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The Prevalence and Morphometry of the Atlas Vertebra Retrotransverse Foramen

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Abstract

Objective. The current study records the prevalence of the accessory foramen, located posterior to the transverse foramen (TF), the so-called the retrotransverse foramen (RTF), its morphometry, exact location, and coexistence with ossified posterior bridges. Additionally, factors associated with the length of the RTF are investigated. **Materials.** One-hundred and forty-one dried atlas vertebrae were examined. **Results.** Thirty-seven out of the 141 vertebrae (26.2%) had at least one RTF. The RTF was unilateral in 67.6% and bilateral in 32.4%. The mean RTF anteroposterior diameter (length) was 4.2±1.4 mm on the right and 3.8±1.0 mm on the left side. The mean RTF laterolateral diameter (width) was 2.6±1.2 mm on the right and 2.5±0.8 mm on the left side. Both dimensions were symmetrical. The RTF was symmetrically located from the TF, at a mean distance of 4.6±1.1 mm on the right and of 4.5±0.9 mm on the left side. For the given TF-RTF distance, laterality, and presence of posterior bridges, each mm increase in the RTF width was associated with a 0.74 mm increase in the relevant length. **Conclusion.** The estimated prevalence was higher than most of those reported in other studies. However, the between-studies prevalence varies to a significant degree. Hence, a systematic review and meta-analysis should be performed to identify a more precise estimate due to the clinical importance of the RTF.

Key Words: Retrotransverse Foramen ▪ Accessory Foramen ▪ Variation ▪ Atlas Vertebra ▪ Morphometry ▪ Regression Analysis.

Introduction

The atlas, the topmost cervical spine vertebra (C1), provides a stable support for the head, by means of its ring-shaped form. The posterior arch has a vertebral artery (VA) groove for transmission of the homonymous artery and the dorsal ramus of the first cervical spinal nerve. The transverse foramen (TF) transmits the VA, the vertebral vein (VV), and the sympathetic nerves (1). The presence of an accessory foramen posterior to the TF, a so-called retrotransverse foramen (RTF), or posterolateral foramen or canaliculus venosus (2) is noticed as a variant, with a reported prevalence that differs widely between studies in different populations (Table 1). Most of the published studies investigating the RTF have examined dried vertebrae, while a few cadaveric (3-6) and imaging (6-10) studies have provided additional information on the RTF perforating structures, or have described possible clinical implications (headache, migraine, and loss of consciousness relating to certain neck movements) (11). However, knowledge of RTF variants is not only limited to such manifestations, since an accessory foramen may be of paramount surgical importance in upper cervical spine surgery when exposing the C1 posterior arch (12), and when interpreting neck compression syndromes, due to VA entrapment (13).

The present study provides information about the prevalence of RTF, its morphometric characteristics, exact location, and coexisting ossified variants (posterior bridges-PBs) in a dried C1 vertebrae sample of Greek origin. On a secondary basis, an attempt to identify factors associated with the RTF length was performed.

Table 1. Identification of the Presence (Prevalence) and Laterality of the Retrotransverse Foramen (RTF) in Cervical Vertebrae, Among the Published Studies

