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Morphological Analisys of Ponticulus Posticus: a Case Report

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ABSTRACT

Introduction: ponticulus Posticus is a bony bridge formed between the posterior arches and the lateral masses of C1. The bridge may encase the vertebral artery and its groove, forming the Arcuate Foramen (AF) in complete or incomplete forms on one or both sides. It is relatively common compared to other anatomical variations and typically asymptomatic. It is often an incidental finding on imaging studies such as X-rays or CT scans.

Objective: this study aims to describe three atlases containing the AF and explore the anatomical variation and its clinical and surgical implications

Results: AF was present in all three vertebrae examined. Vertebrae A, B, and C showed this anatomical variation in bilateral complete, unilateral complete, and bilateral incomplete forms, respectively. They were categorized as Type V, III, and I, following Neldecu *et al.*'s classification. A unique feature was noted on the right side of a vertebra (A): a pointed spicule extending from the main bone structure and running parallel to it. This condition probably caused significant symptoms due to the increased risk and severity of compression on the structures within the vertebral groove of C1.

Conclusion: our research offers in-depth insights into the morphometry and classification of three different types of FA. This data is essential for elucidating the relationship between the shape, measurements, and potential clinical significance of FA. Anatomical studies offer significant potential for translational research, providing valuable evidence that can be directly applied to improve human health through treatment.

Keywords: Atlas; Atlanto-occipital membrane; Cervical spine mobility; Anatomical variation.

Introduction

Atlas (C1) is the first of the seven vertebrae in the cervical spine of humans. One of the most common hypotheses for the name "Atlas" is related to the Titan of Greek mythology who, just as the vertebra directly supports the base of the human skull, supports the weight of the Earth with his own hands (Jackowe, Biener, 2022). Atlas is unique as it lacks a vertebral body and consists of two arches, an anterior and a posterior one, each formed by two laminae. It also has lateral masses with articular surfaces for connecting with the occipital bone and the second cervical vertebra (Axis). Additionally, it features an articular fovea for the odontoid process of the Axis and tubercles for muscle attachment (Gray, 1988). These characteristics make the Atlas crucial for both function and anatomy, as it plays a significant role in cervical spine mobility, Atlas is the vertebra with the greatest mobility of the cervical spine, and requires understanding for treating cervical injuries and surgical procedures (Neldecu et.al, 2016; Kim *et al*., 2023; Elliot, Omar, 2014).

In the posterior arches of C1, grooves are formed by the passage of the vertebral arteries and the spinal nerve. A posterior bony bridge called Ponticulus Posticus may form between the posterior arches and the lateral masses of C1. This bridge can partially or totally cover the vertebral artery and its sulcus, creating the Arcuate Foramen (AF) (Mudit, Srinivas, Sateesha, 2014). This anatomical variation of C1 has been well-documented in literature. Allen (1879) linked the presence of the foramen to the atlanto-occipital membrane that covers the posterior arch of the vertebra. In some individuals, ligaments of this membrane can ossify and create a small bony projection above the sulci. This variation has given different names over the years, including sagittal foramen or Kimmerle's anomaly (Schilling J, Schilling A, Suazo, 2010).

AF can manifest in complete or incomplete forms unilaterally or bilaterally. It is relatively common compared to other anatomical variations, with prevalence varying based on geographical, ethnic, and gender factors in different populations. Studies indicate that the overall prevalence of complete AF is 9.1%, with North America showing the highest incidence at 11.3%. Incomplete AF has an estimated overall prevalence of 13.6%, with the African population having the highest incidence at 30.2% (Pękala *et al*., 2017).

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AF can be easily diagnosed through several different ways, such as lateral radiographs of the cervical region, computed tomography (CT) scans, and cadaveric studies (Xu *et al*., 2022). Early detection is crucial as this anatomical variation can compress nerve and vascular structures, leading to symptoms like dizziness, severe migraines, and pain in the cervical and scapular regions (Cho, 2009; Macrí *et al*., 2023). Barré-Liéou syndrome, torticollis, and facial asymmetry are common diagnoses associated with AF (Li, Wang, Q, Wang G, 2022). While many individuals with AF may not experience symptoms, those who do can have their quality of life affected (Mudit, Srinivas, Sateesha, 2014).

The detection of AF is clinically important, and its surgical relevance is also highlighted, especially in procedures involving the cervical region of the spine, such as stabilization surgeries using screws in the lateral atlas masses. It is crucial to be aware of the presence of AF in patients to prevent potential damage to vital structures like the vertebral arteries. This study aims to describe three atlases with AF presence and explore the anatomical variations and their implications in clinical and surgical settings (Young *et al*., 2005; Arslan *et al*., 2018).

