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Morphological Analysis of the Arcuate Foramen (*"Ponticulus Posticus"*) in Atlas Vertebrae from Northeastern Brazil

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ABSTRACT
Introduction: the arcuate foramen (AF) is an anatomical variation in the vertebral artery groove of the atlas vertebra (C1). Understanding this variation is fundamental, given the clinical and surgical repercussions it can have, allowing for greater safety in cervical spine procedures.
Objectives: To analyze the morphology and morphometry of the AF in dry atlas vertebrae from a population in Northeastern Brazil.
Methodology: 58 atlas vertebrae from adults in the city of Cajazeiras-PB were analyzed. The vertebrae were examined for the presence or absence of FA and then categorized according to the type of ossification into 5 types: Type I - unilateral incomplete; Type II - bilateral incomplete; Type III - unilateral complete; Type IV - mixed (unilateral complete bone bridge and contralateral incomplete bone bridge); Type V - bilateral complete. Using a digital caliper, the external (AE) and internal (AI) foramen heights were measured; the thicknesses of the anterior (EPA), middle (EPM) and posterior (EPP) bone bridges; and the external (LE) and internal (LI) widths.
Results: in the sample, 16 FAs were found. As for the type of ossification, 2 atlas vertebrae (12.5%) were type I, 5 (31.25%) were type II, 4 (25%) showed type III ossification, 3 (18.75%) were type IV, and 2 (12.5%) were type V. For the measurements of LI and LE, AI and AE, and EPA, EPM and EPP between the right and left sides, there was no statistical difference in the morphometric analysis of this study ($p<0.05$).
Conclusion: this morphological study revealed a higher prevalence of type II AF (bilateral incomplete) and original morphometric data for the population studied. This analysis may help to better understand this anatomical variation, contributing to safer medical practice, especially in surgical procedures in this region.
Keywords: C1 vertebra; Cervical atlas; Arched foramen; Anatomical variation; *Ponticulus Posticus*.

Introduction

The atlas vertebra (C I) is an atypical vertebra in spinal anatomy. It has a ring-like structure with a pair of lateral masses that are united by the anterior and posterior arches[1,2]. The posterior arch has an indentation on its superior surface, known as the vertebral artery groove, through which the suboccipital segment of the vertebral artery and the suboccipital nerve pass. This groove, when enclosed by partial or complete ossification of the posterior atlanto-occipital membrane or the connective tissue surrounding the vertebral artery, defines the location of the arcuate foramen (AF)[3,4].

AF has been described in the literature under various terms, such as retroarticular vertebral ring, retroarticular canal, retrocondylar vertebral artery ring, Kimmerle's anomaly or deformity, posterior ponticle of the atlas, "*Ponticulus Posticus*", sagittal foramen, retroarticular vertebral artery ring, superior retroarticular foramen, retrocondylar osseous foramen, atlantal posterior foramen, atlas bridge, among others[5-8]. The AF has a variable morphology and can be identified unilaterally or bilaterally. It can also be presented in its complete or incomplete form.

The arcuate foramen is considered a regressive primitive structure due to its greater expression in lower primates[9]. In humans, this anatomical variation generally does not require therapeutic interventions, however, it can become symptomatic[7,9]. Symptoms such as chronic headache, vertigo, pain in the neck, shoulder, and arm region, tearing, and hearing loss have been associated with the presence of this foramen. Furthermore, it is believed that there is an increased predisposition to vertebral artery dissection, a higher incidence of syndromes such as Barre-Lieou and Bowhunter, and posterior circulation strokes in patients with the arcuate foramen. This is because repetitive movements at the atlanto-occipital joint can lead to an excessive pressure on the vascular segment[3,10-12].

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Therefore, given the anatomical variability and the possible clinical and surgical repercussions of the arcuate foramen, the present study aimed to analyze the morphometry of the arcuate foramen and its variations in dry atlas vertebrae in a population from Northeast Brazil. The goal is to enable safer practices for professionals performing procedures in this anatomical region.

Materials and Methods

Fifty-eight (58) atlas vertebrae were analyzed, without identifying gender, ethnicity or age, from bone collections in the Human Anatomy Laboratory at Santa Maria University Center (UNIFSM), Cajazeiras, Paraíba, Brazil. Vertebrae with significant degradation, pathology or infantile conformation were excluded from the study, as their specific analysis was impossible.