Authors	Publication year	Continent	Study type	Total sample	Frequency	Prevalence (%)
Le Double et al.	1912	Europe	Dried bone	500	60	12.0
Barbosa Sueiro et al.	1933	Europe	Dried bone	400	33	8.3
Sassu et al.	1965	Europe	Dried bone	66	13	19.7
Sylla et al.	1976	Africa	Dried bone	50	32	64.0
Veleanu. et al.	1977	Europe	Dried bone	71	9	12.7
Taitz et al.	1978	Asia	Dried bone	480	34	7.1
Gupta et al.	1979	Asia	Dried bone	35	2	5.7
De Boeck et al.	1984	Europe	Dried bone	55	7	12.7
De Boeck et al.	1984	Europe	Imaging	14	1	7.1
De Sousa et al.	1989	Europe	Dried bone	200	18	9.0
Le Minor	1997	Europe	Dried bone	500	71	14.2
Wysocki et al.	2003	Europe	Dried bone	100	1	1.0
Jaffar et al.	2004	Europe	Dried bone	29	3	10.3
Bilodi and Gupta	2005	Asia	Dried bone	34	3	8.8
Das et al.	2005	Asia	Dried bone	132	2	1.5
Paraskevas et al.	2005	Europe	Dried bone	115	17	14.8
Chinnappan and Manjunath	2008	Asia	Dried bone	102	9	8.8
Ilie et al.	2008	Europe	Dried bone	75	6	7.6
Karau et al.	2010	Africa	Dried bone	102	16	15.7
Sharma et al.	2010	Asia	Dried bone	200	16	8.0
Kaya et al.	2011	Asia	Dried bone	262	59	22.5
Murlimanju et al.	2011	Asia	Dried bone	363	6	1.7
Aggarwal et al.	2012	Asia	Dried bone	176	11	6.3
Agrawal et al.	2012	Asia	Dried bone	28	1	3.6
Chaudhari et al.	2013	Asia	Dried bone	133	31	23.3
Gupta et al.	2013	Asia	Dried bone	123	23	18.7
Karau et al.	2013	Africa	Dried bone	102	4	3.9
Laxmi et al.	2013	Asia	Dried bone	210	10	4.8
Rathnakar et al.	2013	Asia	Dried bone	140	8	5.7
Katidireddi and Setty	2014	Asia	Dried bone	100	3	3.0
Murugan et al.	2014	Asia	Dried bone	150	19	12.7
Ramachandran et al.	2014	Asia	Dried bone	120	19	15.8
Rekha et al.	2014	Asia	Dried bone	153	10	6.5
Yadav et al.	2014	Asia	Dried bone	120	8	6.7
Akhtar et al.	2015	Asia	Dried bone	174	25	14.4

Authors	Publication year	Continent	Study type	Total sample	Frequency	Prevalence (%)
Apurba et al.	2015	Asia	Dried bone	150	33	22.0
Sultana et al.	2015	Asia	Dried bone	100	1	1.0
Travan et al.	2015	Europe	Dried bone	129	11	8.5
Quiles-Guiñau et al.	2016	Europe	Dried bone	86	2	2.3
Gul et al.	2017	Asia	Dried bone	100	9	9.0
Sanchis et al.	2017	Europe	Dried bone	206	15	7.3
Sanchis et al.	2017	Europe	Imaging	110	4	3.6
Gupta et al.	2019	Asia	Dried bone	161	42	26.1
Natsis et al.	2019	Europe	Dried bone	244	116	47.5
Medeiros et al.	2021	America	Dried bone	44	4	9.1
Xing et al.	2021	Asia	Imaging	427	50	11.7
Ranjan et al.	2022	Asia	Dried bone	170	24	14.1
Unweighted average						11.9
Present study	2022	Europe	Dried bone	141	37	26.2

Materials and Methods

One hundred and forty-one dried C1 vertebrae obtained from the ossuaries of the Anatomy and Surgical Anatomy Department of the Aristotle University of Thessaloniki (AUTh) (100 vertebrae) and from a local Greek cemetery located in the city of Serres (41 vertebrae) were used. All these specimens were of unknown sex and age, and free of fractures or deformities.

Measurements

Prior to measurement, each RTF patency was evaluated using an orthodontic wire of 0.2 mm thickness. Foramina that were not perforated fully (blind - grooves) were considered as absent. All the remaining subjects were visually inspected bilaterally for RTF presence, and the total, bilateral and unilateral frequencies were recorded. On the basis of these frequencies, the prevalence and laterality (bilaterally or unilaterally present foramina in each vertebra) were estimated. Additionally, the coexistence of completely ossified PBs was calculated (Figure 1).