Materials and Methods

Morphological Analysis

Three C1 cervical vertebrae were analyzed morphologically. The sample was collected from the Human Gross Anatomy Laboratory, at the Federal University of Sergipe, in Sergipe, Brazil.

The vertebrae were randomly named A, B, and C and were assessed from various angles including anterior, posterior, lateral, superior and inferior view. The presence of Ponticulus Posticus was observed and classified according to Neldecu *et al*., 2016. Faces, margins, size, length, thickness and shape of Ponticulus Posticus were observed.

After analysis, the vertebrae were placed on a flat and stable surface with a low light reflection index and photographed using the Canon EOS Rebel T5 camera with an EFS 18-55mm lens. The camera was positioned above the surface in a perpendicular position for top-view photos and laterally for side-view photos. The scale was placed close to the samples.

Morphometric Analysis

The morphometric analysis was conducted by directly measuring the dimensions. A digital pachymeter from MTX® was used for measurements, with a range of 0-150 mm and a resolution of 0.01 mm.

The measurements were conducted in the Anatomy Laboratory under natural light conditions. To ensure precision, each measurement was repeated twice by the same observer.

Measurements included the horizontal and vertical lengths of vertebrae with complete AF, as well as the lengths and thickness (e) of the Ponticulus Posticus, measured bilaterally on all three vertebrae.

The collected data was organized in tables with descriptive measures (Table 1).

Results

The objective of this study was to investigate three atlas bones with AF and to explore the implications of these variation in clinical and surgical settings.

Under detailed macroscopic morphological analysis, it was noted that the three bones were undamaged and free of any abnormalities. There were no pathological indications such as osteolytic or osteoblastic lesions, periosteal reaction, subchondral sclerosis, low bone density, erosions, fractures, osteophytes, or presence of cysts.

The presence of Ponticulus Posticus was observed in all three vertebrae analyzed. Vertebrae A (Figure 1), B (Figure 1), and C (Figure 1) exhibited this anatomical variation in bilateral complete, unilateral complete, and bilateral incomplete forms, respectively. They could be classified as Type V, III, and I (Neldecu *et al*., 2016).

Table 1 displays the measurements obtained for each vertebra. The horizontal length and vertical length of the vertebrae, as well as the length of the rear bridge and the thickness of the posterior bridge were measured. In the analysis of the morphology of Ponticulus Posticus, a unique feature was identified on the right side of vertebra A, where a pointed spicule protrudes from the main bone formation origin and follows a relatively parallel path to it (Figure 1). No similar feature was observed in the other two vertebrae examined.

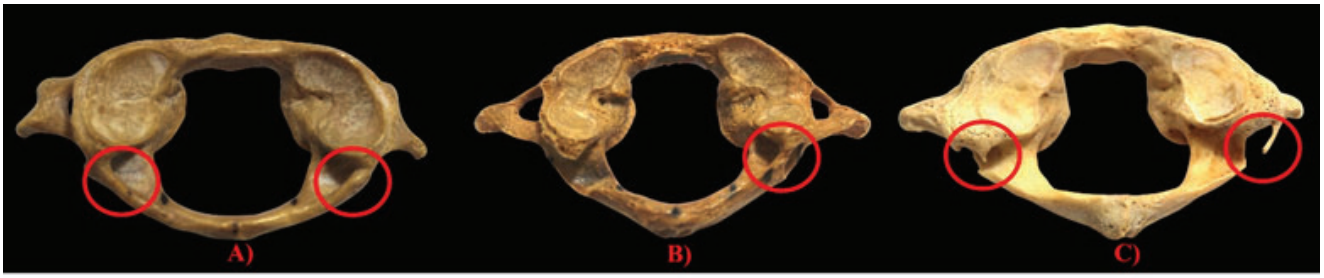

Figure 1. Ponticulus Posticus.

Table 1. Dimensions of the arcuate foramen in the vertebrae.

Measurement	Vertebra A		Vertebra B		Vertebra C	
	Right side	Left side	Right side	Left side	Right side	Left side
Horizontal length	5.68 mm	6.09 mm	6.98 mm	-	-	-
Vertical Length	2.91 mm	3.45 mm	5.82 mm	-	-	-
Length of the rear bridge	9.19 mm	10.49 mm	8.15 mm	-	7.66 mm	3.84 mm
Thickness of the posterior bridge	3.17 mm	4.84 mm	2.78 mm	-	2.95 mm	1.15 mm

Discussion

AF is a significant anatomical variation located between the posterior arch and the lateral masses of the atlas. It can fully or partially enclose structures like the vertebral artery and the suboccipital nerve (Afsharpour *et al*., 2016; Tubbs *et al*., 2007). The presence, origins, and related factors of AF are crucial in clinical and surgical contexts and have been extensively studied in the literature (Cossu *et al*., 2019; Sanchis-Gimeno *et al*., 2018).