The vertebrae were examined for the presence or absence of the arcuate foramen and then categorized according to the classification proposed by[13], which considers anatomical and radiological aspects and subdivides arched foramina into 5 types: Type I - unilateral incomplete; Type II - bilateral incomplete; Type III - unilateral complete; Type IV - mixed (unilateral complete bone bridge and contralateral incomplete bone bridge); Type V - bilateral complete (Figure 1).

After classifying the arched foramen, the thickness of the foramen's bone bridges, the external and internal height, and the internal and external width were measured using an Eccofer® digital caliper with a capacity of 150 millimeters and 0.01 mm accuracy (Figure 2).

This research was approved by the Research Ethics Committee with CAAE number: 23867119.8.0000.5180, in accordance with the regulatory standards for research involving human beings in Resolution No. 466/2012 of the National Health Council[14].

The data was analyzed using Jamovi statistical software. The Shapiro Wilk test was applied to verify the normality of the data. In the case of normally distributed quantitative variables, the data was expressed as mean and standard deviation, obtained using the Student's t-test. Data with a non-parametric distribution was analyzed using the Mann-Whitney test and recorded using the median and interquartile range. For all tests, a significance level of $p<0.05$ was considered.

Results

A total of 58 vertebrae were examined, of which 16 (27.6%) presented an arcuate foramen. Regarding the type of ossification, 2 atlas vertebrae (12.5%) were classified as Type I, showing an incomplete unilateral bony bridge; 5 (31.25%) were classified as Type II (bilateral incomplete); 4 (25%) showed Type III ossification (unilateral complete); 3 (18.75%) were Type IV (mixed, with a complete unilateral bony bridge and an incomplete contralateral one); and 2 (12.5%) were Type V, presenting complete bilateral ossification

Figure 1. Types of arcuate foramen.
Legend: (A) Type I - Unilateral incomplete (white arrow); (B) Type II - Bilateral incomplete (white arrows); (C) Type III - Unilateral complete (white arrow); (D) Type IV - Mixed (unilateral complete bone bridge - blue arrow, and unilateral incomplete - white arrow); (E) Type V - Bilateral complete (white arrows); (F) Absence of arcuate foramen.

