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Research article - Basic and applied anatomy

Retrotransverse foramen in atlas vertebrae of the late 17th and 18th centuries

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Abstract

Anatomical variations of the atlas vertebra are of particular importance because of their possible repercussions on the vertebral vessels. In view of the extensive articular mobility of the atlas, any anomaly where the vertebral artery and veins run through the transverse foramen could impair blood flow. However, in spite of the possible effect of this anomaly on the vertebral artery and veins, there are few data on the presence of an abnormal accessory transverse foramen, termed retrotransverse foramen, which is smaller and located behind the transverse foramen of the atlas. The aim of this research was to analyse the prevalence of retrotransverse foramen in a sample of 88 dry C1 vertebrae from a Spanish rural population of the late 17th and the early 18th centuries, as well as to study the possible repercussions of the presence of this anatomical variant on the size of the transverse foramen. The anteroposterior diameter and the lateral diameter of the transverse foramen of all the atlas vertebrae and retrotransverse foramina were measured using digital calibres. Two atlases with retrotransverse foramina (2.27%) were found in which the presence of the anatomical variant caused a larger anteroposterior diameter and a smaller lateral diameter than those of the transverse foramina of the normal 86 C1 vertebrae that were analysed. Our results show that a thorough study should be performed on the prevalence of this anatomical variant in the current population, as well as its possible clinical repercussion on the vertebral artery.

Key words

Cervical atlas, anatomical variation, transverse foramen, Spain

Introduction

The unique morphology of the first cervical vertebra makes it clearly different from the rest of the cervical vertebrae. The key role the atlas plays in the biomechanics of the craniovertebral junction induces its characteristic ring shape. This vertebra is also particularly important in the way it affects the last section of the vertebral artery and vertebral veins. In the same way as occurs in the rest of the cervical vertebrae, the atlas presents a transverse foramen (TF) in both transverse processes, which the vertebral artery and vertebral veins run through. Once the vertebral artery emerges from the TF of C1, it continues on with the dorsal ramus of the first cervical spinal nerve and venous plexus along a groove, which varies in size and depth, in the posterior arch of the atlas and eventually enters the cranial cavity through the foramen magnum.

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Given the extensive articular mobility the cervical spine presents, particularly the atlas, any anomaly where the vertebral vessels run through the TF of the atlas could impair the blood flow. Added to this critical situation is the high anatomical variability of the atlas (Wysocki et al., 2003). One of the morphological variants that could affect the vertebral vessels is the presence of an abnormal accessory foramen on the posterior root of the transverse process, called retrotransverse foramen (RF), which is smaller and located behind the TF of the atlas and is formed by a bony bridge extending from the posterior root of the transverse process to the root of the posterior arch of the atlas. Since the existing studies on this variant were carried out on dry vertebral samples (Veleanu et al., 1977; Gupta et al., 1979; De Boeck et al., 1984; De Sousa et al., 1989; Le Minor, 1997; Jaffar et al., 2004; Bilodi and Gupta, 2005; Paraskevas et al., 2005; Chinnappan and Manjunath, 2008; Nayak, 2008; Karau et al., 2010; Agrawal et al., 2012; Gupta et al., 2013; Karau and Odula, 2013; Rekha and Neginhal, 2014), there are few studies that give information about the structures that run through it or describe their possible clinical implications (Dubreuil-Chambardel, 1921; Veleanu et al., 1977), such as headache, migraine and loss of consciousness relating to certain neck movements (Nayak, 2008). Furthermore, the key position of the RF with regard to the passage and calibre of the vertebral vessels should be taken into account in surgical procedures that involve the atlas.

The aim of this work is to determine the prevalence of the presence of RF in a sample of atlas vertebrae in a Spanish rural population from the late 17^{th} to the early 18^{th} centuries, as well as to analyse the possible repercussion of the presence of this anatomical variant on the size of the TF by means of measuring the anteroposterior diameter and the lateral diameter of the TF of normal C1 vertebrae compared with those with RF.

Material and methods

Atlas vertebrae samples used in this study were discovered between 1999 and 2005 during restoration works at the fortress-church "Nuestra Señora de los Ángeles", in Castielfabib (Rincón de Ademuz, Valencia, Spain). The buried osseous remains found under its floors and within its walls date from the late 17^{th} to the early 18^{th} centuries, as has been revealed by the objects found in the tombs as well as by the historical context.

Skeletal samples were labelled according to their stratigraphic unit and analysed at the Anthropometry and Paleopathology Laboratory, Department of Anatomy and Human Embryology, University of Valencia, as recommended by the Spanish forensic anthropology and odontology association known as "Asociación Española de Antropología y Odontología Forense" (Serrulla, 2013).

