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Osseous Variants of the Cervical Spine with Potential Pathological Significance: Possible Evidence of Vertebrobasilar Insufficiency in a Skeletal Sample from the Post-Classical Cemetery of Corfinio (12th–15th Centuries CE, L'Aquila, Italy)

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Abstract: The vertebral arteries supply blood to the upper spinal cord, brainstem, cerebellum, and posterior part of the brain. These arteries are susceptible to deformation from external factors such as muscular, ligamentous, or bony structures, and any interruption of blood flow may result in vertebrobasilar insufficiency. Among the osseous variants of the cervical spine with potential pathological significance, variations in the number, shape, and size of the foramen transversarium, as well as the presence of bony bridges in the first cervical vertebra, may suggest a predisposition to vertebrobasilar insufficiency. A skeletal sample from the post-Classical cemetery of Corfinio (12th–15th centuries CE; L'Aquila, Italy) was examined. Regarding the morphology of the foramen transversarium, shape variations were identified in 32 of the 108 vertebrae analysed (a prevalence of 29.6%). Particularly noteworthy are three findings in the atlas: (i) a high prevalence of foramen transversarium variants (35.7% for hypoplastic and double foramina), (ii) a coefficient of roundness consistent with a brachymorphic shape, and (iii) a high prevalence of bony bridges —especially *ponticulus posticus* (52.9%) and retrotransverse foramen (64.7%). All of these findings may indicate a predisposition to vertebrobasilar insufficiency in the individuals studied. It is hypothesised that external mechanical factors, such as carrying heavy loads on the head, neck, and shoulders due to work activities, along with possible genetic influences related to kinship, may have contributed to the high prevalence of these osseous variants.

Keywords: foramen transversarium; cervical spine; osseous variants; vertebrobasilar insufficiency; palaeopathology

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1. Introduction

Anatomical variation is defined as a deviation in the size, form, or structure of the body from that described in the classical medical literature and considered normal human anatomy [1]. These variations are important for several reasons. On the one hand, there are many types, often associated with specific populations [1,2], geographical regions, environmental adaptation, or exposure to chemical pollutants or radiation [1]. On the other hand, they offer insight into the variability of human anatomy and play a significant role in clinical practice [3–5]. Anatomical variations are commonly identified during routine clinical practice [6], and recognizing them is essential for accurate diagnosis and effective treatment. Understanding anatomical variations can not only improve clinical outcomes but also provide valuable information for reconstructing the physical health and living conditions of past populations through the study of human skeletal remains [7,8]. Although anatomical variations are not pathological by definition, some studies have suggested that certain variants may predispose individuals to pathological processes under specific conditions [9,10]; thus, palaeopathological studies of skeletal remains can offer important insights into potential risk factors for disease and the overall health of past populations [11].

The aim of this study was to determine the prevalence of osseous variants of the cervical vertebrae with potential pathological significance. These include variations in the number, shape, and size of the foramen transversarium (FT), as well as the presence of bony bridges in the first cervical vertebra (atlas), such as the *ponticulus posticus* (PP), *ponticulus lateralis* (PL), and the retrotransverse foramen (RTF), in a skeletal sample from the post-Classical cemetery of Corfinio (12th–15th centuries CE; L'Aquila, Italy).

Cervical Spine Anatomy Overview

The cervical region is the segment of the spine with the greatest mobility. Unlike other spinal segments, the cervical vertebrae each contain transverse foramina that accommodate the major arteries of the neck—the vertebral arteries (VAs)—which supply approximately 20% of the brain's blood, with the remaining 80% provided by the carotid system [12]. Each bilateral VA originates from the subclavian arteries (SCAs) and ascends along either side of the neck, merging within the cranium to form the single, midline basilar artery (BA). The VA is typically divided into four segments based on its anatomical course: VA1 (pre-foraminal), VA2 (foraminal), VA3 (extradural), and VA4 (intradural). The VA1 segment extends from the VA's origin at the SCA to its entry into the FT of the C_6 vertebra. The VA2 segment ascends through the FT from C_6 to C_2. The VA3 segment begins as the VA exits the FT of C_2, loops around C_1, and enters the dura mater. The VA4 segment—the intracranial portion—starts at the dura mater and continues to the point where the two VAs merge to form the BA within the cranium [13,14].

Within the vertebrobasilar vascular system, the VAs supply blood to the upper spinal cord, brainstem, cerebellum, and posterior part of the brain [15]. However, in their course from the SCA to the BA, the VAs are susceptible to deformation or damage from external factors such as muscular, ligamentous, or bony structures [16], and any significant interruption of blood supply may result in vertebrobasilar insufficiency (VBI), presenting a variety of symptoms depending on which region of the brain is predominantly affected. These symptoms include vertigo, dizziness or syncope, nausea and vomiting, 'drop attacks' (i.e., the patient experiences sudden generalised weakness), diplopia or loss of vision, paraesthesia, confusion, dysphagia or dysarthria, headache, facial pain, altered consciousness, ataxia, contralateral motor weakness, and incontinence, among others [15,17].

Among the variants in bone structure that can cause VBI, particular attention should be given to those affecting the FTs of the cervical vertebrae [18]. As noted above, the FTs serve as the passageways through which the VA ascends from the SCA to enter the cranium bilaterally. In some cases, the FTs may be absent, hypoplastic, or subject to deformations (e.g., abnormal osteophytic encroachments), or may exhibit variations in size, number, and shape [19–21], potentially compressing vital neural and vascular structures such as the VA.

Of particular importance is the first cervical vertebra (atlas, C_1), which is characterised by distinctive structural and morphological features that contribute to its specialised function within the cervical spine. This vertebra plays a significant role in the biomechanics of the craniovertebral joint and, along with the second cervical vertebra (axis, C_2), enables the nodding and rotational movements of the skull. Given the high mobility of the cervical spine, any abnormality in the path of the vertebral vessels through the FT of the atlas may impair blood flow to the brain. Compounding this critical issue is the high anatomical variability of C_1, with the PP, PL, and RTF being other osseous variants that can affect the vertebral vessels. The PP/PL is a small bony bridge between the posterior portion of the superior articular process (PP) and the posterolateral portion (PL) of the superior margin of the posterior arch [22,23]. The RTF is a small bony bridge extending from the posterior root of the transverse process to the root of the posterior arch of the atlas, forming an accessory foramen on the posterior root of the transverse process [24]. In C_1, the presence of bony spurs such as the PP and PL may exert external pressure on the VA as it passes from the FT of the vertebra to the foramen magnum of the skull. During extreme rotatory movements of the cervical spine, the VA may become compressed. A reduction in its cross-sectional area, combined with pathology in the contralateral VA, may compromise blood flow and result in VBI [25,26].