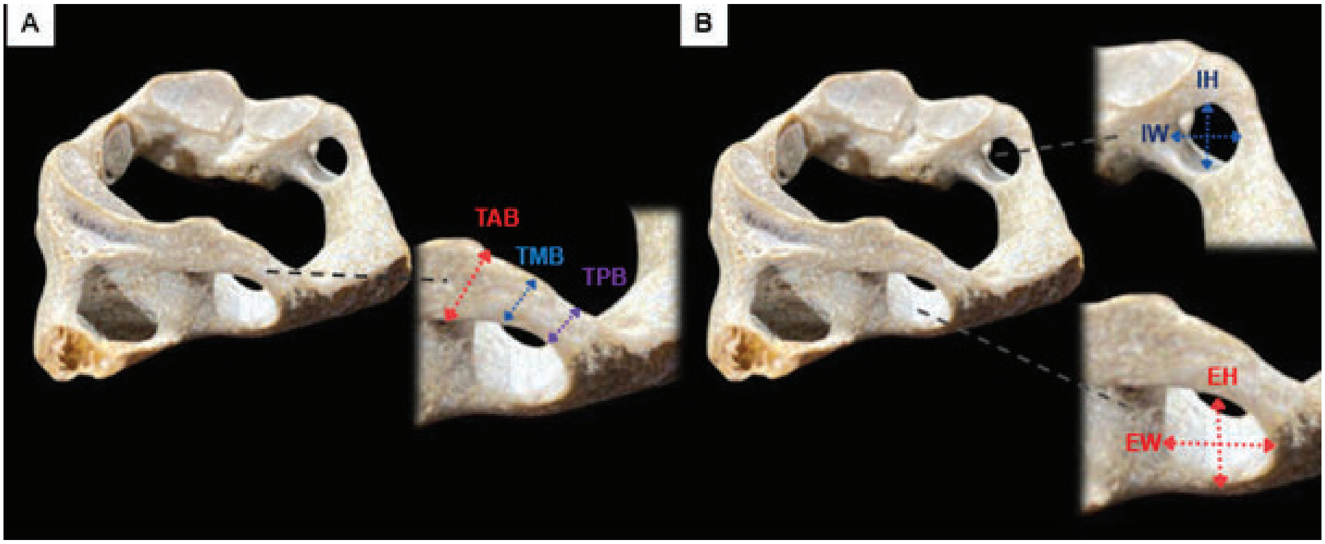

Figure 2. Morphometric parameters assessed for the arcuate foramen of the atlas vertebra.
Legend: (A) TAB: Thickening of the anterior bony bridge (point at the posterior end of the lateral mass of the atlas); TMB: Thickening of the middle bony bridge (midpoint of the bony bridge); TPB: Thickening of the posterior bony bridge (point where it joins the posterior arch of the atlas). (B) EH: External height (superoinferior measurement of the external face of the ossification); IH: Internal height (superoinferior measurement of the internal face of the ossification); EW: External width (anteroposterior measurement of the external face of the ossification); IW: Internal width (anteroposterior measurement of the external face of the ossification).

(Table 1). With regard to the laterality of the foramens, distributed according to the classification described above, it can be seen that the right and left sides had the same number of foramens, with a predominance of the incomplete bilateral type 5 (31.25%), on both sides.

In the morphometric analysis, the mean values for the internal and external widths on the right side were 7.12 mm and 7.87 mm, respectively; on the left side, the mean values were 7.22 mm and 7.52 mm, respectively. The observed means for the internal and external heights on the right side were 6.20 mm and 6.38 mm, respectively; on the left side, they were 6.30 mm and 6.23 mm, respectively (Table 2).

The thickness measurements of the anterior and posterior bony bridges were represented by median and interquartile range values. Thus, for the anterior bony bridge thickness, a median of 3.43 mm was obtained on the right side and 3.11 mm on the left side. For the posterior bony bridge thickness, the median observed was 2.75 mm on the right and 2.38 mm on the left. For the middle bony bridge thickness, data were represented by mean and standard deviation, with an average value of 3.26 mm on the right and 2.92 mm on the left. The atlas vertebrae analyzed in this study showed no significant differences between the right and left sides in any of the variables studied (p>0.05) (Table 2).

Discussion

Prevalence of arcuate foramen

The arcuate foramen (AF) consists of a variable ossification that may partially or fully cover the vertebral artery groove and the passage of the suboccipital nerve. In the present study, an AF prevalence of 27.6% (16 cases) was observed in a total sample of 58 dry atlas vertebrae from Northeast Brazil. Other countries reported a lower prevalence (Table 3). For example, Kamdi *et al.* evaluated 50 vertebrae in the Indian region and observed a prevalence of 14% (7 cases) of the arcuate foramen[15]. Cirpan *et al.* analyzed 81 atlas vertebrae in Turkey and reported a prevalence of 16.05% (13 cases) of the foramen[16]. Meanwhile, Sales *et al.* also in Northeast Brazil, found a prevalence of

Table 1. Prevalence of bony bridges in atlas vertebrae from Northeastern Brazil.

Bony bridges	Prevalence	Laterality		
		Right	Left	Both (Mixed)
Type I – Unilateral incomplete	2 (12.5%)	-	2 (12.5%)	-
Type II – Bilateral incomplete	5 (31.25%)	5 (31.25%)	5 (31.25%)	-
Type III - Unilateral complete	4 (25%)	3 (18.75%)	1 (6.25%)	-
Type IV - Mixed	3 (18.75%)	-	-	3 (18.75%)
Type V – Bilateral complete	2 (12.5%)	2 (12.5%)	2 (12.5%)	-
Total	**16 (100%)**	**10**	**10**	**3**

Table 2. Morphometric analysis of arcuate foramina in atlas vertebrae from the present study.

