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Morphological and Morphometric Study of Calcification of the Pterygoalar Ligament in Dry Human Skulls

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ABSTRACT

Introduction: the pterygoalar ligament is a fibrous band located between the lateral lamina of the pterygoid process and the infratemporal surface of the sphenoid bone. The literature has described that calcifications in this ligament may compress the branches of the mandibular nerve and hinder anesthetic and/or surgical techniques in the infratemporal region.
Objective: To evaluate the frequency of pterygoalar ligament calcifications and their relationship with the sides of the skull, sex, and age.
Methods: one hundred and sixteen dry human skulls from adult individuals were evaluated. Skulls were classified into four morphological patterns according to the percentage of calcification: 1- no calcification; 2- less than 50%; 3- between 50% and 100%; 4- complete calcification. Measurements were performed using a digital caliper. Data were tabulated and analyzed using the statistical software Jamovi version 2.2.5, with a significance level of 5%.
Results: calcifications occurred on 39.7% of the skulls. Thirty one skulls (26.7%) showed calcifications on the right side and 30 (25.9%) on the lef side. The most frequent classification was type 2 for both sides. The female skulls showed statistically smaller measurements of the distance between the points of attachment of the pterygoalar ligament.
Conclusion: the frequency of pterygoalar ligament calcification was considerable and was not associated with the sides or sex of the skull. The distance between ligament attachment points was statistically smaller in females.
Keywords: Skull; Skull Base; Ligaments; Calcification; Physiologic.

Introduction

Many skull base ligaments are unknown to most physicians and other healthcare professionals because they are not described in conventional Human Anatomy textbooks and atlases[1,2]. The evaluation of these ligaments is important because the natural calcification processes of these ligaments can cause compression of neurovascular structures, causing various clinical symptoms, or difficulties in surgical access involving the base of the skull[2–5].

Among these, the pterygoalar ligament stands out, which is described as a fibrous band located between the lateral lamina of the pterygoid process and the infratemporal aspect of the sphenoid bone, laterally to the spinous foramen and unrelated to the spine of the sphenoid bone[6–10]. Complete calcification of this ligament forms a foramen, which was first described by Hyrtl, in 1862, as porus crotaphitico-buccinatorius[6,11].

Several studies have shown that the calcification of the pterygoalar ligament forms complete or incomplete bars close to the foramen ovale, which may compress branches of the mandibular nerve, hinder the mandibular nerve block anesthetic technique or hinder surgical procedures for the treatment of trigeminal neuralgia, such as percutaneous rhizotomy of the trigeminal ganglion[7–9,12,13].

A study carried out with a sample of 312 skulls belonging to a University in the Southeast of Brazil showed an occurrence of 22.43% of incomplete calcifications of the pterygoalar ligament and of 3.84% of complete calcifications[6].

On the other hand, a systematic review and meta-analysis that included 25 primary studies, representing a sample of 16,168 individuals, demonstrated an occurrence of 8.4% of incomplete calcifications and 4.4% of complete calcifications of this ligament[3].

The frequency of complete and incomplete calcifications of the pterygoalar ligament has varied between studies, with the incomplete and unilateral form being more commonly found[6,8,9,11,12,14].

However, there are still doubts regarding the relationship between these calcifications and the sides of the skull, sex and age.

Thus, the present study aimed to evaluate the frequency of calcifications in the pterygoalar ligament in dry human skulls and their relationship with the sides of the skull, sex and age.

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Materials and Methods

A cross-sectional study was performed at the Human Anatomy Laboratory of the Institute of Biological and Health Sciences (Federal University of Alagoas, Maceió, Alagoas, Brazil) and at the Forensic Anthropology and Osteology Laboratory (Department of Anatomy, Federal University of Pernambuco, Recife, Pernambuco, Brazil). The study was conducted after institutional approval and was in accordance with the determinations of the Brazilian Federal Law number 8051, of November 30, 1992, which regards the use of unclaimed cadavers for the purposes of studies or scientific research[15,16].

The sample consisted of 116 dry human skulls according to the following inclusion criteria: intact skulls from adult individuals without restriction of sex and ancestralism. Were excluded: damaged or incomplete skulls; skulls sectioned in the sagittal direction; skulls of children; skulls with evidence of trauma to the skull base; and skulls with craniofacial deformities.

