatal cerebral infarction, especially in aneurysmal cases. Retraction or mobilization of the cavernous segment of the ICA is difficult when CCB is present, even if dural rings are released. Therefore, the preoperative recognition

Table 3
Comparison of the reported incidence of the caroticoclinoid (CCB) and interclinoid (ICB) osseous bars among various studies.

Author	Year	Specimens/method	Population	Caroticoclinoid bridges (CCB)			Interclinoid bridges (ICB)
				Unilaterally	Bilaterally	Total	
Camp	1923	110 autopsies	N/M	-	-	-	5.5% complete
Keyes	1935	2187 skulls	Caucasian Americans	-	-	27.46%	8.68%
Busch	1951	343 autopsies	N/M	-	-	-	1.74% partial 1.54% complete
Platzer	1957	220 autopsies		-	-	-	5.9% complete
Lang	1977	120 adults autopsies 45 fetuses autopsies	N/M N/M	- -	- -	- -	2.5% complete 2.5% partial 4.4% complete
Bergland et al.	1968	225 autopsies	N/M	-	-	-	6%
Azeredo et al.	1988–1989	270 skulls	Portuguese	6 (2.2%)	11 (4.05%)	17 (6.27%)	3.04%
Cireli et al.	1990	50 skulls	N/M	3 (6%)	-	3 (6%)	1 (2%)
Inoue et al.	1990	50 skulls	N/M	11 (22%)	7 (14%)	18 (36%)	2 (4%)
Deda et al.	1992	88 skulls	N/M	6 (6.82%)	7 (7.95%)	13 (14.77%)	4 (4.54%)
Gurun et al.	1994	198 skulls	N/M	16 (8.08%)	11 (5.55%)	27 (13.63%)	2 (1.01%)
Lee et al.	1997	73 skulls (146 sides)	Koreans	11 (15.7%)	1 (1.4%)	12 (17.1%) 4.1% complete 11.6% partial	-
Ertuk et al.	2004	171 skulls (342 sides) 119 skulls+52 cadaveric heads	Turks	41 (23.98%)	20 (11.69%)	61 (35.67%) total 14 (4.09%) complete 16 (4.68%) in contact 51 (14.98%) partial	14 (8.18%) 2.34% on the right 1.75% on the left
Ozdogmus et al.	2003	50 skulls (100 sides)	Turks	-	-	45% total 27% complete 18% partial	6%
Peker et al.	2006	80 skulls	Turks	-	-	-	34.17% total 29.1% on the right 31.7% on the left 3.7% partial 17.5% complete
Archana et al.	2010	250 skulls	Indians	23 (9.2%)	7 (2.8%)	30 (12%)	5.6% AIB 4% PIB 0.4% mixed type bars
Desai and Sreepadma	2010	223 skulls	N/M	53 (23.74%) 37 partial (16.58%) 16 complete (7.16%)	30 (13.45%) 7 partial (3.13%) 23 complete (10.31%)	83 (37.19%) total 44 (19.71%) partial 39 (17.47%) complete	
Raveendranath et al.	2010	242 skulls	South Indians	-	-	9.92% complete 4.13% partial	-
Aggarwal et al.	2011	70 skulls	N/M	-	-	15.7%	-
Boyan et al.	2011	34 skulls	Turks	2 (5.9%)	10 (29.4%)	35%	-
Kolagi et al.	2011	112 skulls	Indians	-	-	-	9 (8.04%) in total 6 (5.35%) unilaterally 3 (2.67%) bilaterally
Freire et al.	2011	80 skulls	Brazilians	5 (6.25%)	2 (2.5%)	7 (8.75%)	
Aggarwal et al.	2012	67 skulls (134 sides)	Indians	16 (11.9%)	3 (2.2%)	22 (16.4%) total 4 (2.9%) complete 18 (13.4%) partial	9 (6.7%) AIB 7 (5.2%) PPB
Kanjiya et al.	2012	200 skulls	Indians	-	-	29 (14.5%) total 23 (11.5%) complete 6 (3%) incomplete	15 (7.5%) total 9 (4.5%) complete 6 (3%) incomplete
Kapur and Mehic	2012	200 skulls (400 sides)	Bosnians	9.3%	7.5%	16.8% total 17 (4.25%) complete 39 (9.75%) partial	6.8% in total
Sanobar et al.	2012	100 skulls	N/M	10 (10%)	14 (14%)	24 (24%) 6 (6%) complete 18 (18%) partial	-
Archana et al.	2013	50 skulls	Indians	1 (2%)	1 (2%)	2 (4%)	-
Dagtekin et al.	2013	25 skulls (50 sides)	Turks	-	-	(10%) complete (15%) partial	-
Brahmbhatt et al.	2015	50 skulls	Indians	0.5%	0.5%	6%	0.5% in total
Ota et al.	2015	72 cadavers	Japanese	6 (8.3%)	6 (8.3%)	12 (16.6%)	-
Current study	2017	123 skulls (246 sides)	Greeks	39 (31.7%) 16 (13%) 23 (18.7%)	35 (28.45%) 13 (10.6%) 22 (17.9%)	74 (60.16%) total 29 (23.6%) complete 45 (36.6%) partial	24 (19.5%) in total 18 (14.6%) unilaterally 6 (4.9%) bilaterally

