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Accessory Transverse Foramen

Foramen Transverso Accesorio

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SUMMARY: Accessory transverse foramen (ATF) is a rare anatomical variation of the cervical vertebrae that can alter the course of the vertebral artery, and this may lead to vascular and neurological complications. The existence, morphological diversity and clinical significance of ATF have been studied in different populations. This review aims to emphasize the importance of ATF in terms of diagnostic imaging and surgical procedures by examining its embryological origins, morphological variations and clinical significance in detail. In this context, a comprehensive literature review including osteological, radiological and clinical studies including the incidence, classification and associated risks of ATF was conducted. It was determined that ATF is most frequently seen between C1 and C6 vertebrae and has a prevalence rate ranging from 1.6 % to 22.7 %, depending on the population. Morphologically, ATF can be unilateral or bilateral, open or closed and can be found in different shapes such as round, oval or irregular. It has been determined that closed ATFs can occlude vascular pathways and cause neurological symptoms such as migraine, dizziness and vertebrobasilar insufficiency related to vertebral artery compression. Preoperative detection of this variation is of great importance for surgical planning and advanced radiologic techniques such as computed tomography and magnetic resonance angiography are preferred for this purpose. Understanding the anatomical variations of ATF is of great importance especially for spinal surgeries and vascular evaluations. Preoperative imaging and awareness of the risks associated with ATF are critical requirements to prevent surgical complications and increase surgical success.

KEY WORDS: Accessory transverse foramen; Cervical vertebra; Vertebral artery; Anatomical variation.

INTRODUCTION

Cervical vertebrae develop embryologically from sclerotomes derived from somites and constitute the cervical segment of the spine, a crucial component of the skeletal system. Regarding normal anatomy, the transverse foramen of the cervical vertebrae permits the passage of the vertebral artery, vertebral vein and sympathetic nerve plexus (Taitz *et al*., 1978). However, during embryological development, the merging of vertebral arteries from their segmental sources occurs in various manners, and alterations in the ossification process may result in anatomical variations such as accessory transverse foramen (ATF). This variation can lead to changes in the course of the vertebral artery and may predispose individuals to vascular and neurological complications (Nisari *et al*., 2016; Zibis *et al*., 2016).

Accessory transverse foramen develops during cervical vertebral formation and is influenced by factors such as incomplete fusion of the costotransverse bar or vertebral artery duplication. Embryologically, differences in how individual vertebral arteries form from primary segmental arteries may lead to extra holes in the transverse foramen (Shrivastava *et al*., 2023). Accessory foramina observed between the C6 and C1 vertebrae can cause the vertebral artery to take an extra cervical path, potentially resulting in clinical issues such as vertebrobasilar circulatory disorders, migraines and occipital neuralgia (Chaudhari *et al*., 2013). The occurrence of ATF varies among populations, with osteological and radiological studies showing prevalence rates from 1.6 % to 20 % (Murlimanju *et al*., 2011; Çırpan *et al*., 2018).

This review thoroughly examines the ATF's embryological origin, morphological variety and clinical relevance. Grasping the embryological progression of cervical vertebrae is crucial, particularly before spinal surgeries and when assessing clinical symptoms linked to vascular anomalies.

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ANATOMICAL FEATURES OF THE ACCESSORY TRANSVERSE FORAMEN

Definition and Developmental Mechanisms. The ATF is an additional variation of the transverse foramen found in the processus transversus of cervical vertebrae. It typically arises from an abnormal course of the vertebral artery, vertebral vein and sympathetic nerve plexus (Hyyppä *et al*., 1974). The morphological variations of the transverse foramen result from multiple factors, including alterations in the junction pattern of the vertebral artery with segmental arteries during embryonic development, mechanical stress and the size and quantity of vascular and neural structures that pass through the foramen. Given that vertebral vessels significantly influence the development of the transverse foramen, any anatomical variations in these vessels can lead to differences in the foramen itself. The ATF may also be linked to the duplication or fenestration of the vertebral artery, which directly relates to alterations in the artery's course and distribution (Nisari *et al*., 2016; Shrivastava *et al*., 2023).