A non-probabilistic convenience sampling was carried out, seeking to select all eligible dry skulls, according to the aforementioned eligibility criteria.

The skulls were photographed to record the calcifications using a DSLR digital camera; then, were evaluated for the presence of incomplete or complete calcifications in the pterygoalar ligament, as well as their presentation on the sides of the skulls and relationships with sex and age (only for skulls on which this information was available). The presence of areas indicative of calcifications was evaluated bilaterally at the points of attachment of the pterygoalar ligament, according to the following description[2,7,14]:

Inferior attachment: upper end of the posterior margin of the lateral lamina of the pterygoid process of the sphenoid bone.

Superior attachment: underside of the greater wing of the sphenoid bone, laterally to the spinous foramen.

The skulls were classified according to the presence and to the extent of calcifications in four patterns (adapted from Touska *et al.*[2]:

Type 1 – Absence of calcifications;

Type 2 – Presence of calcifications on less than 50% of the ligament`s total length;

Type 3 – Presence of calcifications between 50% and 100% of the ligament`s total length;

Type 4 – Completely calcified ligament, forming a foramen.

In all skulls, the distances between the anatomical points of attachment of the pterygoalar ligament were measured, as previously described. In the presence of incomplete calcifications, the lengths of calcified ligament areas were also measured. These calcification measurements were summed, allowing the determination of the total calcification value for each side of the skull. Then, the percentage of calcification was determined, based on data referring to the distance between the points of attachment of the pterygoalar ligament.

Measurements were performed using a digital caliper with a precision of 0.01 mm (MTX®, Tools World, Guarulhos, SP, Brasil - MTX-316119). Three measurements were taken, and the mean of the three measurements was considered.

Cases that presented a line of union between the two calcified ends of the ligaments were classified as type 4[2].

In skulls classified as type 4, the following additional morphometric analyzes were performed: (1) length of the calcified bar, (2) larger diameter and (3) smaller diameter of the formed foramen. In addition, the formula for calculating the area of ellipses was used to calculate the area of the respective foramen:

Area = a x b x π, where (a) represents the largest radius, (b) the smallest radius, and π equals 3.14. The diameter is calculated by multiplying the radius by two.

All analyzes were performed by a single examiner after prior calibration. After the calibration process, the inter-examiner Kappa coefficient was calculated. Therefore, 20% of the sample was analyzed and classified by the examining researcher and by a second evaluator, an anatomist with an experience of ten years in the field. Data collection started only when the inter-examiner Kappa coefficient ≥ 0.8 (almost perfect agreement) was reached.

Statistical analysis

Data were tabulated in the Jamovi program, version 2.2.5, and analyzed using descriptive and inferential statistics. Statistical differences related to the frequencies of calcifications between the sides of the skull were determined using the McNemar test. Differences in calcification frequencies between males and females were determined using Pearson's chi-square test or Fisher's exact test.

For morphometric data, the Shapiro-Wilk test was initially performed to assess data distribution, which demonstrated a non-parametric distribution ($p < 0.05$). Thus, the statistical differences related to the distance between the points of attachment of the pterygoalar ligament to the sides of the skull were determined using the Wilcoxon test. The Mann-Whitney U test was used to assess possible differences related to the length of the calcifications and the area of the formed foramen (complete calcifications) between the right and left sides. The Mann-Whitney U test was also used to assess possible differences related to morphometric measurements in males and females. Spearman's correlation was performed to assess the variables age, degree of calcifications, and length of calcifications. For all analyses, the significance level was set at 5% (0.05).

Results

The Kappa coefficient observed in this study was 0.81, indicating excellent agreement between examiners. Of the 116 dry human skulls evaluated, 59 had their sex determined, being 22 female (37.3%) and 37 male (62.7%). 41 skulls had exact definition of age, with a mean of 57.7 years (±20.2 standard deviation). Forty-six skulls (39.7%) had some degree of calcification of the pterygoalar ligament, regardless of the side. Thirty-one skulls (26.7%) showed calcification on the right side and 30 skulls (25.9%) on the left side (Table 1). Figure 1 shows representative images of the four patterns regarding the presence of pterygoalar ligament calcifications. In skulls with some calcification, both on the right and left sides, the most prevalent classification was type 2 (calcification <50% of the ligament), followed by type 3 (calcification between 50% and 100%). Five skulls (4.3%) showed complete calcification of the pterygoalar ligament on the right side and four skulls (3.4%) on the left side (Table 2). No statistical differences were observed for the frequencies of calcifications between the sides of the skull (Table 3). Also, no statistically significant differences were observed between calcification frequencies and sex for both sides of the skull (Table 4).