AIB = anterior interclinoid bar; PIB = posterior interclinoid bar; PPB = posterior petroclinoid bar; N/M = not mentioned.

of CCF by CT imaging is of paramount clinical significance when operating on sellar lesions.

In particular, the AIB may influence the ICA flow or cause orbital muscle dysfunction due to possible oculomotor nerve entrapment and/or compression. In subtemporal and transtentorial petrosal approaches, preoperative evaluation of the PPB ossification extent is of fundamental importance in order to avoid any intraoperative injury to the sixth cranial nerve (Inal et al., 2016). Moreover, cases of trigeminal neuralgia secondary to an ossified PCL are referred to (Komminoth and Woringer, 1964) as not localized on CT scans (Kimball et al., 2015).

The ACP is by far the most important bony projection, and hides part of the optic nerve and ICA. The skull base surgeon should keep in mind possible racial/ethnic, gender and age differences as well as side asymmetry regarding ACP dimensions when performing anterior clinoidectomy. Variations in the patterns of bony ACP and MCP may pose a significant risk for ICA injury during parasellar approaches, especially those involving clinoidectomy and optic strut drilling (Sharma et al., 2017). Drilling of the ACP may also cause inadvertent injury to the optic nerve (Gupta et al., 2005). Both anterior and posterior clinoidectomies are technically demanding (Seoane et al., 1998; Skrzat et al., 2014), as high neurovascular injury risk is possible (Gupta et al., 2005; Boyan et al., 2011; Dagtekin et al., 2014), especially in cases of ICB or CCB coexistence. Thus, paraclinoid or cavernous sinus tumors, giant and complex aneurysms near the proximal ICA or upper basilar artery, or aneurysms hidden by the PCP should be treated only by experienced and skillful surgeons. In such cases, drilling in cavernous sinus region should be performed very carefully to avoid possible venous bleeding, cerebrospinal fluid fistula, oculomotor and abducens nerve injury or ICA injury (Seoane et al., 1998; Youssef and van Loveren, 2009). Moreover, cases of pneumatized ACP should be recognized preoperatively, and coexistence of optic nerve and ICA protrusion into the sphenoid sinus should also be ruled out (Hewaidi and Omami, 2008). The extensive drilling of the ACP and optic unroofing (Spektor et al., 2013) will provide the widest possible exposure, optic nerve mobilization and resection of the tumor and the involved dura as well (Dagtekin et al., 2014). Cases of particularly fragile incomplete osseous bars should be also recognized by the neurosurgeon, when the clinoidal part of the ICA is mobilized. In order to prevent catastrophic complications, the dimensions and configuration of the ACP should be always appreciated by the skull base surgeon. Therefore, careful and detailed preoperative imaging is strongly advised.

4.1. Study limitations

Only skulls with small calcifications, well-defined borders and symmetry to the midline or bilateral were included in this study, indicating the normal developmental ossification process. The age impact on PIL and PPL ossification could not be detected due to the small number of cases. Moreover, the pathological background could not be correlated with the incidence of osseous bridges due to the limited number of pathological skulls.

5. Conclusion

In summary, the current study showed that the osseous bars in sellar region is not a rare phenomenon. The notable differences in the incidence of CCB, AIB, PIB and PPB in skulls of Greek individuals compared to findings reported in other populations highlight the growing awareness of ethnic differences in skull base anatomical landmarks. Variations and measurements provided by this study may help clinicians to better understand the regional anatomy and make skull base procedures safer, and ultimately contribute to an optimal preoperative patient counseling. The findings of the present study would benefit radiologists and neurosurgeons, particularly in cases of extensive ossification, in which technical modification of the surgical approach is required.

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Conflict of interest

The authors confirm that they have no conflict of interest to declare.

Informed consent

Informed consent was obtained from the body donors; their skulls were included in the study.

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