	Right side		Left side	
Parameters	**Min-Max**	**Mean ± SD**	**Min-Max**	**Mean ± SD**
IW	5.95 - 7.96	7.12 ± 0.76	6.34 - 8.73	7.22 ± 0.92
EW	5.78 - 10.2	7.87 ± 1.30	5.67 - 10.3	7.52 ± 1.50
IH	4.88 - 9.17	6.20 ± 1.20	4.76 - 8.25	6.30 ± 1.18
EH	5.34 - 8.72	6.38 ± 0.94	4.72 - 7.81	6.23 ± 1.01
TAB	2.26 - 7.59	3.43 ± 1.66*	2.18 - 8.26	3.11 ± 1.54*
TMB	1.74 - 6.29	3.26 ± 1.58	2.03 - 4.81	2.92 ± 1.31
TPB	1.77 - 7.05	2.75 ± 2.46*	1.84 - 7.56	2.38 ± 2.54*

IW: Internal width; EW: External width; IH: Internal height; EH: External height; TAB: Anterior bony bridge thickness; TMB: Middle bony bridge thickness; TPB: Posterior bony bridge thickness; Max/Min: Maximum and Minimum values; Mean ± SD: Mean and standard deviation; *Median and IQR.

Table 3. Prevalence of arcuate foramen in different continents.

Author/ Year	Continent/ Country	Analyzed material	Sample	Prevalence
Present study	America - Brazil	Dry vertebrae	58	27.6% (16)
Gul; Atik, 2024	Asia - Turkey	Computed tomography	1365	21.1% (288)
Rodríguez-Luengo *et al*., 2024	America – Chile	Digital teleradiographs	450	42.4% (191)
Felipe *et al*., 2023	America - Brazil	Radiographs	673	23.35% (167)
Kamdi *et al*., 2023	Asia - India	Dry vertebrae	50	14% (7)
Mokhtari, 2023	Asia - Iran	Lateral Cephalography	150	21.3% (32)
Nedelcu *et al*., 2023	Europe - Romania	Computed tomography	487	34.9% (170)
Sales *et al*., 2022	America - Brazil	Dry vertebrae	38	23.68% (9)
Tripodi *et al*., 2019	Europe - Italy	Computed tomography	524	28.24% (148)
Cirpan *et al*., 2017	Asia - Turkey	Dry vertebrae	81	16.05% (13)
Closs *et al*., 2017	America - Brazil	Radiographs	242	21.89% (53)
Afsharpour *et al*., 2016	America – USA	Radiographic exams on cadavers	40	7.5% (3)

23.68% (9 cases) in a sample of 38 vertebrae, thus closer to the prevalence found in the present study[4].

Most part of the studies that analyzed the AF have adopted advanced imaging techniques, such as cone-beam computed tomography, lateral digital cephalometric radiographs, cephalic teleradiographs, and 3D angiography. In Southern Brazil, a study conducted by Felipe *et al*. analyzed 673 radiographs, of which 167 showed the presence of the arcuate foramen, resulting in a prevalence of 23.35%[17]. Similar results were also found in Southeast Brazil, in a sample of 242 radiographs, where an arcuate foramen prevalence of 21.89% (53 cases) was described[18].

Considering studies conducted on different continents using imaging techniques, it is possible to find prevalence rates similar to those observed in Brazil. For instance, Gul and Atik reported an arcuate foramen prevalence of 21.0% in Asia based on computed tomography scans[19]. In turn, Tripodi *et al*. found an arcuate foramen prevalence of 28.24% in 524 computed tomography images from a European population sample[20].

However, still within the European continent, Nedelcu *et al*. examined 487 CT images and found 170 cases of arcuate foramen, representing a prevalence of 34.9%, higher than other reported rates so far[21]. In the Americas, Rodríguez-Luengo *et al*. identified an even higher prevalence of 42.4% for the presence of arcuate foramen using digital teleradiographs[22]. Conversely, within the same continent, Afsharpour *et al*. reported the lowest prevalence mentioned in this study, with only 7.5% of arcuate foramen observed in radiographic exams of cadavers[23].

In summary, based on the studies described above and shown in Table 3, it is not possible to establish a prevalence relationship with the origin of the sample examined. This limitation can be attributed to methodological differences between the studies, including variations in imaging techniques, sample size and the types of materials analyzed. Such variability, combined with potential genetic influences, prevents a direct and reliable comparison of the prevalence of the arcuate foramen in different geographical regions.

Distribution of the arcuate foramen by type of ossification

The arcuate foramen exhibits different forms of classification according to its ossification. In the present study, adopting the classification of Nedelcu *et al.* a prevalence of type II AF (bilateral incomplete) was observed, accounting for 31.25% (5) of occurrences[21]. In contrast, a lower prevalence was found for type I (unilateral incomplete) and type V (bilateral complete) foramina, representing 12.5% (2) of the AF findings.