Table 1. Frequency of ligament calcifications.

General Frequency		
	N	%
No calcification	70	60.3%
With calcification	46	39.7%
Frequency on the right side		
	N	%
No calcification	85	73.3%
With calcification	31	26.7%
Frequency on the left side		
	N	%
No calcification	86	74.1%
With calcification	30	25.9%

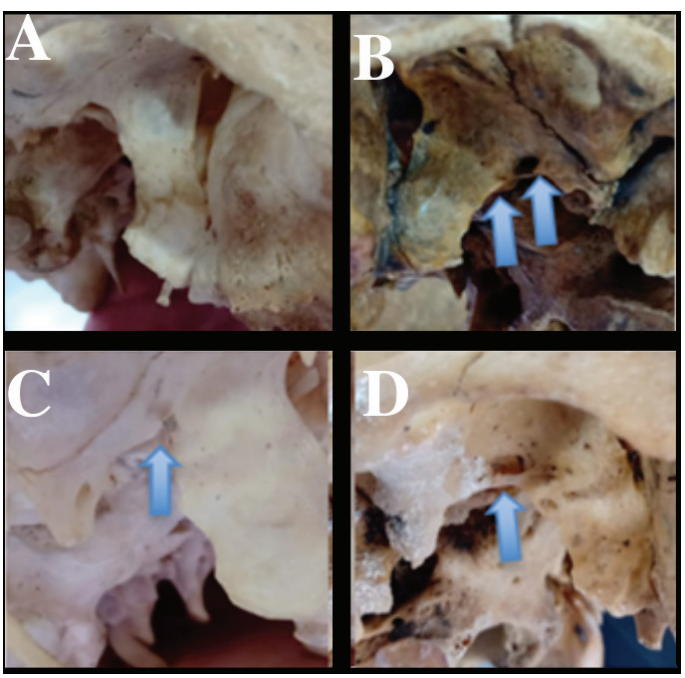

Figure 1. Morphological patterns of calcification of the pterygoalar ligament. A) Type 1; B) Type 2; C) Type 3; D) Type 4.

Table 2. Classification of the degree of ligament calcification.

Right Side		
	N	%
Type 1	85	73.3%
Type 2	20	17.2%
Type 3	6	5.2%
Type 4	5	4.3%
Left Side		
	N	%
Type 1	86	74.1%
Type 2	21	18.1%
Type 3	5	4.3%
Type 4	4	3.4%

Table 3. Association between the presence of calcification and the sides of the skulls.

	Left side			
Right side	**No calcification**	**With calcification**	**Total**	**p-value***
No calcification	70	15	85	0.857
With calcification	16	15	31	
Total	86	30	116	

* McNemar test

Table 4. Association between the presence of calcification and sex.

Right Side				
Sex	**No calcification**	**With calcification**	**Total**	**p-value***
Female	18	4	22	0.365
Male	25	12	37	
Total	43	16	59	
Left Side				
Sex	**No calcification**	**With calcification**	**Total**	**p-value****
Female	17	5	22	0.889
Male	28	9	37	
Total	45	14	59	

*Fisher's Exact Test - ** Pearson's chi-square test

The median distance between the anatomical points of attachment of the pterygoalar ligament on the right side was 7.74 mm (interquartile range - IQR: 2.45) and 8.00 mm (IQR 2.92) on the left side. In skulls with some degree of calcification, the median calcification length on the right side was 3.09 mm (IQR 3.08) and 3.28 mm (IQR 2.86) on the left side. The median area of the foramen formed in cases with complete calcifications on the right side was 15.2 mm^2 (IQR 7.24) and 9.96 mm^2 (IQR 7.69) on the left side. No statistically significant differences were observed between the right and left sides for the distance between the ligament attachment points and calcification length (Table 5). Female skulls had statistically smaller measurements of the distance between ligament attachment points compared to male skulls for both sides of the skull. No statistical difference was observed for the length of the calcifications (Table 6).

Spearman's correlation test did not demonstrate statistically significant correlations between the variables age and degree of calcification (Type 1, 2, 3 and 4) and age and length of calcification on both sides of the skull.