Considering the course of the vertebral artery, it is known that the ATF is frequently observed between the C1 and C6 vertebrae. Although the function of the ATF has not yet been fully elucidated, reports indicate that these anatomical variations alter the course of the vertebral artery, sometimes causing it to adopt an extra cervical route and increasing the risk of vascular compression. Furthermore, it is noted that differences in both number and size may lead to clinical conditions such as sympathetic plexus irritation, vertebrobasilar insufficiency, varying degrees of headache, migraine and frequent fainting related to cervical movements (Taitz *et al*., 1978; Chaudhari *et al*., 2013).

Morphological Classification. Unilateral or bilateral, completed (closed) or incomplete (open), patent or obliterative variations have been described in relation to ATF, and differences in size and shape between these variations have also been reported. When the literature on the incidence of ATF is analysed, it is evident that different rates are presented among various populations. In a study by Murlimanju *et al*. (2011), the total incidence of ATF in 363 analysed cervical vertebrae was 1.6 %. Of these, 1.4 % exhibited double ATF and 0.3 % displayed triple ATF. A study conducted by Patil *et al*. (2014), on 175 cervical vertebrae identified the incidence of double transverse foramen as 5.71 %, of which 3.42 % were unilateral and 2.28 % were bilateral. Additionally, in a study by Zibis *et al*. (2016), 102 cervical vertebrae were evaluated, and 13.72 % were found to have double ATFs. The authors also reported finding one triple foramen transversarium. In a study by Çırpan *et al*. (2018), ATF was found in 12.34 % of 81 cervical vertebrae; 9.87 % were unilateral, and 2.47 % were bilateral. Kaya *et al*. (2011), detected ATF at a high rate of 22.7 % in their study on 22 cervical vertebrae from the 6th century AD and stated that 13.63 % of them were unilateral and 9.09 % were bilateral. All these studies show that the unilateral incidence of ATF is higher than the bilateral incidence, and it is found most often in the lower cervical vertebrae (C4 and below). In particular, the presence of ATF in the atlas and axis is rare (Fig. 1).

Fig. 1. Accessory transverse foramen of atlas as a rare variation.

Studies indicating unilateral detection of ATF, with specified sides, report a higher rate on the right (Murlimanju *et al*., 2011; Çırpan *et al*., 2018).

Research indicates that the passage of vertebral arteries, venous structures and sympathetic nerves through the foramen varies depending on whether the ATF is open or closed. Murlimanju *et al*. (2011), noted that in all examined cases, the foramen was open, facilitating the passage of vascular structures. Patil *et al*. (2014), also found that most ATFs were open. Conversely, Zibis *et al*. (2016), studied 102 vertebrae and reported that some ATFs were entirely occluded by bone, preventing vascular passage. This occlusion may arise from variations in vertebral artery supply during embryonic development. The clinical implications of a closed ATF include the risk of the vertebral artery taking an extraosseous route outside the transverse foramen, potentially resulting in accidental arterial injury during surgery. Thus, the state of the ATF, whether open or closed, should be a key consideration in radiological evaluations of the cervical region, particularly in computed tomography and magnetic resonance angiography, alongside vascular anatomical variations during preoperative planning (Fig. 2).

As the cervical vertebrae develop, the processus transversus consists of two main components: the original transverse process and the vestigial costal element. These two structures normally form a single bony bridge (costotransverse bar) to form the transverse foramen. If, during development, the two separate costal elements do