The morphometric characteristics of the anteroposterior diameter (APD) or length and the laterolateral diameter (LLD) or width, as well as the RTF-TF minimum distance (Figure 2) were independently measured by two assessors, using the digital sliding caliper (Mitutoyo ABSOLUTE 500-196-20), accurate to 0.01 mm.

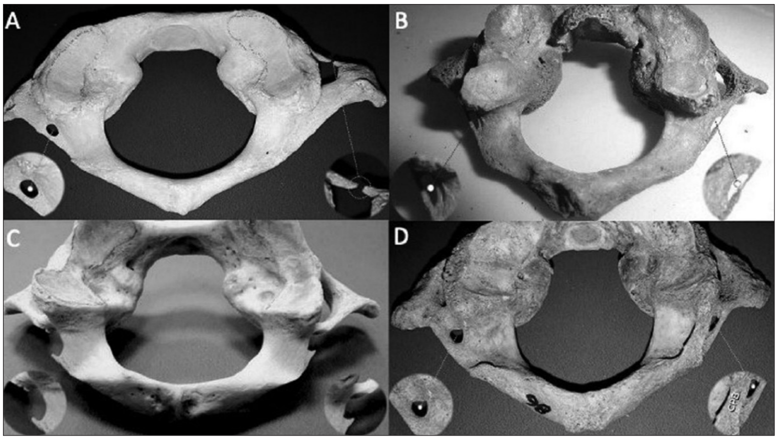

Figure 1. Photograph collection demonstrating the main characteristics of the retrotransverse foramina (RTF). A. unilateral RTF, B. bilateral RTF, C. an unclosed RTF (considered as absent), D. a case of coexistence of a RTF with a complete ossified posterior bridge (CPB). A case of an incomplete transverse foramen (TF) is depicted by an asterisk (*) in frame A.

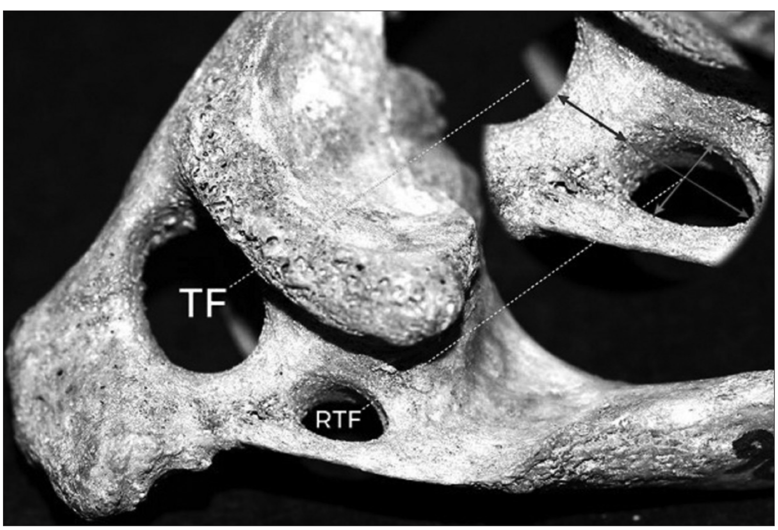

Figure 2. Schematic demonstration of the calculated diameters of the retrotransverse foramen (RTF) (anteroposterior and laterolateral diameters- double arrows) and the minimum distance between the transverse foramen (TF) and the RTF (red double arrow).

Ethics Statement

The vertebrae from the osseous collection of the Anatomy and Surgical Anatomy Department of AUTh belonged to body donors that offered their bodies before death, by signing an informed consent (body donation program). In relation to the rest of the sample (41 vertebrae), the Ethics Committee of the AUTh gave full permission prior to the beginning of the study. The current research was conducted in accordance with the principles of the 1964 Declaration of Helsinki and its later amendments.