2. Materials and Methods

2.1. Original and Study Skeletal Samples

The original sample consisted of the skeletal remains of 34 individuals from the post-Classical cemetery of Corfinio (12th–15th centuries CE, L'Aquila, Italy). The osteological collection is housed at the Laboratory of Archaeology in the Department of Sciences at the 'G. d'Annunzio' University of Chieti-Pescara, Italy. Sex and age at death of the skeletal remains were previously estimated using standard osteological procedures. Sex was estimated using two complementary approaches: the descriptive method proposed by Ferembach et al. [27], which is based on cranial and pelvic features, and application of the *Diagnose Sexuelle Probabiliste v2* program [28] to the os coxae. Age at death was estimated for all individuals using the Transition Analysis 3 program [29], designed to estimate age at death from partial skeletal remains. Based on the estimated age at death, individuals were divided into three age categories following conventional anthropological classification [30]: young adults (21–40 years), middle-aged adults (41–60 years), and senile adults (>61 years).

2.2. Archaeological Background of the Funerary Area

From pre-Roman times to the Middle Ages, *Corfinium* was one of the principal settlements in the southern part of the Valle Peligna, located along the route of the consular roads *Tiburtina Valeria* and *Claudia Nova*, in the inland region of Abruzzo (central-southern Italy) [31,32]. Between 1988 and 1994, and later between 2013 and 2018, a series of archaeological excavation campaigns identified a funerary area to the south of the oratory of *Sant'Alessandro* [33–35]. According to current research, based on stratigraphic data [36] and radiocarbon analysis (CEDAD–Lab, University of Salento, Italy), it can be concluded that the osteological sample analysed in the present study dates to between late 12th century CE and the mid-15th century CE. This period corresponds to an intensification in the use and frequentation of the cemetery area. Regarding the organisation of the burial space, archaeological investigations suggest that during the early part of this period, graves throughout the funerary area were laid out in a coherent manner, consisting of individual simple burials that facilitated identification of specific interments. Later, in the vicinity of the *Sant'Alessandro* oratory, intensive use of the funerary space and the consequent need to free up room led to significant stratification and superposition of older and more recent graves. This process compromised the preservation of the graves and the skeletal remains [37,38].

2.3. Analytical and Methodological Procedures

To ensure that the cervical vertebrae were fully developed [39], only individuals aged ≥21 years—based on age-at-death estimates—were included in the analysis. All vertebrae that could not be classified as C_1–C_7 were excluded from the study. All osseous variations of the cervical spine were recorded through macroscopic evaluation.

Before conducting the morphological analysis and collecting variables related to the FT, PP, PL, and RTF, all cervical vertebrae were assessed for potential limiting factors that might negatively influence subsequent analysis. These factors included traumatic injuries or fractures; occipitocervical fusion of the atlas, hemivertebrae, vertebral tumours, and infections; degenerative changes with osteophytic encroachments in the FT, PP, PL, or RTF; and taphonomic or diagenetic effects. Following the exclusion of affected FT, PP, PL, or RTF for each vertebra, morphological and metric data were collected bilaterally.

2.3.1. Morphological Data Collection

For the morphological analysis of the FT (C_1–C_7), osseous variations were classified into six categories (Figure 1) [21,40]: (i) normal FT, defined as a single FT in the transverse process of the vertebra; (ii) absence of FT, defined as the failed development of the FT; (iii) hypoplastic FT, defined as an FT with a diameter of <2 mm; (iv) complete double (accessory) FT, defined as an FT divided into two foramina by a bony spicule—when the additional foramen is separate from the primary FT, it is referred to as an accessory FT; (v) incomplete double (accessory) FT, defined as an FT not completely divided into two foramina by a bony spicule; and (vi) multiple FT, defined as an FT divided into three or more foramina by bony spicules. An accessory foramen was considered and recorded if the distinct foramen had a diameter of >1 mm. After classification into these six categories, FTs were further categorised as unilateral or bilateral.

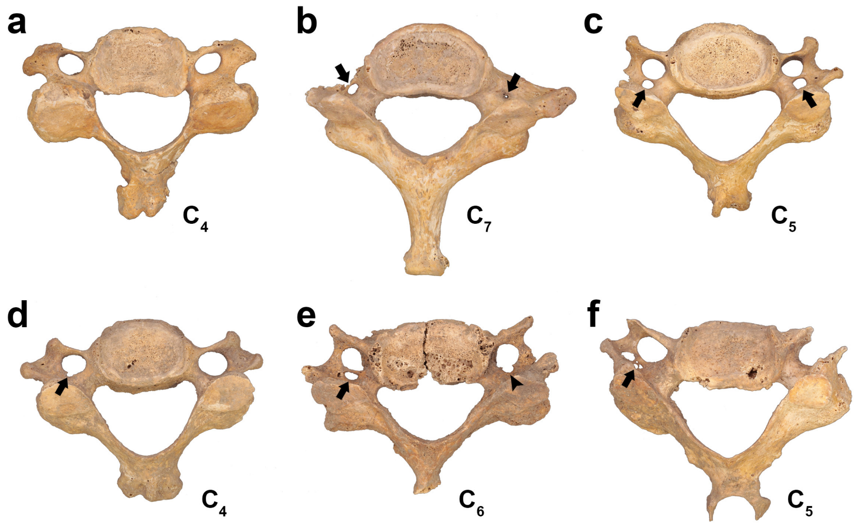

Figure 1. Normal anatomy and variations of the FT on the cervical vertebrae from the skeletal remains of the post-Classical cemetery of Corfinio. (**a**) Superior view of vertebra C_4. Bilateral normal FT belonging to individual Corf-038. (**b**) Superior view of vertebra C_7. Bilateral hypoplastic FT (arrows) belonging to individual Corf-021. (**c**) Superior view of vertebra C_5. Bilateral complete double FT belonging to individual Corf-014. (**d**) Superior view of vertebra C_4. Incomplete double FT on the left side (arrow) belonging to individual Corf-013. (**e**) Superior view of vertebra C_6. Incomplete double FT on the right side (arrowhead) and complete double FT on the left side (arrow) belonging to individual Corf-079. (**f**) Superior view of vertebra C_5. Multiple FT on the left side (arrow) belonging to individual Corf-018.

The PP, PL, and RTF were recorded only for vertebra C_1. These osseous variants were classified into three categories (Figure 2) [22,26]: (i) absence of PP, PL, or RTF, defined as the lack of a bony bridge; (ii) complete PP, PL, or RTF, defined as the presence of a bony bridge forming a complete bony ring; and (iii) incomplete PP, PL, or RTF, defined as the presence of a bony bridge with some portions of the ring missing or defective. After classification into these categories, each variant was further categorised as unilateral or bilateral.