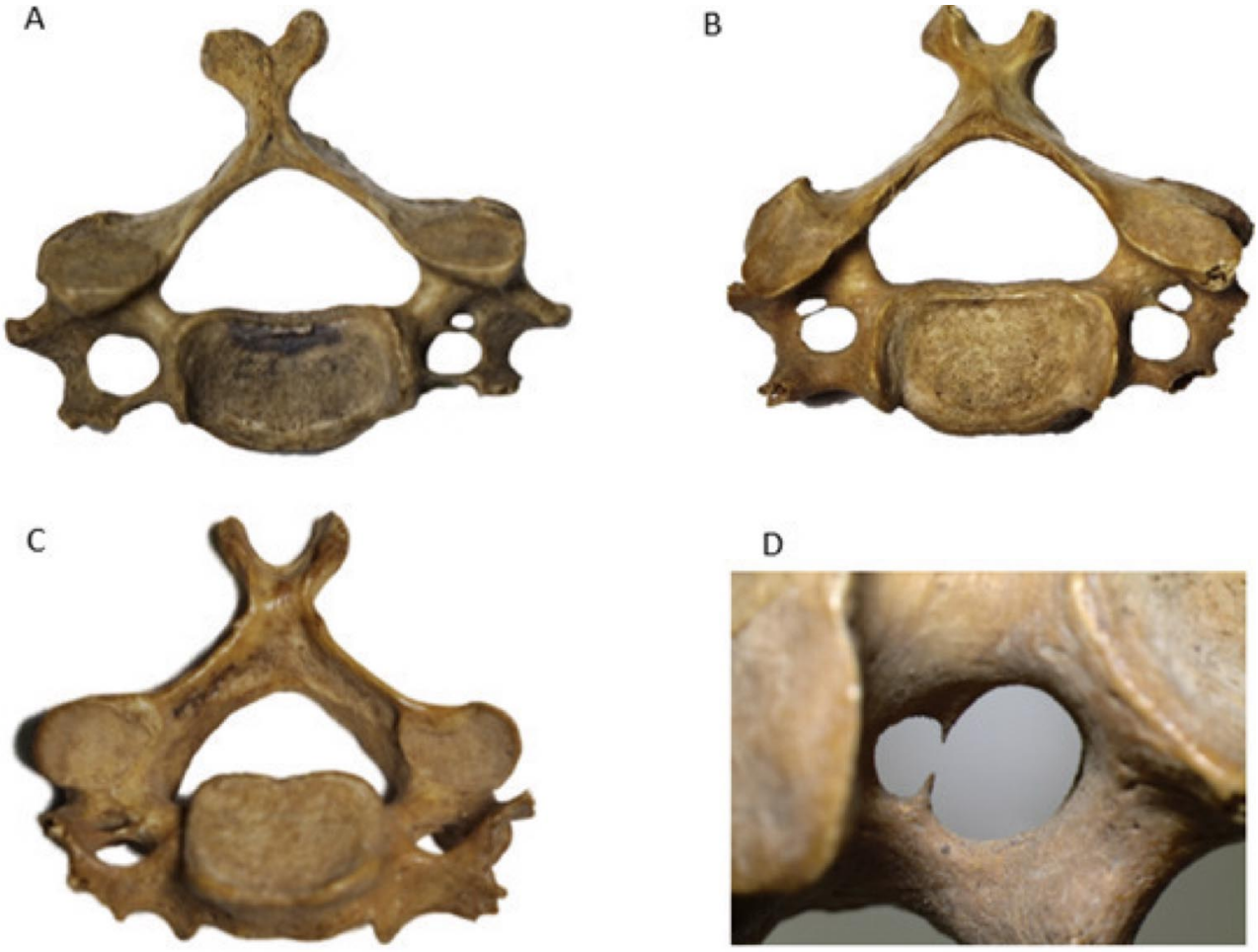

Fig. 2. Types of accessory transverse foramina. A. Unilateral ATF, B. Bilateral ATF, C. Obliterative ATF, D. Incomplete ATF.

not fuse on the same side and remain separate, and this extra bone bridge forms a new hole, three transverse foramina are formed (Taitz *et al*., 1978). Usually, there is one more ATF in addition to the transverse foramen, but it is very rare to have two, i.e. triple foramina transversaria. Among the studies reporting the presence of triple foramina transversaria, Taitz *et al*. (1978), Murlimanju *et al*. (2011), and Zibis *et al*. (2016), reported that only 1 ATF was triple among the vertebrae they examined.

Studies on ATF have generally defined four or five types based on shape. In a study conducted on the vertebrae of an Egyptian population, four types were identified: round (54.1 %), oval (29.6 %), irregular (10.4 %) and rectangular (5.8 %; Aziz & Morgan, 2018). Odula & Bundi (2013), classified five types as round, elliptical, elliptical with transverse diameter, right to left oblique diameter and left to right oblique diameter in their study on a Kenyan population. In the study conducted on a Turkish population, a sixth irregular type of ATF was recognised in addition to the five types defined by Odula & Bundi (2013).