Bone samples were initially cleaned with a soft-bristle brush under a constant low-pressure water jet and then dried under mechanical ventilation at room temperature (Serrulla, 2013). After drying no consolidation procedures were necessary. The species and anthropological identification was based on a morphological and morphometric analysis (Reverte-Coma, 1991). An estimated minimum number of individuals was used whenever osseous remains were collected from common graves, in which bone samples from two or more individuals are mixed. In the case of single graves we took care to confirm that all the osseous remains belonged to the same individual (Puchalt-Fortea and Villalaín-Blanco, 2000). Then, bones samples were separated as adult or child bones. Gender of adult skeletons was determined by bone length of humerus, radius, femur and tibia, and by morphological traits of pelvis and skull (Reverte-Coma, 1991).

Due to the lack of availability of old registers on age at death from each individual in the study, their age was estimated from sternal extremities and ribs traits (Burns, 2008), thyroid cartilage ossification (Loth and Iscan, 1989), cranial bone synostoses and pubic symphysis morphology (Reverte-Coma, 1991). Adult individuals were classified by age in either 25-40 year-old or 41-65 year-old.

Only atlas vertebrae from adult skeletons with a clear-cut age and gender classification and complete cervical spine were used to measure vertebral TF anteroposterior and lateral diameters, as well as those of the RF if it was present. Measurements were done with a digital calibre Powerfix 0-150 mm, in triplicates, and their average was used for further analysis.

We analysed if RF was present in each atlas. This variation could be present bilaterally or only on the left or the right side. In order to compare our results with previous published studies, we considered that a RF was present only if it was complete; partial forms or transition types were not considered for analysis.

SPSS 15.0 software was used for statistical analysis. Levene test was used to confirm homogeneous variance between groups, and t-test was used to analyse statistical significance. When the number of cases was low, a non-parametric Wilcoxon test was used instead.

This study was approved by the Ethical Committee for Research on Humans from the University of Valencia; furthermore, the corresponding authorisation was obtained from the local authorities at "Consellería de Cultura de la Comunidad Valenciana".

Results

Among the 17th century osseous remains found in the fortress-church "Nuestra Señora de la Ángeles" a total of 331 specimens were identified as humans, of whom 177 (53.47%) were adults.

As our study only focused on C1 vertebrae from skeletons with a complete cervical spine whose gender and age were identifiable, we finally selected 88 adults, 36 (40.90%) of whom were classified as male and 52 (59.09%) as female. The majority of these specimens were from individuals who had died between 25 and 40 years of age (64.09%).

There were two vertebrae that presented RF (2.27%) in the sample of 88 C1 vertebrae. One belonged to a woman, with left unilateral RF (Figures 1a,b) and the other belonged to a man, with bilateral RF (Figures 1c,d) which also presented incomplete closure of the right TF. In both cases the RF was smaller than the TF and located on the posterior root of the transverse process. Table 1 shows the dimensions of the anteroposterior diameter and lateral diameter of the TF of these two vertebrae, and Table 2 shows the RF diameters.

When the TF diameters of the two atlases with RF were compared with those of the remaining 86 normal C1 vertebrae, it could be seen that the TF in the two ver-

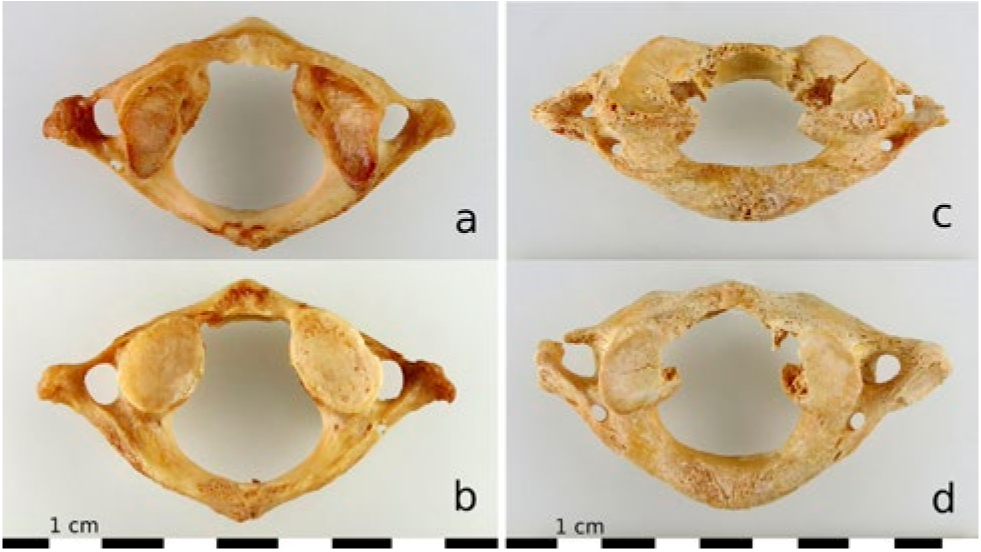

Figure 1 - Two atlas vertebrae with retrotransverse foramen (RF). a: Upper view of a female atlas with RF in the left side. b: Lower view of the same atlas as (a). c: Upper view of a male atlas with bilateral RF. d: Lower view of the same atlas as (c).