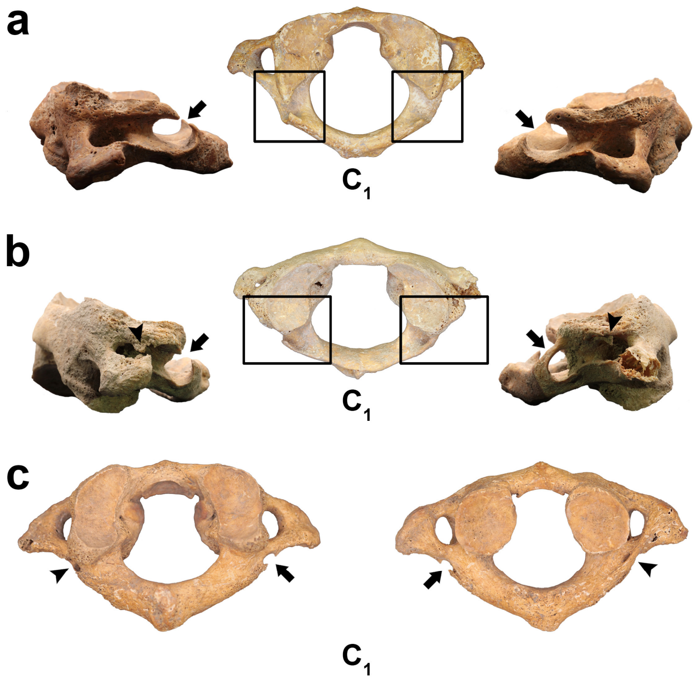

Figure 2. Osseous variations—PP, PL, and RTF—on the first cervical vertebra from the skeletal remains of the post-Classical cemetery of Corfinio. (**a**) Superior and lateral views of vertebra C_1. Bilateral incomplete PP (arrows) belonging to individual Corf-062. (**b**) Superior and lateral views of vertebra C_1. Incomplete PP (arrow) and complete PL (arrowhead; note: the thin bony bridge was broken during manipulation photography) on the left side, and complete PP and incomplete PL on the right side (arrowheads), belonging to individual Corf-024. (**c**) Superior (**right**) and inferior (**left**) views of vertebra C_1. Incomplete RTF on the right side (arrow) and complete RTF on the left side (arrowhead), belonging to individual Corf-081.

2.3.2. Metric Data Collection

For the metric analysis of the FT, digital callipers with a precision of 0.01 mm (Masel Orthodontics Inc., Carlsbad, CA, USA) were used to measure the anteroposterior and mediolateral diameters on both sides. In vertebrae showing a complete accessory FT, only the primary FT was measured (the accessory FT was excluded from the analysis). According to Cagnie et al. [41], both anteroposterior and mediolateral diameters were measured on the inferior surface of each vertebra. Differences in size greater than 2 mm between the right and left FT within the same vertebra—either in the anteroposterior or mediolateral diameter—were classified as major asymmetry. To describe the characteristics of FT geometry, the coefficient of roundness was calculated according to Equation (1):

$$R = \frac{Mediolateral\ diameter}{Anteroposterior\ diameter} \quad (1)$$

According to Taitz et al. [20], the coefficient of roundness was classified as brachymorph (R > 85), mesomorph (R from 75 to 85), or dolichomorph (R < 75).

2.3.3. Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics software, version 25 [42]. Descriptive analysis of the final study sample is reported as percentages for categorical variables and as means and standard deviations for continuous variables. Because vertebral sample sizes were expected to be small, possible associations between categorical variables were explored using Fisher's exact test. The non-parametric Mann–Whitney *U*-test was used to identify significant differences in FT diameters according to sex and laterality at each cervical level. Differences between the means of the primary FT in vertebrae with normal anatomy and the primary foramen in vertebrae with complete double FT were also analysed using the Mann–Whitney *U*-test. The significance level for all statistical tests was set at $p \leq 0.05$.

3. Results

After evaluating the various limiting factors for the 34 individuals in the original sample (136 vertebrae), 27 adult individuals remained with the preservation of at least one cervical vertebra. The study was conducted on this final sample of 27 individuals (13 males, 11 females, 3 of unknown sex; age range: 21–69 years), with a total of 108 cervical vertebrae examined. Table 1 shows the demographic distribution of the original sample of cervical vertebrae according to sex and age group.

Table 1. Distribution of the original sample of cervical vertebrae according to sex and age group.

	Males			Females			Unknown Sex			
Cervical Level	**YA**	**MAA**	**SA**	**YA**	**MAA**	**SA**	**YA**	**MAA**	**SA**	**Total**
C_1	3	6	0	1	6	1	0	0	0	17
C_2	4	5	0	2	7	1	0	1	0	20
C_3	3	5	0	1	7	2	0	0	0	18
C_4	3	5	0	1	7	2	0	1	0	19
C_5	4	5	0	1	7	2	0	1	0	20
C_6	4	5	0	1	7	2	0	1	0	20
C_7	4	7	0	1	5	2	2	1	0	22
Total	25	38	0	8	46	12	2	5	0	136

YA, young adult (21–40 years); MAA, middle-aged adult (41–60 years); SE, senile adult (>60 years) (modified from Vallois [30]).

3.1. Osseus Variations of FT

3.1.1. Variations in Number

Table 2 shows the prevalence of osseous variations in the numbers of FTs. Of the 108 vertebrae examined, variations were observed in 32, representing a prevalence of 29.6%. Among these, hypoplastic FT was identified in two vertebrae (1.9%), both on the left side. Complete double FT was observed in nine vertebrae (8.3%) and incomplete double FT in 18 vertebrae (16.7%). A combination of complete and incomplete FT within the same vertebra was found in two cases (1.9%). Only one vertebra displayed multiple FT (0.9%), located on the left side, and no vertebrae exhibited complete absence of FT (i.e., failed development).

The results indicate that unilateral accessory FTs were more common than bilateral ones. Among cases of the complete double FTs, seven were unilateral and two were bilateral, showing a significant difference in prevalence (Fisher's exact test = 2.778, $p = 0.028$). For incomplete double FTs, 16 were unilateral and two were bilateral, also showing a significant difference (Fisher's exact test = 18.000, $p = 0.007$). Osseous variations of the FT—including hypoplastic, complete double, incomplete double, and multiple FTs—were present in all cervical vertebrae except C_2, with 26 unilateral and four bilateral variants, reflecting a statistically significant difference in prevalence (Fisher's exact test = 18.641, p = 0.000). Of the 26 unilateral variations, 11 were on the right and 15 on the left, although this difference in laterality was not statistically significant (Fisher's exact test = 2.248, p = 0.619).

Table 2. Prevalence of osseous variants of the FT in the cervical vertebrae.

Cervical Level	Excluded Vertebrae due to Limiting Factors	Normal Verte-brae [n (%)]	Osseous Variants of the Foramen Transversarium [n (%)]											Total [n (%)]
			Absence		Hypoplastic		Complete Double		Incomplete Double		Multiple		Complete + Incomplete Double	
			UL	BL	UL	BL	UL	BL	UL	BL	UL	BL		
C_1	3	9 (8.33)	0 (0)	0 (0)	1 (0.93)	0 (0)	3 (2.78)	0 (0)	1 (0.93)	0 (0)	0 (0)	0 (0)	0 (0)	14 (12.97)
C_2	4	16 (14.81)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	16 (14.81)
C_3	2	15 (13.89)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.93)	0 (0)	0 (0)	0 (0)	0 (0)	16 (14.81)
C_4	3	14 (12.96)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.93)	1 (0.93)	0 (0)	0 (0)	0 (0)	16 (14.81)
C_5	4	8 (7.41)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1.85)	5 (4.63)	0 (0)	1 (0.93)	0 (0)	0 (0)	16 (14.81)
C_6	7	3 (2.78)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2.78)	0 (0)	6 (5.56)	0 (0)	0 (0)	0 (0)	1 (0.93)	13 (12.04)
C_7	5	11 (10.19)	0 (0)	0 (0)	1 (0.93)	0 (0)	1 (0.93)	0 (0)	2 (1.85)	1 (0.93)	0 (0)	0 (0)	1 (0.93)	17 (15.75)
Total	28	76 (70.37)	0 (0)	0 (0)	2 (1.85)	0 (0)	7 (6.48)	2 (1.85)	16 (14.81)	2 (1.85)	1 (0.93)	0 (0)	2 (1.85)	108 (100)

n, number of vertebrae; UL, unilateral; BL, bilateral.