Discussion

Understanding the occurrence of skull base ligament calcifications is important, as these calcifications can imprison and compress neurovascular structures, resulting in clinical symptoms or difficulties in surgical access[2–5].

Table 5. Statistical differences for morphometric measurements in relation to skull sides.

Distance between ligament attachment pointsa			
	Median	**Interquartile Range (IQR)**	**p-value***
Right side	7.74	2.45	0.670
Left side	8.00	2.92	
Calcification lengthb			
	Median	**Interquartile Range (IQR)**	**p-value****
Right side	3.09	3.08	0.863
Left side	3.28	2.86	
Foramen area (complete calcification) c			
	Median	**Interquartile Range (IQR)**	**p-value****
Right side	15.2	7.24	0.73
Left side	9.96	7.69	

*Wilcoxon W test
** Mann-Whitney U test
a N= 116 on the right side and 116 on the left (paired comparison)
b N= 31 on the right side and 30 on the left side
c N= 5 on the right side and 4 on the left side

Table 6. Statistical differences for morphometric measurements in relation to sex.

Distance between ligament attachment points Right sidea			
	Median	**Interquartile Range (IQR)**	**p-value***
Female	6.6	1.66	P<0.001
Male	8.32	1.72	
Distance between ligament attachment points eft sidea			
	Median	**Interquartile Range (IQR)**	**p-value***
Female	6.76	2.14	0.002
Male	8.3	2.4	
Calcification length Right sideb			
	Median	**Interquartile Range (IQR)**	**p-value***
Female	2.66	0.828	0.684
Male	3.06	2.39	
Calcification length Left sidec			
	Median	**Interquartile Range (IQR)**	**p-value***
Female	2.28	3.44	0.689
Male	3.14	1.09	

* Mann-Whitney U test.
a N= 22 female and 37 male
b N= 4 female and 12 male
c N= 5 female and 9 male

In this sense, studies conducted in different populations have demonstrated the occurrence of calcifications in the pterygoalar ligament[2,3,6–9,12,14], suggesting that these calcifications may compress the mandibular nerve trunk or the lingual nerve[10]. The literature has also suggested that calcifications of the pterygoalar ligament may compress the buccal, auriculotemporal and chorda tympani nerves[7,12].

The symptoms resulting from the compression of these nerves can be estimated from the understanding of their nervous components and innervation territories. Thus, compression of the mandibular nerve, especially of its temporal, masseteric, and pterygoid branches, may result in paresthesia or weakness of the masticatory muscles[7,17–19]. Compression of the buccal nerve can result in paroxysmal pain similar to neuralgia or numbness of the buccal region[7]. Involvement of the auriculotemporal nerve can cause pain or numbness in the skin of the external ear, temporomandibular joint and temporal region, in addition to impaired salivation, as this nerve carries postganglionic secretory fibers originating in the otic ganglion to the parotid gland[17–19]. On the other hand, compression of the lingual nerve could cause pain and paresthesia in the lingual gingiva, sublingual compartment and anterior 2/3 of the tongue. As the chorda tympani nerve carries special visceral afferent fibers for taste from the anterior 2/3 of the tongue and preganglionic fibers (general visceral efferent fibers) that participate in the regulation of

the sublingual and submandibular glands, these functions can also be compromised[7,17–19].

In this study, it was demonstrated that 46 skulls, representing a percentage of 39.7% of the evaluated sample, presented some degree of calcification of the pterygoalar ligament, regardless of the side. Studies conducted in different countries have shown varying frequencies, with the following percentages being observed: 26.27% (sample of 312 dry skulls in Brazil)[6]; 31.7% (sample of 145 dry skulls in Greece)[7]; 30% (sample of 100 dry skulls in India)[12]; 22.67% (sample of 55 dry skulls in India)[8]; 6.3% (computerized tomography images from 240 individuals in the United Kingdom)[2]; and 2.4% computerized tomography images from 315 individuals in Bulgaria)[14]. These results suggest that calcifications may be influenced by geographic and anthropological factors. On this subject, a systematic review and meta-analysis suggested that incomplete calcifications of the pterygoalalar ligament are more common in South Americans (19.2% [CI 95%: 0.0-52.2]), followed by Asians (7.0% [CI 95%: 0.7-17.7]), Europeans (6.0% [CI 95%: 1.4 -13.2]) and North Americans (5.6% [CI 95%: 0.0-17.9]). As for complete calcifications, it suggested that they are more frequent in Asia (7.0% [95% CI: 2.7-13.0]), followed by South America (5.0% [95% CI: 1. 2-10.8]), North America (5.0% [95% CI: 3.3-7.1]) and Europe (2.6% [(95% CI: 1.4-4.2]). However, the meta-analysis showed no statistically significant difference[3].