tebrae that presented RF had a greater anteroposterior diameter and a smaller lateral diameter than those of the TF of the 86 normal C1 vertebrae that were analysed. Nonetheless, these results were not statistically significant (Table 3).

Discussion

The morphological variant detailed in this study, which analyses two C1 vertebrae with RF, has already been described in the literature as a smaller-sized foramen than the TF located on the posterior root of the transverse process, as we also found (Sylla et al., 1976; Veleanu et al., 1977; Gupta et al., 1979; De Boeck et al., 1984; Le Minor, 1997; Jaffar et al., 2004; Bilodi and Gupta, 2005; Paraskevas et al., 2005; Chinnappan and Manjunath, 2008; Nayak, 2008; Karau et al., 2010; Agrawal et al., 2012; Gupta et al., 2013; Karau and Odula, 2013; Rekha and Neginhal, 2014). However, the diversity of the nomenclature in these publications is striking. Numerous synonyms have been used, leading to confusion: “secondary hole” (Sylla et al., 1976), “retrotransverse canal” (Veleanu et al., 1977; Gupta et al., 1979; Bilodi and Gupta, 2005), “retrotransverse foramen” (De Sousa et al., 1989; Le Minor, 1997; Paraskevas et al., 2005; Karau et al., 2010), “retroarticular canal” (Gupta et al., 2013), “abnormal foramen on the posterior arch of atlas” (Nayak, 2008; Agrawal et al., 2012; Gupta et al., 2013), “accessory costotransverse foramen” (De Boeck et al., 1984), “accessory foramen transversarium” (Jaffar et al., 2004; Chinnappan and Manjunath, 2008; Rajani, 2014), “double foramina” (Karau and Odula, 2013; Rekha and Neginhal, 2014) and “double transverse

Table 1 – Measurement of the transverse foramen of both C1 vertebrae with retrotransverse foramen (RF).

	AP Ø * Right	Lat Ø † Right	AP Ø * Left	Lat Ø † Left
Female C1 with left RF	-	-	7.0	5.5
Male C1 with bilateral RF	7.1	5.7	7.0	5.4

RF: retrotransverse foramen; * anteroposterior diameter of the transverse foramen (mm); † lateral diameter of the transverse foramen (mm).

Table 2 – Measurement of the retrotransverse foramen (RF) of both C1 vertebrae with this anatomical variant.

	AP Ø * Right	Lat Ø † Right	AP Ø * Left	Lat Ø † Left
Female C1 with left RF	-	-	2.3	1.8
Male C1 with bilateral RF	3.9	2.8	3.6	2.9

RF: retrotransverse foramen; * anteroposterior diameter of the retrotransverse foramen (mm); † lateral diameter of the retrotransverse foramen (mm).

Table 3 – Comparison between transverse foramen of C1 vertebrae with and without retrotransverse foramen (RF).

		Presence of RF	Mean±SD	Range	p ‡
C1 2 with RF 86 without RF	Ø AP *	Yes	7.0±0.1	7.0-7.1	0.337
		No	6.9±0.8	5.0-8.3	
	Ø lat †	Yes	5.5±0.1	5.4-5.7	0.593
		No	5.8±0.9	4.1-8.3	

RF: retrotransverse foramen; SD: standard deviation; * anteroposterior diameter of the transverse foramen (mm); † lateral diameter of the transverse foramen (mm); ‡ p-value (Student's t-test)

foramina" (Karau and Odula, 2013). Among the variety of nomenclatures used to describe this anatomical variant, "retroarticular canal" (Gupta et al., 2013) particularly causes confusion as it has also been used for another anatomical variant of the atlas, the posterior bony ponticle or ponticulus posticus (Mitchell, 1998; Karau et al., 2010). In our study we chose the term "retrotransverse foramen" since it was the most frequently used in previous studies.