Osseous variations in the number of FTs were most frequent in the C_6 vertebra (76.9%), followed by C_5 (50.0%), C_1 (35.7%), and C_7 (35.3%). Variations were less common in C_4 (12.5%), and C_3 (6.3%), while C_2 showed no osseous variation. For the C_1, C_3, C_4, and C_7 vertebrae, normal FT numbers were more prevalent than variations, with statistically significant differences for C_3 and C_4 (C_1, Fisher's exact test = 1.143, p = 0.424; C_3, Fisher's exact test = 12.250, p = 0.001; C_4, Fisher's exact test = 9.000, p = 0.004; C_7, Fisher's exact test = 1.471, p = 0.332). In C_5, the number of normal FTs equalled the number of variations (Fisher's exact test = 0.000, p = 1.000), while in C_6, variations were more prevalent than normal FT, although the difference was not statistically significant (Fisher's exact test = 3.769, p = 0.092).

Of the 32 osseous variations in the FT, 13 were observed in male vertebrae, 16 in female vertebrae, and three in vertebrae of unknown sex; however, the difference in prevalence between males and females was not statistically significant (Fisher's exact test = 0.826, p = 0.388).

3.1.2. Variations in Size

Normal FT

Table 3 presents the measurements of the anteroposterior and mediolateral diameters of normal FT across all cervical vertebrae, categorised by sex and laterality. The anteroposterior diameter ranged from a mean of 3.25 to 7.55 mm, while the mediolateral diameter ranged from a mean of 3.95 to 7.05 mm. For pooled sexes and sides, the largest anteroposterior mean diameter was observed in C_1 and the largest mediolateral mean diameter in C_4. The smallest mean diameters for both anteroposterior and mediolateral measurements were found in C_7.

Thus, across all cervical levels, males generally exhibited larger anteroposterior and mediolateral mean FT diameters than females on both sides, except in 10 instances where females showed larger values: mediolateral diameter on both sides in C_1; anteroposterior and mediolateral diameters on the right side in C_2, C_3, and C_5; anteroposterior diameter on the right side in C_4; and anteroposterior diameter on the right side and mediolateral diameter on both sides in C_7. With regard to laterality, the anteroposterior and mediolateral mean diameters were typically larger on the left side for all cervical levels, except in 11 cases where the right side showed larger values: anteroposterior diameter for males and mediolateral diameter for females in C_1; both diameters for females in C_2, C_3, C_5, and C_7; and anteroposterior diameter for females in C_4. However, comparisons using the non-parametric Mann–Whitney *U*-test revealed no statistically significant differences for sex or laterality at any cervical level ($p > 0.05$).

Table 3. Descriptive statistics and comparison of differences in anteroposterior and mediolateral diameters, as well as the coefficient of roundness, in normal FT across all cervical vertebrae, presented according to sex and laterality.

Cervical Level	Diameter	Males				Females				Comparison of Differences			
		Right		Left		Right		Left		By Sex		By Laterality	
		n	Measure	*n*	Measure	*n*	Measure	*n*	Measure	*U*	*p*	*U*	*p*
C_1	A–P	5	7.55 ± 1.09	6	7.17 ± 1.07	5	6.56 ± 0.96	3	6.63 ± 0.21	33.00	0.364	34.00	0.369
	M–L	5	6.14 ± 1.48	6	6.48 ± 0.90	5	6.44 ± 1.09	3	6.03 ± 0.54	39.00	0.680	43.00	0.870
	R	5	80.27 ± 9.92	6	91.01 ± 12.12	5	98.91 ± 14.19	3	90.92 ± 7.77	23.00	0.083	41.00	0.744
C_2	A–P	7	5.18 ± 0.81	6	6.02 ± 1.04	8	6.63 ± 1.27	7	5.68 ± 0.71	63.00	0.112	108.50	0.884
	M–L	7	5.85 ± 1.30	6	6.38 ± 0.91	8	6.39 ± 0.83	7	6.07 ± 2.04	88.00	0.662	107.50	0.852
	R	7	112.94 ± 21.63	6	106.88 ± 12.03	8	98.42 ± 16.52	7	106.91 ± 33.96	82.00	0.475	92.00	0.406
C_3	A–P	7	4.98 ± 0.87	5	5.63 ± 0.54	4	5.36 ± 0.81	6	4.92 ± 0.54	54.00	0.692	53.00	0.622
	M–L	7	6.18 ± 0.91	5	6.92 ± 0.75	4	6.71 ± 0.56	5	6.60 ± 0.36	47.50	0.644	37.50	0.218
	R	7	124.82 ± 8.92	5	123.01 ± 6.72	4	126.77 ± 16.59	5	139.21 ± 16.92	35.00	0.177	46.00	0.526
C_4	A–P	5	4.96 ± 0.78	6	5.78 ± 1.04	8	5.54 ± 0.77	5	5.35 ± 1.07	70.00	0.931	66.00	0.514
	M–L	5	6.49 ± 1.03	6	7.05 ± 1.11	7	6.46 ± 0.71	5	6.55 ± 0.63	52.00	0.389	56.00	0.356
	R	5	131.30 ± 13.56	6	122.72 ± 12.20	7	120.42 ± 19.36	5	127.16 ± 34.91	57.00	0.580	55.00	0.326
C_5	A–P	4	5.26 ± 0.85	4	6.14 ± 0.75	1	5.65	2	5.27 ± 0.46	8.00	0.414	9.00	0.273
	M–L	5	6.23 ± 1.07	4	6.97 ± 0.57	1	6.55	2	5.50 ± 1.22	8.00	0.309	16.00	0.749
	R	4	114.00 ± 13.63	4	114.34 ± 11.08	1	115.93	2	105.88 ± 32.34	11.00	0.838	13.00	0.715
C_6	A–P	3	5.80 ± 1.69	2	6.10 ± 1.50	0	—	2	5.76 ± 1.32	4.00	0.699	7.00	0.773
	M–L	3	6.06 ± 0.99	2	6.76 ± 1.85	1	4.35	2	6.10 ± 0.82	5.00	0.456	8.00	0.624
	R	3	106.60 ± 12.74	2	110.42 ± 3.23	0	—	2	107.07 ± 10.21	5.00	1.000	6.00	0.564
C_7	A–P	3	3.25 ± 0.27	6	3.73 ± 0.93	4	3.94 ± 0.79	3	3.59 ± 1.05	24.00	0.427	34.00	0.922
	M–L	3	3.95 ± 0.64	6	4.51 ± 1.02	4	4.80 ± 1.03	3	4.61 ± 1.41	23.00	0.368	31.00	0.696
	R	3	122.32 ± 22.88	6	123.01 ± 20.16	4	122.29 ± 15.74	3	128.48 ± 18.53	29.00	0.791	26.00	0.380

Data are means ± standard deviation (where relevant). Measurements are in mm. *n*, number of foramina transversaria; —, data not available. A–P, anteroposterior diameter; M–L, mediolateral diameter; R, coefficient of roundness; *U*, Mann–Whitney *U*-test; *p*, *p*-value.