Statistical Analysis

Statistical analysis was carried out using STATA statistical software (Release 14.0, Stata Corp., TX, USA) for MacOS. The Shapiro–Wilk test, the evaluation of skewness and kurtosis values, as well as the visual interpretation of the produced histograms were used to assess data normality. In the case of a normally distributed quantitative variable, mean and standard deviation (SD) values were used, otherwise the median and the interquartile range (IQR) were recorded. All qualitative variables were expressed in absolute (N) and relative (%) frequencies. For the continuous variables, the presence of interobserver error (differences in measurements between assessors) was estimated by calculating the intraclass correlation coefficient (ICC), and interpreted using Koo and Li's reported guidelines (14). Paired sample Student's t-tests were performed to assess whether the APD, LLD and TRF-TF minimum distance varied by laterality and by the presence of PBs, respectively. Chi-Square tests of independence or Fisher's exact tests were performed to evaluate the potential difference in prevalence and laterality according to the coexistence of a PB. Univariate and multivariate linear regression analyses were performed to assess the relationship between APD and all recorded variables. Unless otherwise stipulated, $P<0.05$ was considered statistically significant.

Results

Retrotransverse Foramen Prevalence

At least one RTF was identified in 37 vertebrae, leading to an estimated prevalence of 26.2%. An RTF was detected unilaterally in 25 vertebrae (67.6%; 17 right, 68.0% and 8 left, 32.0%) and bilaterally in 12 (32.4%) (Table 2). Ossified PBs were identified in 12 atlas vertebrae (32.4%). No significant differences were detected between the side of the location of RTF (laterality) and the presence of PBs (P=0.711) or side of their location (P=0.998).

Table 2. Description of the Frequencies of Main Characteristics and the Estimated Mean Values of the Morphometric Characteristics Investigated

Qualitative variables		Quantitative variables	
Variable	Frequency (%)	Variable	Mean (± SD)
Prevalence	37 (26.2)	APD*	
Laterality		Right side	4.2 (±1.4) mm
Bilateral	12 (32.4)	Left side	3.8 (±1.0) mm
Unilateral	25 (67.6)	Mean	4.1 (±1.3) mm
Right side	17 (68.0)	LLD†	
Left side	8 (32.0)	Right side	2.6 (±1.2) mm
Presence of posterior bridges		Left side	2.5 (±0.8) mm
No	25 (67.6)	Mean	2.6 (±1.1) mm
Yes	12 (32.4)	RTF‡ – TF§ distance	
Right side	9 (75.0)	Right side	4.6 (±1.1) mm
Left side	3 (25.0)	Left side	4.5 (±0.9) mm
-		Mean	4.6 (±1.0) mm

*Anteroposterior diameter; †Laterolateral diameter; ‡Retrotransverse foramina; §Transverse foramina.

The mean values, standard deviations (SD), and the differences between right and left side (including the respected P-values) for each measurement are provided in the text.

Retrotransverse Foramina Morphometry and Minimum Distance from the Transverse Foramina

ICC calculation supported the existence of the excellent reliability of the measurements between observers (ICC=0.921, P>0.05). The morphometric details RTF (APD, LLD and RTF-TF minimum distance) followed the normal distribution (P>0.05). Symmetry was found in all morphometric parameters. Significant differences in the APD and LLD were identified in relation to the presence or absence of PBs (Table 3). The mean values of the APD, LLD and RTF-TF minimum distance were 4.1±1.4 mm, 2.6±1.1 mm, and 4.6±1.0 mm (Table 2). None of these values varied by laterality, the presence of PBs or their location (Table 3).