The accessory foramen behind the transverse foramen is the retrotransverse foramen (RTF), posterolateral foramen or canaliculus venosus (Le Minor & Trost, 2004). In one study, 26 % of 141 atlases exhibited at least one RTF, with 32.4 % being bilateral (Lyrtzis *et al*., 2022). Another study indicates that RTF in cervical vertebrae may reach as high as 47.5 % (Natsis *et al*., 2019). It is noted that a vein traverses the RTF, forming a connection between the vertebral artery, vertebral vein or suboccipital cavernous sinus, as well as the vertebral artery and vertebral venous plexus (Xing *et al*., 2021). Clinically, unrecognised RTF presence can be a risk factor for venous plexus haemorrhage during surgical procedures in this area. The likelihood of injuring the vertebral artery is particularly elevated during posterior interventions in the upper cervical spine (Lunardini *et al*., 2014). Given that even minor vertebral artery lesions can

lead to severe haemorrhage or fatalities, detecting variations in this region before the intervention is crucial.

Few studies have measured normal transverse foramen and ATF diameters. According to these values, the anteroposterior and transverse diameters of the normal transverse foramen typically range from 4.96 to 6.65 mm, while the foramen diameters increase from C3 to C6 but tend to decrease significantly at C7. The diameters of ATFs are considerably smaller than those of normal transverse foramina and are usually below 3.5 mm (Imre & Kocabıyık, 2016). The anteroposterior and transverse diameters of the first, second and third transverse foramina were measured as 2.95/4.97, 3.85/2.71 and 0.60/2.12 mm, respectively, in a cervical vertebra with triple transverse foramina (Patra *et al*., 2022). It is noted that the diameters diminish as the number of foramina increases. Similarly, in vertebrae with two transverse foramina, the diameter of the second foramen is smaller than that of the first.

Incidence and epidemiological results

Current knowledge regarding the population-specific distribution of ATF is limited because this anatomical variation is relatively rare and not frequently studied. Several factors complicate the observation of ATF, including structural differences, the absence of foramina, fragmentation and the physical, chemical and biological changes that skeletal elements undergo during the fossilisation process (Ogut *et al*., 2023). Therefore, precise data on the frequency of ATF within and among specific populations remain insufficient. Some studies report that ATF occurs at varying rates in different ethnic and geographical groups. For instance, Nagar *et al*. (1999) found a double transverse foramen in 8.6 % of Romans in an archaeological anthropological study, whereas Das *et al*. (2005) found this rate to be 1.5 % within the Indian population. Kaya *et al*. (2011) reported a high incidence of 22.7 % among Jewish individuals, Odula & Bundi (2013) noted a rate of 3.9 % in the Kenyan population, and Molinet *et al*. (2017) reported a rate of 17.35 % in the Chilean population. Additionally, Aziz & Morgan (2018) reported the prevalence of ATF as 17.7 % within the Egyptian population, while Ogut *et al.* (2023) reported this rate as 8.4 %. These data suggest that the incidence of ATF may exhibit significant differences between populations, with genetic, environmental or developmental factors potentially influencing the formation of this variation.

Diagnostic methods and clinical relevance

Identifying the presence of ATF before surgical interventions is critical to preventing vascular complications during cervical surgery. The methods used to diagnose ATF aim to accurately determine anatomical variations and evaluate the associated vascular and neurological structures. Techniques such as radiological imaging, angiography and postmortem cadaver studies are employed in ATF diagnosis. Conventional radiography (direct radiography), which includes anteroposterior and lateral radiographs of the cervical vertebrae, serves as the primary imaging method for detecting ATF, while high-resolution computed tomography is preferred for more detailed examinations or magnetic resonance imaging for assessing vascular structures. Magnetic resonance angiography and digital subtraction angiography are additional methods used to ascertain the vertebral artery's course and variations and identify ATFs linked with these variations. Osteological and cadaver dissection studies are also frequently employed as direct methods to determine anatomical variations of the ATF (Murlimanju *et al*., 2011; Ogut *et al*., 2023).