A size difference of >2 mm between the right and left FT in the same vertebra—whether in anteroposterior or mediolateral diameter—was observed in five vertebrae from four of the 27 individuals (14.8%). In three cases, the affected vertebra was C_2 (one case involving the anteroposterior diameter and two involving the mediolateral diameter); in one case, it was C_6 (mediolateral diameter), and in one case C_7 (mediolateral diameter). The asymmetry measured 2.23 mm for the anteroposterior diameter and ranged from 2.10 to 3.51 mm for the mediolateral diameter. In four vertebrae (two C_2, one C_6, and one C_7 from the same individual), the right FT was larger than the left, while in one C_2 vertebra, the left FT was larger than the right.

Finally, moving cranio-caudally along the cervical spine (Figure 3), a differential trend in the anteroposterior and mediolateral diameters was observed. Overall, with both sexes and sides pooled, anteroposterior diameters decreased from C_1 to C_3, increased slightly from C_3 to C_6, and then decreased markedly at C_7. By contrast, mediolateral diameters increased slightly from C_1 to C_4, decreased slightly from C_4 to C_6, and further decreased at C_7.

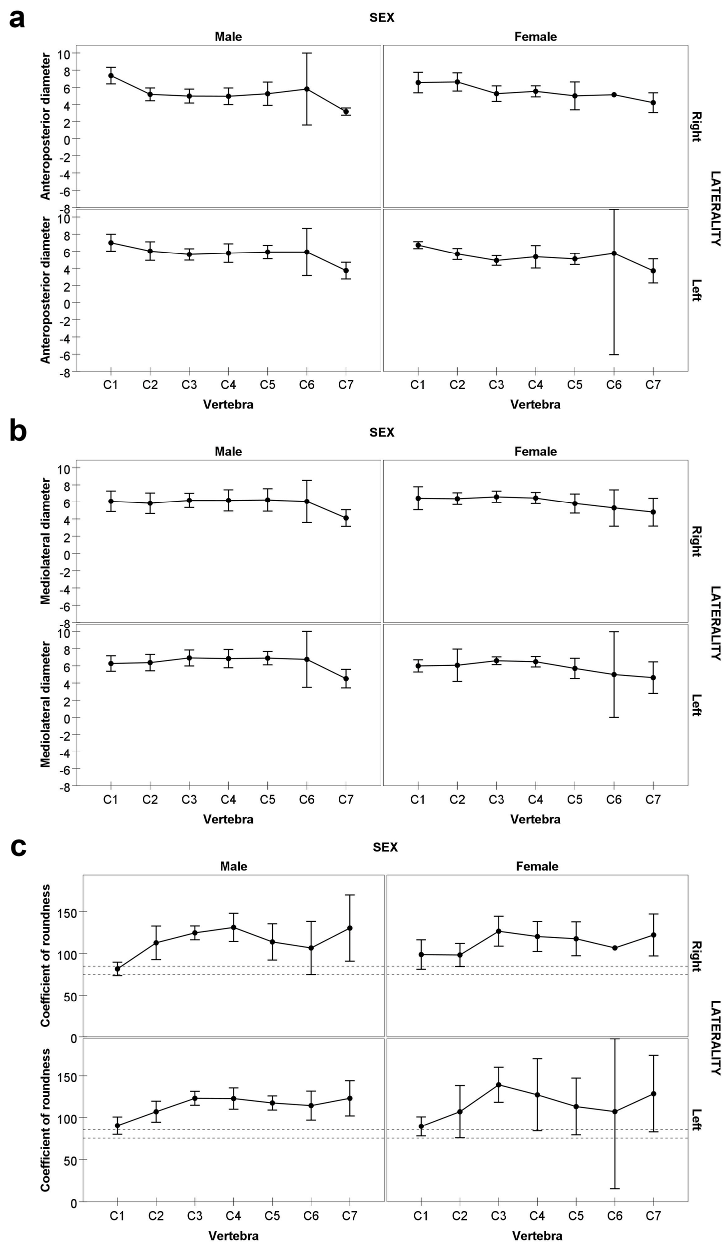

Figure 3. Mean (**a**) anteroposterior and (**b**) mediolateral diameters and the (**c**) coefficient of roundness of the normal FT at each vertebral level, divided by sex and laterality. Data are presented as means with 95% confidence intervals. In (**c**), dashed lines indicate the boundaries between mesomorph and brachymorph FT (upper dashed line; R = 85) and between mesomorph and dolichomorph FT (lower dashed line; R = 75).

3.1.3. Variations in Shape

Normal FT

Table 3 and Figure 3 present the descriptive statistics and the distribution of the mean coefficient of roundness, respectively, according to sex and laterality for the normal FT of the vertebrae. All FTs, for both sexes and sides, were classified as brachymorph, with the exception of C_1 (on the right side in males). Across cervical levels, no significant differences were observed with respect to sex or laterality ($p > 0.05$).

Finally, moving cranio-caudally along the cervical spine, a trend in the coefficient of roundness was also noted (Figure 3). When pooling both sexes and sides, the coefficient of roundness increased markedly from C_1 to C_3, decreased slightly from C_3

to C_6, and then increased significantly at C_7, with all vertebrae remaining within the brachymorph classification.

3.2. Osseous Variations of Vertebra C_1

Of the 17 specimens examined, 15 presented at least one anomaly—PP, PL, or RTF— representing a prevalence of 88.2%.

3.2.1. Ponticulus Posticus (PP)

Of the 17 specimens examined, nine (52.9%) exhibited PP. Among these, four (23.5%) were incomplete, three (17.6%) were complete, and two (11.8%) displayed both complete and incomplete PP within the same vertebra (Table 4). Unilateral PP (observed in five vertebrae) was more common than bilateral PP (two vertebrae), though the difference was not statistically significant (Fisher's exact test = 5.053, $p = 0.095$). Of the nine PP observed, six were found in male vertebrae and three in female vertebrae; however, this difference in prevalence between sexes was also not considered statistically significant (Fisher's exact test = 2.019, $p = 0.456$).

Table 4. Prevalence of PP, PL, and RTF in vertebra C_1.

Osseous Variant	Normal Vertebra C_1 [n (%)]	Presence of Osseous Variants in Vertebra C_1 [n (%)]					
		Complete		Incomplete			
		Unilateral	Bilateral	Unilateral	Bilateral	Complete + Incomplete	Total
Ponticulus posticus	8 (47.06)	3 (17.65)	0 (0)	2 (11.76)	2 (11.76)	2 (11.76)	17 (100.0)
Ponticulus lateralis	16 (94.12)	0 (0)	0 (0)	0 (0)	0 (0)	1 (5.88)	17 (100.0)
Retrotransverse foramen	6 (35.29)	0 (0)	1 (5.88)	7 (41.18)	2 (11.76)	1 (5.88)	17 (100.0)

n, number of vertebrae.