Our population sample showed a lower prevalence of vertebrae with RF (2.27%) than those of other authors (Table 4). Those studies were mostly based on dry vertebrae samples. The frequencies observed by previous authors vary between 3.57% and 25.49%. In any case, the discrepancy between RF prevalence from different studies could be due to the diverse ethnic origin of the population samples that were studied.

The possible clinical repercussions of RF could depend on the contents of the RF itself, although they could also depend on how the presence of this anatomical variant influences the size of the TF.

Table 4 – Summary of retrotransverse foramen (RF) prevalence described in the literature.

Author and year	Origin	Total C1 vertebrae	C1 with RF n (%)	Right RF n (%)	Left RF n (%)	Bilateral RF n (%)
Sylla S et al (1976)	Senegal	50 (dry vertebrae)	32 (16.0%)	unilateral: 16 (8.0%)	16 (8.0%)	
Velanu C et al (1977)	Romania	71 (dry vertebrae)	9 (12.6%)	2 (2.8%)	6 (8.4%)	1 (1.4%)
Gupta SC et al (1979)	India	123 (dry vertebrae)	23 (18.6%)	10 (8.1%)	8 (6.5%)	5 (4.0%)
De Boeck M et al (1984)	Belgium	55 (dry vertebrae)	7 (12.7%)	n.d.	n.d.	n.d.
		14 (CT images)	1 (7.1%)	n.d.	n.d.	0 (0.0%)
De Sousa CA et al (1989)	Portugal	200 (dry vertebrae)	18 (9.0%)	n.d.	n.d.	n.d.
Le Minor JM (1997)	France Austria	500 (dry vertebrae)	71 (14.2%)	27 (5.4%)	23 (4.6%)	21 (4.2%)
Jaffar AA et al (2004)	Caucasoid	29 (dry vertebrae)	n.d. (approx. 10%)	n.d.	n.d.	n.d.
Bilodi AK and Gupta SC (2005)	India	34 (dry vertebrae)	3 (8.8%)	2 (5.8%)	1 (2.9%)	0 (0.0%)
Chinnappan M and Manjunath KY (2008)	India	102 (dry vertebrae)	9 (8.8%)	5 (4.9%)	3 (2.9%)	1 (0.9%)
Nayak B et al (2008)	India	1 (dry vertebrae)	1 (-)	0 (-)	0 (-)	1 (-)
Karau PB et al (2010)	Kenya	102 (dry vertebrae)	26 (25.4%)	16 (15.6%)	10 (9.8%)	0 (0.0%)
Agrawal R et al (2012)	India	28 (dry vertebrae)	1 (3.5%)	0 (0.0%)	0 (0.0%)	1 (3.5%)
Gupta C et al (2013)	India	35 (dry vertebrae)	2 (5.7%)	n.d.	n.d.	n.d.
Karau PB et al (2014)	Kenya	102 (dry vertebrae)	4 (3.9%)	3 (2.9%)	1 (0.9%)	0 (0.0%)
Rekha BS et al (2014)	India	153 (dry vertebrae)	10 (6.5%)	4 (2.6%)	3 (1.9%)	3 (1.9%)
Present study	Spain	88 (dry vertebrae)	2 (2.2%)	1 (1.1%)	0 (0.0%)	1 (1.1%)

RF: retrotransverse foramen; n: number of vertebrae analyzed; CT: computed tomography; n.d.: non disclosed.

There are few studies that describe the contents of the RF. Veleanu et al. (1977), when analysing twelve cadavers, observed that the RF contained an anastomotic vein connecting atlanto-occipital and atlanto-axodian venous sinuses. Dubreuil-Chambardel (1921) observed in some cases also a thin artery accompanying these venous elements. Sylla et al. (1976) postulated that a dorsal branch of the first cervical spinal nerve runs through the RF. Other authors hypothesised that the RF could separate the passage of the vertebral artery and vein, or change the course of the vertebral artery and lead to its compression (Nayak, 2008; Rajani, 2014), or that it could also be related to the presence of a duplication of the vertebral artery (Kaya et al., 2011). Whatever the case, according to the observations of Le Minor (1997), the RF appears to be a variant that is absent in all nonhuman primates, which would support an evolutionary origin regarding the acquisition of bipedalism associated with adaptations in the vascular system in response to hydrostatic pressure and gravity, draining the blood from the cranium into the vertebral venous plexus. In favour of this hypothesis, Paraskevas et al. (2005) observed a high incidence of coexistence of the posterior bridge of the atlas and the RF (72.22%), which they attributed to the blood flow being directed into the small vein of the RF, possibly due to compression of the vertebral veins in the posterior bridge.