Understanding the origin and development of AF is crucial due to its potential clinical implications and the variety of surgical procedures that can be performed in the C1 region, which houses vital structures prone to trauma and injury (Li, Wang Q, Wang, G, 2022; Ahn *et al*., 2018; Wang *et al*., 2020; Yeom *et al*., 2012). Various theories exist regarding the development of AF. Allen (1879) suggests a congenital origin, while genetic factors have also been implicated in the literature (Selby, Garn, Kanareff, 1955). Additionally, some authors propose that external and age-related factors may contribute to the onset of AF.

Pyo (1959) and Paraveskas (2005) demonstrated the potential for progressive ossification with age, as a higher prevalence of AF was observed in adults compared to children. Taitz (1986) suggested that AF could develop progressively through physical exertion, like carrying heavy objects on the head, which may also lead to other anomalies in C1. In contrast, Lamberty (1973) noted that AF is more common in children and may regress over time. Schilling (2010) found cases of complete and incomplete AF in children under 10 years old, challenging the idea of progressive growth with age. Some researchers propose that this anatomical variation is due to an embryonic anomaly (Pellizzaro *et al*., 2017; Cossu *et al*., 2019; Sanchis-Gimeno *et al*., 2018; Tubbs *et al*., 2007). The AF is believed to be a remnant of the proatlas, an embryonic structure that contributes to the formation of C1 and C2, as well as the craniocervical joint.

Nedelcu *et al.* introduced a morphological classification of AF of C1 based on ossification degree, bilateral or unilateral presence, and radiological features. The vertebra can be categorized as Type I - incomplete unilateral, Type II - incomplete bilateral, Type III - complete unilateral, Type IV - a combination of complete and incomplete on the opposite side and Type V - complete bilateral. This classification aids in linking C1 morphology to potential clinical complications associated with AF presence.

As in the present study, some authors performed morphometric analysis of the AF samples. Keser *et al*. (2019) found an average length of 6 mm for the right side and 7.5 mm for the left side, as well as an average height of 6 mm for the AF. These values were similar to those found in our study for horizontal length, with a mean of 7.69 mm, but higher for vertical length, with a mean of 4.06 mm. Additionally, Afsharpour *et al*. (2016) reported higher values for both dimensions, with vertical lengths ranging from 5 to 7.5 mm and horizontal lengths from 13 to 14 mm, indicating a clear morphological difference compared to the three vertebrae analyzed in our study. Similarly, Hasan (2001) measured 34 vertebrae, with anteroposterior lengths ranging from 8.5 to 8.8 mm and rostrocaudal lengths from 7 to 7.3 mm. In contrast, a systematic review of 127 articles, including eight with morphometric evaluations, reported a mean horizontal length of 5.65 mm and a mean vertical length of 5.16 mm for the AF (Pękala *et al*., 2017).

The fact that AF is a common anatomical variation among the world population reflects its relevance in surgery and clinical practice. Understanding such variations, like AF, is crucial in cervical spine procedures to ensure successful outcomes without complications (Keser *et al*., 2019; Nedelcu *et al*., 2016). Among the various surgical procedures performed in the cervical region of the spinal column, we highlight the fixation of screws in the lateral masses of C1, since the presence of AF is a variable of interest to several specialties, such as neurosurgery and orthopedics (Pękala *et al*., 2017). There are few studies that analyze in depth the feasibility and possible injuries that may result from screw fixation, but it is believed that the presence of AF is not a contraindication for performing the procedure (Zhang *et al*, 2017; Yeom *et al*., 2012). Even so, stabilizing the atlantoaxial joint with screws carries inherent risks due to its proximity to venous plexuses, the vertebral artery, and the suboccipital nerve (Xu *et al*., 2022).

Among the types of injuries that can occur during fixation, we highlight those that affect the vertebral artery, which follows the vertebral groove of C1. It is important to emphasize that AF, when present, covers

the artery, and there may be compression of its third segment (V3) (Tubbs *et al*., 2007; Xu *et al*., 2022; Ahn *et al*., 2018; Lvov *et al*., 2017). Thus, it is characterized as an important variable during this procedure, because the surgeon may confuse AF with the posterior arch of C1 itself, which is presented in a thicker form (Zhang *et al*., 2017; Young *et al*., 2005; Pękala *et al*., 2017). The possibility of confusion between these two structures is a risk factor for V3 injury during screw insertion in the lateral masses of C1 (Tubbs *et al*., 2007). This possible complication during the procedure is considered quite serious, as the injury to the vertebral artery can cause stroke or even death (Kim *et al*., 2007).