3.2.2. Ponticulus Lateralis (PL)

As shown in Table 4, only one of the 17 specimens examined (5.9%) exhibited PL, presenting a combination of complete and incomplete PL within the same C_1 vertebra. This specimen belonged to a female individual, and the difference in the prevalence of this osseous variation between sexes was not statistically significant (Fisher's exact test = 2.577, $p = 0.471$).

3.2.3. Retrotransverse Foramen (RTF)

Of the 17 specimens examined, 11 (64.7%) presented RTF. Among these, nine (52.9%) were incomplete and one (5.9%) was complete. A combination of complete and incomplete RTF within the same vertebra was observed in one C_1 specimen (5.9%) (Table 4). The results indicated that unilateral RTF (eight vertebrae) was more common than bilateral RTF (three vertebrae), with a statistically significant difference (Fisher's exact test = 9.310, $p = 0.012$). Of the 10 RTF cases included in the sex-based analysis (one C_1 was excluded due to unknown sex), five were observed in male vertebrae and five in female vertebrae. This difference was not statistically significant (Fisher's exact test = 1.053, $p = 0.762$).

Overall, 5 of the 17 analysed C_1 vertebrae (29.4%) exhibited two or more simultaneous osseous variants (PP, PL, and/or RTF). Specifically, one individual displayed the presence of all three variants (PP + PL + RTF), while four individuals presented a combination of PP and RTF. No cases were found with only PL + RTF or PP + PL without the third variant.

4. Discussion

4.1. Osseous Variations of FT

4.1.1. Variations in Number

In the study sample from Corfinio, the most notable findings include hypoplastic FT in two vertebrae (C_1 and C_7; 1.9%), multiple FT in one vertebra (C_5; 0.9%), and duplication of the FT in 29 vertebrae (26.8%), observed across all cervical levels except C_2. No vertebrae showed failed development of the FT (i.e., complete absence).

According to the current literature, hypoplastic FT (i.e., <2 mm in diameter) is particularly rare, with reported prevalence ranging from 0.1% to 4.5% in studies based on dry cervical vertebrae (see Supplementary Table S1; [18,20,21,25,43–81]). The results from the Corfinio sample are consistent with these. Abd El Gawad et al. [82] note that the FT diameter serves as a reliable indicator of VA size and that a small FT may suggest VA hypoplasia. The diameter of the FT holds clinical relevance in the cervical spine because individuals with VA hypoplasia may face a heightened risk of posterior circulation stroke [83]. However, in the Corfinio sample, it is unclear whether the VA was hypoplastic or followed an alternative pathway, as suggested in studies by Ikegami et al. [84] and Shoja et al. [85]. Multiple FT is even rarer [20,21,59,65,72,79,80], with the literature reporting a prevalence of 0.1% to 1.0%. The result for the Corfinio sample aligns with previous findings, falling at the upper limit of this range. According to Roh et al. [86], the presence of additional foramina in the transverse processes may suggest a multiplication of vascular structures passing through them, although the clinical significance of this remains uncertain.

The double (accessory) FT is the most widely reported osseous variant of the FT in previous studies. The prevalence observed in the Corfinio sample (26.8%) is consistent with earlier research on the cervical spine, where reported rates range from 1.4% [59] to 47.6% [72] (see Supplementary Table S1). However, variations in reported prevalence may stem from differences in methodology used to examine and analyse this osseous variant, as well as from the diverse origins of the studied samples. For instance, several studies were based on specific cervical segments [66], only analysing the C_3–C_6 segment [63], the C_3–C_7 segment, or the entire cervical spine [69,70,72], rather than analysing each cervical vertebra individually. Some also reported data based on the total number of FT rather than the number of vertebrae examined per cervical level [79,80]. The data from the Corfinio sample align with previous studies that identified a higher prevalence of double FT in the C_6 vertebra, followed by C_5, C_4, and C_7, with lower prevalence in C_3 and C_2 [18,20,49,56,62,64,74,75,77,81]. However, unlike these prior findings, the Corfinio sample showed a notably high prevalence of double FT in C_1 (28.6%), contrary to earlier reports that documented lower prevalences for this particular vertebra [18,20,49,56,62,64,74,75,77,81].

Because of the limited availability reported data, few studies have examined the distribution of FT number variations by sex and laterality. Regarding sex distribution, several studies—including those by Viciano et al. [18], Zibis et al. [21], and Quiles-Guiñau et al. [87]—found no significant differences between males and females, and the prevalence data from the Corfinio sample are consistent with these findings. By contrast, when examining the distribution by laterality, unilateral FT variants were more common than bilateral variants in the Corfinio sample. Furthermore, among the unilateral variants, the prevalence was higher on the left side than the right, although this difference was not statistically significant. While most studies have focused on unilateralism versus bilateral occurrence, relatively few have addressed side-specific laterality [21,25,45,51,53,54,56,57,59,60,65–67,72,75,77,81]. The findings from Corfinio align with most of these earlier studies, though they differ from several others—such as those by Yadav et al. [45], Patra et al. [63], Aydınlıoğlu et al. [76], Sharma et al. [68], and Mishra et al. [58]—in which unilateral variants were less prevalent than bilateral ones. However, these latter studies did not specify whether the observed differences were statistically significant. Notably, statistical analyses by Viciano et al. [18] and Quiles-Guiñau et al. [81,87] did indicate a predominance of unilateral over bilateral variants, although in contrast to the Corfinio sample, those studies found a higher prevalence on the right side, with only the findings of Viciano et al. [18] reaching a statistical significance.

4.1.2. Variations in Size

Normal FT

In the Corfinio study sample, the size of the normal FT showed that across all cervical levels, both anteroposterior and mediolateral mean diameters were larger in males than in females and were also larger on the left side than on the right, although these differences were not statistically significant. These findings align with those of previous studies examining differences by sex [18,81,88,89] and laterality [18,89–91]. Various studies suggest that FT size correlates with blood flow, the side of the dominant VA, and the point at which the VA enters the vertebra [20,92,93]. The two VAs are typically unequal in size, with the left VA generally being larger, under higher pressure, and responsible for carrying more blood than the right, thus making the left VA dominant [94]. The size difference between VAs according to laterality is thought to be reflected in FT size, which tends to be larger on the dominant side [95]. One hypothesis proposed to explain such asymmetry is based on the brain's vascular demands for glucose and oxygen, suggesting, for instance, that right-handed individuals may have a dominant left VA to support increased vascular requirements of the left hemisphere. To test this, several researchers [96,97] investigated whether right-handed individuals tend to have a dominant left VA and left-handed individuals a dominant right VA. Their findings revealed no correlation between VA diameter and handedness, leading to the conclusion that this hypothesis cannot be confirmed.