Table 3. Results of the Student's T-tests for the Evaluation of Differences in Measured Diameters and the Retrotransverse Foramen - Transverse Foramen Distance, Retrotransverse Foramen, Transverse Foramen

Test	Mean1	Mean2	Diff.	P value
Anteroposterior diameter				
Sidewise (right – left)	3.98	3.65	0.33	0.304*
Laterolateral diameter				
Sidewise (right – left)	2.22	2.41	-0.2	0.395*
RTF† – TF‡ distance				
Sidewise (right – left)	4.36	4.21	0.16	0.445*
Two-sample Students' t tests				
Anteroposterior diameter				
By the laterality	3.82	4.24	-0.43	0.362*
By the presence of posterior bridges	3.76	4.82	-1.07	0.018*
By the side of posterior bridges	4.91	4.57	0.34	0.686*
Laterolateral diameter				
By the laterality	2.32	2.83	-0.51	0.182*
By the presence of posterior bridges	2.39	3.23	-0.84	0.025*
By the side of posterior bridges	3.27	3.08	0.19	0.837*
RTF† – TF‡ distance				
By the laterality	4.29	4.77	-0.49	0.168*
By the presence of posterior bridges	4.53	4.78	-0.25	0.485*
By the side of posterior bridges	4.69	5.06	-0.36	0.562*

*Paired samples Students' t-tests; †Retrotransverse foramen; ‡Transverse foramen.

Table 4. The Univariate and Multivariate Linear Regression Analyses for the Investigation of the Association between the Recorded Variables and APD[*]

Independent variables	Univariate models			Multivariate model		
	B[†]	95% CI[‡]	P-value	B[†]	95% CI[‡]	P value
LLD[§]	0.77	0.44–1.09	<0.001	0.74	0.36–1.12	<0.001
RTF[‖]–TF[¶] distance	0.14	-0.31–0.58	0.542	-0.17	-0.56–0.21	0.363
Laterality						
Bilateral**	0	-	-	0	-	-
Unilateral	0.43	-0.51 – 1.36	0.362	0.08	-0.69 – 0.86	0.829
Presence of posterior bridges						
No**	0			0		
Yes	1.07	0.19 – 1.94	0.191	0.49	-0.32 – 1.29	0.227

[*]APD; [†]Beta coefficient; [‡]95% Confidence Intervals; [§]Laterolateral dimension; [‖]Retrotransverse foramen; [¶]Transverse foramen; [**]Reference category.

Factors Associated with the Accessory Foramina Anteroposterior Diameter

The APD was only found to be significantly associated with the LLD, on the basis of the univariate (B, 0.77, 95% CI, 0.44 – 1.09, P<0.001) and multivariate (B, 0.74, 95% CI, 0.36 – 1.12, P<0.001) regression analyses (Table 4). On the basis of the interpretation of the multiple linear regression output, holding all the other parameters constant (RTF-TF minimum distance, laterality, and PBs presence), for each mm increase in the accessory foramen LLD, a 0.74 mm increase in the relevant ADP was noticed.

Discussion

The Accessory Foramina Prevalence in Dried Bone Studies

The current study highlights a prevalence of RTF of 26.2%. Significant heterogeneity exists among studies conducted in different populations in relation to estimation of RTF prevalence. Most of them suggest that RTF are mostly found with an unweighted prevalence of 11.9% (Table 1). Studies of Africans (15-17) and Europeans (6-8, 18-28) report higher values of maximum prevalence than those of Asian (4, 5, 9, 29-50) and American origin (51). This discrepancy may be related to the existence of intra- and inter-population differences or may be associated with the fact that in most of the studies the crude (prevalence calculated from all the available specimens) rather than the vertebra-adjusted prevalence (specified for each of the cervical vertebrae) is reported. Hence, systematic reviews and meta-analyses should be performed in an attempt to explain the source of heterogeneity, and to obtain more accurate estimates.

The Retrotransverse Foramen Morphometric Characteristics

The current study's findings regarding RTF morphometry can be considered similar to those provided by Mederios et al. (51). However, the diameters reported by Mederios et al. (51) were calculated by evaluating all the available cervical vertebrae. Hence, vertebrae-specific RTF measurements must be conducted to estimate the RTF exact dimensions accurately per vertebra.