To prevent complications, it is crucial to detect the presence of AF early by using lateral radiographs of the cervical region (Pękala *et al*., 2017; Arslan *et al*., 2018; Young *et al*., 2005). It is also important to employ a safe screw fixation technique (Yeom *et al*., 2012; Arslan *et al*., 2018). Prior to performing the procedure, understanding the patient's anatomy is essential. Research suggests that inserting the screw directly into the posterior arch is suitable for patients with a bone arch thickness greater than 5 mm. For those with a thinner anatomical structure, creating a notch in the lower face of the posterior arch to partially insert the screw is recommended (Pękala *et al*., 2017; Arslan *et al*., 2018; Young *et al*., 2005; Yeom *et al*., 2012; Lee, Cassinelli, Riew, 2006; Paraveskas *et al*., 2005).

These studies also indicate that the traditional method, which introduces the screw directly through the posterior arch, presents a higher risk for vertebral artery injuries and cannot be widely applied in all cases, due to anatomical constraints (Elliott, Omar, 2014; Paraveskas *et al*., 2005). Therefore, using a notch for partial screw insertion in the arch is considered a safer alternative with lower risk of injury, making it applicable to a wider range of patients, including those with smaller posterior arches or degenerative cervical spine conditions (Paraveskas *et al*., 2005). In other words, in addition to the need for a previous diagnosis of AF by radiographs, it is necessary to follow a safe technique, considering the anatomical variation and patient-specific factors during procedures involving the cervical spine.

Compression of the vertebral artery by AF can cause various symptoms, despite being typically considered asymptomatic (Yochum, Rowe, 2005; Cossu *et al*., 2019). These symptoms may include acute headaches and different types of migraines, with or without aura, especially in cases of bilateral complete aberrant artery formation (Ríos *et al*., 2017; Macrì *et al*., 2023). The severity of symptoms may be related to the degree of AF development (Chitroda 2013). We can then connect the information from literature to our findings, particularly with vertebra A, which exhibits a bilateral complete foramen. This vertebra has the smallest diameter of the AF among all vertebrae on both sides. Consequently, we hypothesize that the individual from whom this vertebra was obtained may have experienced significant symptoms due to the increased likelihood and severity of compression on the structures within the vertebral groove of C1. This is attributed to the pointed bone formation in vertebra A that extends parallel to the main AF formation towards its superior articular surfaces, potentially causing compression on V3.

The literature contains several case reports of patients with Barré-Lieou syndrome and AF. Symptoms include dizziness, cervical and retroorbital pain, severe migraines, vision, swallowing, and speech disturbances (Li, Wang Q, Wang, G, 2022; Limousin, 1980; Lvov *et al*., 2017; Nedelcu *et al*., 2016). One notable case report involves a Chinese patient with Barré-Lieou syndrome due to unilateral complete AF. Despite being asymptomatic for 3 years, the patient developed facial asymmetry, torticollis, and local pain. The patient described in the report has the same type of AF as seen in vertebra B. This suggests that the individual from whom vertebra B was obtained may have experienced similar symptoms to those of the patient in question. Surgical removal of AF led to significant improvement in symptoms and quality of life (Li *et al*., 2022). This enhances the clinical impact of AF in patients with Barré-Lieou syndrome.

There are also mentions in the literature that associate the presence of AF with a change in condylar morphology. In a study by Pellizzaro *et al*. (2017) involving 274 patients, 90 were found to have anatomical variations. Among these, 38 had partial form and 52 had complete form, indicating a significant correlation between condylar morphology and AF. The study suggests that the morphological changes may be linked to mandibular position changes, as variations in cervical vertebrae anatomy can affect the mandible's relative position (Lamberty, Zivanovic, 1973; Selby, Garn, Kanareff, 1955). Unfortunately, the isolated analysis of the vertebrae does not provide information about condylar morphology.

Conclusion

Our study provides detailed information on the morphometry and classification of three types of FA found in the Department of Morphology at the Federal University of Sergipe. This information can be valuable for understanding the correlation between the shape, measurements, and potential clinical implications of FA. FA is a common anatomical variation that is often overlooked but can lead to symptoms such as migraines, dizziness, neck pain, and motor impairments. It can also impact procedures in the cervical region, such as treating fractures of the atlas. Therefore, recognizing anatomical variations like FA and assessing their incidence and morphology through methods like cervical radiographs can improve patient outcomes in clinical scenarios involving the cervical spine.

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