On the other hand, size differences of >2 mm between the left and right FT (i.e., major asymmetry) may reflect variations in the size or pathway of the VA [98]. Variations in the normal anatomy of the extracranial VA are relatively common, ranging from general asymmetry between the two VAs to significant hypoplasia of one VA [99]. In terms of VA pathway, the C_6 vertebra is the most frequent entry point, with the VA typically bypassing the FT of C_7 (in >90% of cases [100–102]); in rare instances, however, the VA follows an extra-transverse course through the neck, entering at almost any cervical level [100,103]. In the Corfinio study sample, major asymmetries were observed in two of the 108 vertebrae (1.9%): one at C_1 and one at C_7. The asymmetry at C_7 may suggest a variation in VA entry level, most likely entering directly at C_6. More concerning is the hypoplastic FT observed in the C_1 vertebra. The presence of a hypoplastic VA before entering through the foramen magnum is associated with an elevated risk of ischaemic stroke and neurological complications due to reduced blood flow to structures in the posterior cranial fossa [83,104].

Along the cervical spine, the cross-sectional area of the FT generally decreased from C_1 to C_3, increased slightly from C_3 to C_6, and then decreased markedly at C_7. Similar trends have been reported by other researchers (e.g., [18,41,79]). According to Cavdar et al. [105], the size of the VA—and thus the FT— decreases from C_6 to C_3 and then increases toward C_1, where cervical spine extension and rotation, associated with head movement, may lead to mechanical compression of the blood vessels in the neck, potentially resulting in VBI [106,107]. Cavdar et al. [105] propose that the physiological variability in VA size from C_6 to C_3 may function as a regulatory mechanism for arterial blood pressure, allowing the VA to dilate when necessary to control the pressure reaching the brain. Additionally, vasoconstriction of the VA at the lower cervical levels (below C_3) may be a response to the challenge of blood flow against gravity. In this context, vasoconstriction could serve to increase pressure, ensuring that sufficient blood reaches higher cervical and cranial levels.

Thus, the variability in VA size may play a key role in modulating cerebral blood pressure structurally adapting—via dilation or narrowing—to the circulatory demands of the brain.

Complete Double FT

Across all cervical levels with complete double FT, the Corfinio study sample showed that the accessory FT was consistently smaller than the primary FT, in agreement with previous studies [18,81,87]. Given that FT size may influence the calibre and blood flow of the VAs [105], it is important to consider whether vertebrae with complete double FT also exhibit a reduction in the size of the primary FT when compared with vertebrae of normal anatomy. This is particularly relevant because the presence of an accessory FT could potentially affect the dimensions of the primary FT. In the Corfinio sample, complete double FT was associated with a smaller primary FT compared to normal vertebrae, with statistically significant differences observed only in the anteroposterior diameter of C_5. These findings are consistent with previous research [18,81,87], which also suggests that this correlation may be relevant to compressive pathology of the VA, particularly at the C_4 to C_6 levels.

According to the existing literature, the FT may be divided by a bony or fibrous bridge, suggesting that the function of a double FT could relate to the compartmentalisation of its contents. However, there is no consensus on whether the accessory FT contains veins, branches of the VAs, or a branch of the inferior cervical ganglion [59,67,108]. Some researchers propose that a double FT may be associated with duplication or fenestration of the VA [109,110]. In cases of duplication, this condition could offer a protective effect against ischaemic attacks, as the duplicated vessel may help maintain adequate blood flow to the BA. By contrast, fenestration may increase the risk of aneurysm and thrombus formation, potentially leading to severe ischaemic events [111,112], although some authors argue that VA fenestration has no significant pathological consequences [113].

4.1.3. Variations in Shape

Normal FT

In the Corfinio study sample, the FTs of all vertebrae were classified as brachymorph (i.e., with predominance of mediolateral over anteroposterior diameter), except for the FT of C_1 on the right side in male individuals. These findings are consistent with those reported by Kwiatkowska et al. [79] but contrast with the results reported by Viciano et al. [18], Taitz et al. [20], and Kimura et al. [47], who observed that FTs from C_1 to C_4 were mesomorph, C_5 and C_6 brachymorph, and C_7 dolichomorph.

The category of the coefficient of roundness of the FT is related to the passage of the VA at each level of the cervical spine. The anatomy of the VA in the craniovertebral region (i.e., at the C_1–C_2 level) exhibits greater variability than the lower cervical spine (i.e., C_3–C_6), where the VA follows a more straightforward course [114]. Consequently, a higher frequency of a specific roundness category may be associated with mechanical tension and stress imposed on a vertebra due to head movements. Movements such as flexion, extension, and rotation place pressure on the blood vessels and can compress the contralateral VA relative to the direction of rotation, potentially affecting blood flow at the C_1–C_2 level [114]. According to Taitz et al. [20], rotational head movements can alter the length of the VA on the contralateral side by up to 10%. Therefore, excessive or repeated head movements may influence the morphology of the FT at the atlantoaxial junction by affecting the dynamics of the blood vessel passage.

4.2. Osseous Variations of Vertebra C_1

4.2.1. Ponticulus Posticus (PP) and Ponticulus Lateralis (PL)

In the Corfinio study sample, the overall prevalence of PP was 52.9%, higher than that reported in most studies (see Supplementary Table S2; [16,22,24,26,40,44,78,80,82,88,115–152]), which typically range from 5% to 30% in the general population. However, several studies have reported prevalences above 50% [26,82,118,134], consistent with the present findings. As for PL, the Corfinio sample showed an overall prevalence of 5.9%, aligning with the majority of earlier studies (see Supplementary Table S2), which report rates between 1.2% and 10.9%; an exception is Karau et al. [134], who observed a considerably higher prevalence of 21.1%. The small sample size from Corfinio, as well as the geographically and ethnically diverse samples used in previous studies, may help explain these wide variations in reported prevalence. The aetiology of bony bridges (PP and PL) in C_1 remains debated. The earlier literature considered these variants congenital [153,154], while more recent studies have proposed a genetic basis [155,156], pointing to a possible heritable component, although no specific genes have been identified. It is therefore likely that both genetic predisposition and environmental factors contribute to their development.

Several authors have argued that bony bridges of the C_1 vertebra, including the PP and PL, may have a genetic or hereditary basis when analysing human skeletal remains in both archaeological [157–159] and forensic [160] contexts. In particular, some studies have proposed that these osseous variants may reflect inherited skeletal traits that tend to cluster within families or small, genetically homogeneous populations [110,111]. Such patterns could be more pronounced in isolated rural communities where consanguinity and endogamy were more common, especially during the medieval period. The high prevalence of PP in the Corfinio study sample may therefore suggest an underlying influence of familial or population-level genetic factors. This hypothesis is supported by the findings of Sanchis-Gimeno et al. [142], who reported a significantly higher prevalence of PP in a 17th century rural population than in a modern urban sample, attributing the difference partly to reduced genetic diversity in earlier rural settings. Although direct genetic data are not yet available for the Corfinio sample, the prolonged use of the cemetery by a stable, localised population—evidenced by overlapping burials and long-term funerary activity—may support the likelihood of familial ties and limited gene flow, consistent with a genetic component in the high frequency of these osseous variants.