Ossified Posterior Bridges, as Coexisted Variants

Ossified PBs were identified in 12 subjects (32.4%) in the present study. A significantly higher prevalence (72.2%) was recorded by Paraskevas et al. (24) and attributed to the redirection of the blood into the retrotransverse vein, possibly due to VV compression into the PB. The high difference between the two studies highlights the existing heterogeneity.

The Retrotransverse Foramina Content

The current study lacks details of the RTF content, as it was exclusively performed on dried C1 vertebrae. A few cadaveric studies have reported data related to the RTF content. These studies have been considered as the gold standard for identification of C1 variants (6). Veleanu et al. (6) and Bodon et al. (3) identified an anastomotic vein perforating the RTF and connecting the venous sinuses above (suboccipital cavernous sinus) and below (VA and vertebral venous plexus) the C1 posterior arch. Therefore, the presence of RTF could be related to modifications in the regional venous circulation associated with the erect posture and bipedal locomotion of humans (2). However, other studies reported neural (17) or arterial (52) components perforating the RTF. Additionally, the same issue remains when assessing imaging studies dealing with this topic. Particularly, even though some authors have reported that the RTF content may be the VA (9) and/or the VV (11, 47) Xing et al. (9) supported that RTF is only perforated by venous components, as they did not find any case of the passage of the VA. Their conclusion contradicts Kaya et al. (39) who related VA duplication with the existence of a RTF.

Clinical Implications

Knowledge of the surgical anatomy of the C1 vertebra and surrounding structures is important for neurosurgeons, orthopaedic surgeons, and radiologists. An unnoticed RTF may be a risk factor for intraoperative bleeding from the venous plexus, covering the C1 lateral mass and obscuring the surgical field (52). The VA may commonly be injured (53) in posterior exposure of the upper cervical spine, especially when using posterior instrumentation. Even minor lesions of the VA may result in severe hemorrhage, or even death. Madawi et al. (54) highlighted a high prevalence (28.3%) of VA injury during posterior upper cervical spine trans-articular fixation for atlantoaxial instability, in cases in which the RTF is used as a landmark, and the entry point for the lateral mass screw will be just medial to the RTF. Thus, preoperative imaging will help determination of the safe trajectory for screw placements in posterior procedures (55) and has become an essential examination before posterior approach surgeries.

Limitations of the Study

The sample size is small and more studies on a larger population should be conducted. Additionally, the lack of computed tomography (CT) measurements and information regarding the specimens' sex, age and ethnicity, as well as the inability to identify the structures perforating the RTF, should be taken into consideration when interpreting this study's results.

Study Strengths

The calculation of measurements by two assessors and the intraobserver error estimation improved the accuracy and precision of the study findings. This study utilized linear regression analysis to associate the recorded variables with the accessory foramina APD (length).

Conclusions

RTF prevalence is estimated at 26.2%. RTF morphometry (diameters) and location (minimum distance from the TF) showed side symmetry. The RTF anteroposterior diameter is significantly associated with the laterolateral measurement.

What Is Already Known on This Topic:

C1 has the highest variability among the cervical vertebrae. Among C1 variants, the frequency of RTF presence has been studied in different populations. The frequencies of RTF presence vary between 2.3% and 47.5%. The RTF has been associated with a high incidence of C1 posterior bridging (72.2%). A few cadaveric studies focus on the RTF content and are considered the gold standard for assessing the presence of C1 variants. A recent study asserted the exclusive passage of veins through the RTF, as they did not find any case of VA passage. An unnoticed RTF may be a risk factor for intraoperative bleeding from the venous plexus, covering the C1 lateral mass and obscuring the surgical field. Preoperative imaging is an essential examination before posterior approach surgeries.

What This Study Adds:

The study provides additional information on the prevalence and morphometry of RTF. Additionally, information is provided on the location of RTF, as well as an analysis of the factors associated with its length (anteroposterior diameter). Characteristic depictions, meticulous tables and a detailed report of the available data focusing on the RTF clinical importance are provided.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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