The clinical significance of ATF is closely related to its potential to compress the vertebral artery and neighbouring neural structures. The presence of ATF may lead to vertebrobasilar insufficiency, cervical radiculopathy and thoracic outlet syndrome by impinging upon vascular structures. In areas where ATF is frequently observed, the likelihood of vertebral artery compression, hypoplasia, aneurysms or impaired blood flow increases (Odula & Bundi, 2013). Furthermore, the pressure exerted by anomalous vertebral arteries on nerve roots may cause neurological symptoms such as occipital neuralgia, chronic headaches, dizziness, auditory disturbances and postural instability (Aziz & Morgan, 2018).

The presence of ATF is linked to abnormal vertebral artery courses, which can lead to severe conditions such as transient ischaemic attacks and cerebral ischaemia (Gupta & Agarwal, 2019). Research indicates that those with ATF face a greater likelihood of experiencing symptoms such as acute headaches, dizziness and vomiting than those without ATF. Furthermore, a double vertebral artery may offer some protection against ischaemic lesions by facilitating collateral circulation with the basilar artery, yet it can also induce vascular instability (Sanchis-Gimeno *et al*., 2017).

CONCLUSION

Accessory transverse foramen is one of the significant anatomical variations of the cervical vertebrae and is linked to embryological developmental processes, mechanical stress and differentiation of vascular structures. The varying incidence rates reported in the literature suggest that ATF has different rates of occurrence across populations and that genetic and environmental factors may play a role in the development of this variation.

The clinical importance of ATF is closely tied to its possible impact on the vertebral artery's trajectory. This anatomical variation might result in the vertebral artery shifting from its typical alignment, which can cause vascular compression, vertebrobasilar insufficiency, occipital neuralgia and various neurological symptoms. Furthermore, assessing the presence of ATF through radiological imaging before surgical procedures is crucial to avoid potential vascular issues.

This review aims to examine ATF's anatomical and morphological features in detail, highlight the clinical and surgical risks and contribute to future research in the medical and academic fields by revealing the variations in different populations.

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RESUMEN: El foramen transverso accesorio (FTA) es una variación anatómica poco frecuente de las vértebras cervicales que puede alterar el curso de la arteria vertebral, lo que puede provocar complicaciones vasculares y neurológicas. La existencia, la diversidad morfológica y la importancia clínica del FTA se han estudiado en diferentes poblaciones. Esta revisión pretende destacar la importancia del FTA en el diagnóstico por imagen y los procedimientos quirúrgicos, examinando en detalle sus orígenes embriológicos, sus variaciones morfológicas y su importancia clínica. En este contexto, se realizó una revisión bibliográfica exhaustiva que incluyó estudios osteológicos, radiológicos y clínicos, incluyendo la incidencia, la clasificación y los riesgos asociados del FTA. Se determinó que el ATF se observa con mayor frecuencia entre las vértebras C1 y C6, con una prevalencia que oscila entre el 1,6 % y el 22,7 %, según la población. Morfológicamente, el ATF puede ser unilateral o bilateral, abierto o cerrado, y puede presentarse en diferentes formas, como redonda, ovalada o irregular. Se ha determinado que los ATF cerrados pueden ocluir las vías vasculares y causar síntomas neurológicos como migraña, mareos e insuficiencia vertebrobasilar relacionada con la compresión de la arteria vertebral. La detección preoperatoria de esta variación es fundamental para la planificación quirúrgica, y para ello se prefieren técnicas radiológicas avanzadas como la tomografía computarizada y la angiografía por resonancia magnética. Comprender las variaciones anatómicas del ATF es fundamental, especialmente para las cirugías de columna y las evaluaciones vasculares. La obtención de imágenes preoperatorias y el conocimiento de los riesgos asociados con el ATF son fundamentales para prevenir complicaciones quirúrgicas y aumentar el éxito quirúrgico.

PALABRAS CLAVE: Foramen transverso accesorio; Vértebra cervical; Arteria vertebral; Variación anatómica.

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