Regarding the type of calcification, the present study demonstrated that most skulls had type 2 calcifications on both sides. Type 2 is a type of calcifications in less than 50% of the ligament. Type 3 calcifications (between 50% and 100%) were seen in 5.2% on the right side and 4.3% on the left side. Touska *et al.*[2] argue that only calcifications above 50% represent a significant clinical impact. Complete calcifications (Type 4) were observed in the present study in 4.3% and 3.4%, respectively, on the right and left sides of the evaluated skulls. These data corroborate with those observed in the literature, which showed similar percentages[2,3,6–8,12,14]

In this study, it was demonstrated that the frequency of calcification of the pterygoalar ligament does not differ statistically in relation to the sides of the skull or sex. Kamath and Vasantha[12] observed a higher frequency on the left side, but did not perform statistical tests to prove whether the observed difference was statistically significant. Corroborating to our results, a study conducted in Greece demonstrated that the frequency of calcifications does not differ according to the sides of the skull and sex[7]. A similar result was demonstrated in a study with 315 computed tomography images of a population in Bulgaria[14]. A systematic review and meta-analysis also showed no statistically significant difference between sides and sex of analyzed skulls[3].

In the present study, morphometric analyzes were carried out, such as the distance between the points of attachment of the pterygoalar ligament, the length of the calcifications and the area of the foramen formed in complete calcifications. It was observed that these morphometric measurements do not differ statistically between the sides of the skull. We could not find other studies that compared morphometric measurements between the sides of the skull, making direct comparisons with our results difficult. In the meta-analysis carried out by Pekala *et al.*[3], a mean calcification length of 6.27 mm was demonstrated (95%CI 5.51 – 7.03). In the present study, calcification length measurements were smaller, but close to the extremes of the meta-analysis confidence interval. On the right side, the mean length was of 4.07 ±2.47 (median 3.09, IQR 3.08) and of 4.08 ± 2.31 (median 3.28, IQR 2.86) on the left side.

It was also observed that the distances between the ligament attachment points were statistically greater in the male skulls. These data suggest that male skulls are larger, especially in an anteroposterior direction. Although skeletal-related sex differences in modern humans are more difficult to determine, the literature has described that the skull of an adult female tends to be lighter and smaller than the skull of an adult male[18–20]. In view of the reduced sample of skulls with sex identification (59 skulls), further studies should be carried out, with larger samples to assess whether this measure has potential as a craniometry technique for estimating sex in forensic anthropology.

Regarding age, Spearman's correlation did not show statistically significant correlations between the variables age versus calcification pattern or age versus length of calcifications. We could not find studies that evaluated the influence of the age variable on the frequency, degree of calcification, and length of calcifications for the pterygoalar ligament. Natsis *et al.*[7] and Kamath and Vasantha[12] suggest that calcification of the pterygoalar ligament is a secondary process and occurs more frequently in older individuals, however, they did not perform statistical evaluations to prove this relationship. In this study, only 41 skulls had an exact definition of age, with a mean of 57.7 years ± 20.2, minimum age of 17 and maximum of 94 years. Given the small sample, we suggest further studies to obtain a greater understanding of the influence of the age variable on the occurrence and length of calcifications.

New studies conducted with computed tomography images may help clarify the relationship between the formation of calcifications in the skull base ligaments and factors such as age, sex, socioeconomic and occupational factors, eating habits, health conditions and possible consumed medications. In addition, it is necessary to better evaluate the potential clinical effects resulting from these calcifications.

Conclusion

The frequency of calcification of the pterygoalar ligament was considerable, with the majority of calcifications in less than than 50% of the ligament. Calcification frequency was not associated with side or sex of the skull. The distance between ligament attachment points was statistically smaller in female skulls. It is necessary to carry out more studies with larger samples and with tomographic images to elucidate the influence of age, sex, and other factors on the calcification of the pterygoalar ligament.

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