This result is supported by other studies, such as that of Arslan *et al.* in which, through angiography, they observed a higher prevalence of type II (bilateral incomplete) AF, corresponding to 16.2% (5), and a lower prevalence of type I (unilateral incomplete) AF, with 4.6% (1)[24]. Additionally, the study by Buyuk *et al.* which examined computed tomography images, also corroborates the present study, as they found a dominance of 27.3% (102) for type II, however, the lowest dominance was for type III (unilateral complete) AF, with a total of 1.3% (5)[25].

Moreover, further research has found results that differ from those presented above Golpinar *et al.* detected type V (bilateral complete) AF as the most common type, with 5.2% (52) of the total sample, considering a prevalence of 14.8% of PP in computed tomography images[26]. Nedelcu *et al.* also reported discrepant findings, indicating that type I (unilateral incomplete) AF was the most dominant type, with 11.29% (19), while type V (bilateral complete) AF was the least dominant, with 4.72% (8) occurrences in computed tomography samples[21]. Additionally, Chen, Chen and Wang, in their sample of computed tomography scans, found type III (unilateral complete) AF to be the most prevalent, with 51.42% (18), while type II (bilateral incomplete) was the least common, with 2.85% (1) of occurrences[27].

Based on these findings, it is challenging to establish a definitive classification hierarchy due to the small sample size in both the present study and others with a small sample size. Although type II AF was identified as the most prevalent (5), its frequency is closely followed by type III (4), indicating minimal statistical disparity. Additionally, the difference between the most and least frequent types in our sample is marginal, reinforcing the influence of sample size on the variability of results. Larger studies with more substantial datasets tend to provide more reliable prevalence patterns, mitigating potential inconsistencies observed in studies with smaller populations.

Distribution of the arcuate foramen by sex and age

Upon identifying the presence of the AF, several studies have investigated the likelihood of dominance concerning female or male sex. For instance, Zhang *et al.* identified, through computed tomography, a predominance of the AF in the male sex, with an occurrence rate of 66.05%, compared to the female sex, with an occurrence rate of 33.95%[28].

Similarly, Falah-Kooshki *et al.* found a significant predominance between the sexes in lateral cephalograms, with a percentage of male AF at 56.5% and female AF at 35.9%, in a sample of 1.000 cephalograms[29]. Furthermore, research by Tapia, conducted using lateral cephalometric radiographs, showed a superiority of AF in male patients, with 42.3% (200) occurrences, while female patients had 36.1% (171) occurrences[30]. On the other hand, Arslan *et al.* identified a preponderance of AF in female angiography, with a frequency of 17% (5), compared to 12.5% (4) in males[24].

Regarding age groups, Nedelcu *et al.* observed that the presence of the AF was higher in the 41 to 60 years age range, with 41.17% occurrences[21]. On the other hand, Najmuddin, found that cases of complete AF occurred more frequently in the group of patients with an average age of 20.9 ± 1.5 years (range 19–26). Incomplete AF predominated in the average age of 20.6 ± 2.6 years (range 19–26), while the absence of AF was more common in patients with an average age of 23.2 ± 2.7 years (range 18–30)[31].

For the same age classification, the analysis by Hiroli, Kasegaonkar and Gosavi also demonstrated a higher incidence of the AF in patients aged 15 to 30 years[32]. Finally, presenting a dominant distribution for an even younger age group, Lo Giudice *et al.* observed a statistically significant prevalence of AF among individuals aged 7 to 13 years[33].

In the present study, this association was not possible to be investigated, since the material used does not identify the donor's biological sex, nor age.

Distribution of the arcuate foramen by laterality

The ossification leading to the formation of the arcuate foramen is classified according to its shape, as previously discussed, and in cases of unilateral occurrence, some studies identified a prevalence on one side. For instance, Zhang *et al.* using computed tomography, observed that the presence of the AF was more prevalent on the left side (76.54%) than on the right (53.40%)[28].

Supporting this left-sided prevalence, Gul and Atik upon analyzing computed tomography scans, found a higher number of unilateral AFs on the left side[19]. Similarly, Felipe *et al.* using radiographic exams, noted a discrepancy favoring the left side, with the incomplete left AF present in 28.20% of cases compared to the incomplete right AF at 20.51%[17]. Even for the complete left AF, its occurrence was 15.38%, while the complete right AF occurred in 12.82% of cases.