With regard to the possible repercussion of the RF on the size of the TF, although in our study the results were not statistically significant (perhaps due to the scarcity of atlases with RF in our study sample), we observed that the presence of RF could condition a small-sized TF when compared with normal C1 vertebrae. This is why it is striking that among the authors who investigated this anatomical variant none commented on this possible influence, which could affect the flow of blood in the vertebral artery. Only the study by Agrawal et al. (2012) contributed data about the dimensions of the anteroposterior diameter and the lateral diameter of the two RF they analysed in an atlas, whose dimensions were 3 x 2 mm which is similar to what observed in the three RF found in our study.

On the other hand, there are indeed studies that have measured the anteroposterior diameter and the lateral diameter of the TF of the atlas, but none of them says whether the measurements were of C1 vertebrae with RF or not (Rocha et al., 2007; Evangelopoulos et al., 2012; Gupta et al., 2013; Karau and Odula, 2013; Rekha and Neginhal, 2014), except Taitz et al. (1978) who stated that in their sample of 33 atlas vertebrae none presented RF. Moreover, it is worth mentioning that the values for the anteroposterior diameter and the lateral diameter of the TF studied by these authors are very similar to those observed in our study, as shown in Table 5. Regarding the methodology used in these studies, all of them based their calculations on samples of dry vertebrae (Taitz et al., 1978; Rocha et al., 2007; Gupta et al., 2013; Karau and Odula, 2013; Rekha and Neginhal, 2014), with the exception of Evangelopoulos et al. (2012) who analysed computed tomography (CT) images of the atlas. Other authors have turned their attention to measuring the area of the TF of the C1 using the formula to calculate the area of an ellipse (Jaffar et al., 2004; Karau and Odula, 2013), but their results should be considered merely as approximate as the shape of the TF is not an even oval. Therefore, in order to obtain more precise results that could help to elucidate the possible effect of RF on the size of the TF of C1, it would be necessary to perform a study on the area of TF and RF using CT images of the atlas.

Table 5 – Measurements of anteroposterior and lateral diameters of the transverse foramen of C1 previously published in the literature.

Author and year	Origin of the sample	n	AP Ø * Mean±SD		Range (mm)	Lat Ø † Mean±SD		Range (mm)
Taitz C et al (1978)	India and Israel	33	Rigt	7.2±0.8	5.1-8.9	Rigt	5.5±0.9	3.8-7.6
			Left	7.2±0.9	5.4-8.9	Left	5.7±0.7	4.0-7.4
Rocha R et al (2007)	Brazil	20	Rigt	7.3±1.1	5.6-9.4	Rigt	6.6±0.9	5.3-8.1
			Left	7.2±1.1	5.2-9.0	Left	6.5±0.9	5.2-8.0
Evangelopoulos DS et al (2012)	Greece	50 ♂ 50 ♂	Rigt	♂ 7.0±0.9 ♀ 6.8±1.0	n.d.	Rigt	♂ 7.2±1.2 ♀ 6.8±1.2	n.d.
			Left	♂ 7.5±1.1 ♀ 7.4±0.8	n.d.	Left	♂ 7.4±1.2 ♀6.8±0.9	n.d.
Gupta C et al (2013)	n.d.	35	n.d.		n.d.	5.7±n.d.		5.2-6.7
Karau PB et al (2013)	Kenia	102	7.0±n.d.		n.d.	6.5±n.d.		n.d.
Rekha BS et al (2014)	India	153	Rigt	7.9±1.0	5.0-11.9	Rigt	6.3±0.9	4.1-9.1
			Left	7.7±0.9	4.6-10.0	Left	6.3±1.0	4.6-9.1
Present study	Spain	86	6.9±0.8		5.0-8.3	5.8±0.9		4.1-8.3

n: number of vertebrae analyzed; * anteroposterior diameter of the transverse foramen (mm); † lateral diameter of the transverse foramen (mm); SD: standard deviation; n.d.: non disclosed.

The results contributed by this study on RF should encourage professionals to perform a wider-ranging analysis of the prevalence of this anatomical variant in a present-day population sample. Moreover, due to the possible influence the RF may have on the size of the TF, and consequently on the flow of blood in the vertebral artery, it would be interesting to base subsequent analyses on an extensive sample of CT images of C1 which would permit an exact calculation of the area of the TF on the basis of the presence or absence of RF. It would also be necessary to establish unequivocally what anatomical structures run through the RF, either by means of imaging techniques *in vivo* or by dissecting large series of cadavers. In any case, the analysis and understanding of the RF is of the utmost importance for medical professionals, especially orthopaedic surgeons, radiologists and neurosurgeons, for greater precision and safety in surgical procedures of the cervical spine.

Conflict of interest

The authors have no conflict of interest to declare.

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