However, other authors suggest that the bony bridges of the C_1 vertebra may result from ossification associated with ageing [161] or from external mechanical factors [24,26,134], such as the repeated carrying of heavy loads on the head, neck, and shoulders, which may significantly contribute to their development. It has been proposed that PP and PL serve a protective role for the VA at the craniocervical junction—an area particularly vulnerable to damage or compression during head and neck movements [162]. Supporting this perspective, Paraskevas et al. [24] reported a higher prevalence of bony bridges in C_1 among manual labourers (PP: 37.5%; PL: 50%) than among non-labourers (PP: 4.2%; PL: 18.8%), concluding that mechanical stress from physical labour contributes to their formation. The results from the Corfinio study sample show a minimal effect of sex on the prevalence of PP and PL; although bony bridges in C_1 were generally more common in males than females, the differences were not statistically significant. These findings support those of Paraskevas et al. [24], who also observed a higher prevalence in males. However, they contrast with the results of Taitz and Nathan [26] and Karau et al. [134], who associated a higher prevalence in females with cultural practices involving the carrying of heavy loads on the head, neck, and shoulders. It is important to consider that different populations may assign distinct sex-based roles, behaviours, or work activities, which could influence the occurrence of bony bridges and conditions such as VBI syndrome. Given that males in the Corfinio study sample may have been more frequently engaged in such physically demanding tasks, this could offer a plausible explanation for the observed differences.

4.2.2. Retrotransverse Foramen

In the Corfinio study sample, the overall prevalence of RTF was 64.7%, which is notably higher than in most previous studies (see Supplementary Table S2), where reported rates range from 5.6% to 26.2% in the general population. However, these findings are comparable to those of Veleanu et al. [136], who reported a prevalence of 67.6%. As with other variants, the small sample size from Corfinio, along with the diverse geographical and ethnic backgrounds of populations studied in previous research, may partly account for the broad variation in the reported prevalence of vertebrae affected by RTF.

According to Veleanu et al. [136], Bodon et al. [163], and Xing et al. [164], the RTF contains an anastomotic vein connecting the atlantooccipital and atlantoaxial venous sinuses within the posterior arch of C_1. It has been proposed that the presence of the RTF may be linked to evolutionary changes in regional venous circulation associated with the acquisition of upright posture and bipedal locomotion in humans [165,166]. These modifications are thought to be adaptations to hydrostatic pressure, as gravity causes blood from the cranium in upright humans to drain primarily through the vertebral venous plexus [121,122]. However, other studies have identified neural or arterial components within RTFs as well [123,167]. Paraskevas et al. [24] reported a high incidence of co-occurrence of PP and RTF, which could contribute to vertebral vein compression and potentially result in VBI. Notably, if the RTFs were solely a response to bipedalism and vascular adaptation, one might expect a higher frequency of bilateral rather than unilateral RTFs. In the Corfinio study sample, however, unilateral RTFs were significantly more frequent than bilateral ones, suggesting that other factors—possibly developmental or mechanical—may influence this asymmetrical prevalence.

5. Concluding Remarks and Suggestions for Further Research

This study presents a detailed account of the prevalence of osseous variants in the cervical spine with potential pathological significance—specifically variations in the number, size, and shape of the FT, as well as the presence of bony bridges in the C_1 vertebra—based on an osteological analysis of remains from the post-Classical cemetery of Corfinio (12th–15th centuries CE, L'Aquila, Italy). While the findings largely align with existing literature, notable divergences were observed, particularly in relation to the C_1 vertebra. These observations can be summarised as follows:

1. The prevalence of osseous variations of the FT (hypoplastic + double FT) in C_1 is high (35.7%) compared with previous studies.
2. The coefficient of roundness for C_1, when pooling both sexes and sides, is classified as brachymorph (i.e., mediolateral diameter exceeding anteroposterior), contrasting with previous studies in which C_1 FT is typically classified as mesomorph.
3. The prevalence of bony bridges in C_1, particularly PP (52.9%) and RTF (64.7%), is markedly higher than in most published reports.
4. The distribution of FT variations in number, size, and shape, as well as the prevalence of bony bridges in C_1, appears relatively homogeneous between sexes, with no statistically significant sex-based differences.

The C_1 vertebra, the most superior vertebra of the spine, plays a vital role in supporting the cranium, spinal cord, and VAs, while also serving as an attachment point for several neck muscles. As noted above, deformations or disruptions to blood flow caused by osseous variations of C_1 may lead to VBI, which can manifest in a wide range of symptoms depending on the affected region, such as vertigo, dizziness or syncope, nausea and vomiting, 'drop attacks', headache, facial pain, altered consciousness, and contralateral motor weakness. The findings of this study support the conclusions of other authors who argue that osseous variations of the FT and the presence of bony bridges in C_1 may act as predisposing factors for VBI.

At the current stage of research, it has not been possible to determine the specific work activities performed during life by the individuals in the osteological sample from the post-Classical cemetery of Corfinio used in this study. However, we suggest that the practice of carrying heavy loads on the head, neck, and shoulders may partly account for the osseous variations observed in C_1. Furthermore, the relatively homogeneous distribution of these features between sexes indicates no significant differences in gender-related work roles within this skeletal sample. At the same time, we also consider it likely that genetic factors may have contributed to the development of these osseous variations.

It is important to note that the overall prevalence rates of PP, PL, and RTF reported in this study include both complete and incomplete forms, whereas many comparative studies in the literature focus primarily on complete variants. This methodological difference may partly account for the higher prevalence observed in the Corfinio study sample compared with certain other studies. Future research should aim for consistent categorisation of these osseous variants to enable more accurate cross-study comparisons. Nevertheless, our findings align with general trends in the literature and further support both the genetic and mechanical hypotheses regarding the formation of bony bridges in C_1.

The principal limitation of this study is the small sample size of examined vertebrae, particularly C_1. The limited availability of skeletal material from the archaeological context inherently restricts the generalisability of the findings and reduces the statistical power to detect significant differences. Nevertheless, the descriptive and comparative data offer valuable insights into cervical spine osseous variations—especially in C_1—and highlight patterns that merit further investigation in larger samples. While most results are consistent with the existing literature, notable exceptions were observed in the prevalence and morphological patterns of FT and bony bridges in C_1, which deserve closer examination. Given the exceptionally high prevalence of osseous variants in C_1, further research is needed to clarify the role of external mechanical and/or genetic factors in the variations observed in the Corfinio sample. To explore the influence of external mechanical stress, a detailed analysis of skeletal entheseal changes, particularly in the shoulder girdle and upper limbs, is essential. Additionally, to evaluate the potential genetic contribution and to confirm or exclude familial relationships among individuals, DNA analysis or, alternatively, the examination of non-metric cranial, postcranial, and/or dental traits is recommended.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/heritage8050178/s1. Table S1: Brief review of the literature on the prevalence of the anatomical variants of the foramen transversarium for contemporary and ancient populations (data from dry cervical vertebrae). Table S2: Brief review of the literature on the prevalence of the *ponticulus posticus*, *ponticulus lateralis*, and retrotransverse foramen (complete or incomplete) in vertebra C_1 for contemporary and ancient populations (data from dry cervical vertebrae).

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Abbreviations

The following abbreviations are used in this manuscript:

VA	Vertebral artery
SCA	Subclavian artery
BA	Basilar artery
VBI	Vertebrobasilar insufficiency
FT	Foramen transversarium
PP	Ponticulus posticus
PL	Ponticulus lateralis
RTF	Retrotransverse foramen
R	Coefficient of roundness

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