However, reports also exist showing a right-side dominance, as with the study by Cicek *et al.* which, through MRI and computed tomography, found a higher number of complete AF cases on the right side at 16.5%, compared to 15.1% on the left[8]. Additionally, for incomplete AF, the left side was also more prevalent at 41%, while the right side accounted for 33.8% of cases.

Further diverging from the left-sided dominance, Tripodi *et al*. in analyzing cone-beam computed tomography images, identified a frequency of 4% unilateral right AFs and 3.24% unilateral left AFs[20]. Finally, in the present study, it was observed that the right and left sides had the same number of foramens, with a predominance of the incomplete bilateral type 5 (31.25%), on both sides. Therefore, in view of the different observations in studies with different types of materials analyzed, as well as discrepant sample sizes, it is not possible to determine a laterality dominance of the AF.

Morphometric analysis of the arcuate foramen

The morphometric analysis conducted in the present study considered the internal and external widths, as well as the anterior, middle, and posterior bone thicknesses of the AF. Similarly, Sales *et al*. using dry vertebrae observed an average thickness of 3.74 mm for the right side and 3.44 mm for the left side in bilateral incomplete AFs[4]. For complete AFs, the average thickness was 2.47 mm on the right and 2.45 mm on the left. In the present study, the average thickness on the right was 3.26 mm and 2.92 mm on the left. Therefore, it can be seen that the bone thickness of the vertebrae in the study in question is close to the data already reported in the literature, with no statistically significant difference in relation to the type of foramen or laterality.

While Hasani *et al*. using computed tomography, found that the average AF height was 5.95 mm and the average width was 6.52 mm[34]. And Olszewski, Issa, Odri using computed tomography, obtained a mean AF height of 6.7 mm and mean width of 7.4 mm for bilateral-type AF[35].

The values found in the present study, on the other hand, were internal and external heights on the right, with an average of 6.20 mm and 6.38 mm, respectively; and on the left, 6.30 mm and 6.23 mm, respectively. As for width, the internal and external widths on the right were 7.12 mm and 7.87 mm on average, respectively, and on the left 7.22 mm and 7.52 mm on average, respectively. It can be seen here that the height measurements appear to be smaller in diameter than the widths, but with no statistically significant difference.

Limitations of the study

One of the main limitations of this study is that it does not relate the presence of an arcuate foramen to gender and age, since the material used was donated and was not identified in relation to the afore mentioned data. Furthermore, it is not possible to establish an association between symptoms or even pathologies and the presence of an arcuate foramen or its type, since it is not possible to obtain the donors' health history.

However, the arcuate foramen, which generally includes the V3 segment of the vertebral artery (VA) and can also include the accompanying vein, sympathetic nerves, and the posterior branch of the C1 spinal nerve, has a structural configuration that is related to clinical implications in terms of the likelihood of it being the etiological factor of symptoms such as headache, vertigo, photophobia, dizziness, neck pain, and even vertebral artery compression and subsequent vertebrobasilar ischemia[31].

Therefore, the value of diagnosing AF is to recognize either the likelihood of total absence of symptoms or, conversely, to discuss treatment options or aspects of prevention of the clinical implications under discussion[21]. In addition to the pathological clinical implications, the study of this variant is also relevant in relation to surgical determinants, in cases of surgical approach to the C1 vertebra[24,28].

Conclusion

The presence of an arcuate foramen is not uncommon, and its prevalence and types vary in different parts of the world. It can be studied using cadaveric specimens and imaging exams, thus allowing for different classification patterns in terms of ossification, which perhaps explains the difficulty in determining the most prevalent type of ossification. Regarding the morphometric analysis, no differences were observed between antimers.

The association of AF with symptoms such as headache, neck pain, migraine and others, as well as its relevance during surgical interventions in the cervical spine, especially those that require the insertion of screws in the lateral mass of the atlas, represent the importance of the knowledge about this variable presentation of the C1 vertebra. Thus, indicating the need for inspection of this region for professionals responsible for surgical procedures, as well as for those who deal with these symptoms reported here and find it difficult to determine their etiological factor.

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