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Research article - Basic and applied anatomy

Double transverse foramen in cervical vertebrae in a Spanish rural population of the late 17th and 18th centuries

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Abstract

Double transverse foramen is an anatomical variant often observed in the inferior cervical rachis. It consists in the presence of the main transverse foramen and an accessory transverse foramen, which is smaller. Since the vertebral artery runs through the transverse foramen, this anatomical variant may suggest clinical considerations regarding the vertebral artery. In this context, our objective was to study the prevalence of double transverse foramen in a sample of 88 complete cervical sets of vertebrae dating from the late 17th and early 18th centuries and exhumed from a common grave in the "Nuestra Señora de los Ángeles" church, in Castielfabib (Ademuz, Valencia, Spain). We also wanted to analyze the possible correlation between the presence of double transverse foramen and the size of the main transverse foramen. The anteroposterior and lateral diameters of the transverse foramen and the accessory foramen were measured using digital calipers. Double transverse foramen was found in 96 (15.5%) cervical vertebrae, mostly in C6, but also in C4, C5 and C7. Our results show that double transverse foramen can cause the transverse foramen to be smaller when compared with normal vertebrae. Therefore, a thorough study should be performed to analyze the prevalence of double transverse foramen in the current population, as well as its clinical implications on the vertebral artery physiology.

Key words

Spine, vertebral artery, cervical vertebrae, anatomical variation, 17th century, Spain.

Introduction

The cervical spine presents anatomical features which readily distinguish the cervical vertebrae from those of the thoracic or lumbar regions. One of the distinctive peculiarities of the cervical vertebrae is the presence of a transverse foramen (TF) in the transverse process, which gives passage to the vertebral artery and veins, with the exception of the TF in C7 which the vertebral artery does not cross through (Fig. 1) (Jovanovic, 1990). Another particularity of the cervical spine is its unique kinematics, with the highest mobility in comparison with dorsal and lumbar segments. Taking both traits together, potential clinical relevance of the TF surfaces arises in cases of possible trauma or compression of the structures that pass through it, especially

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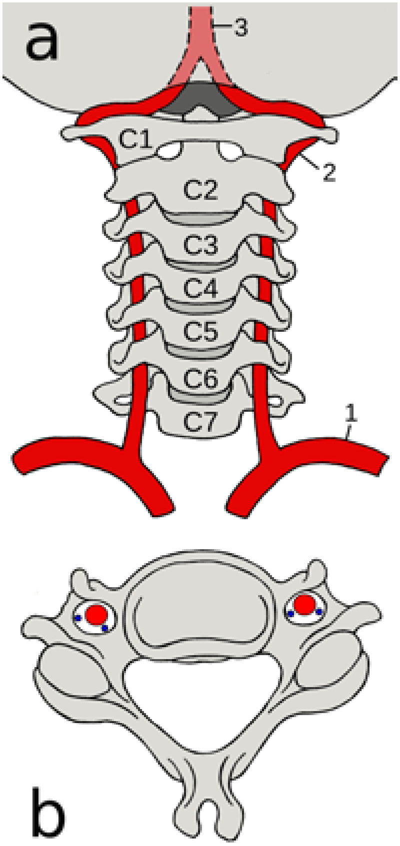

Figure 1 - Scheme of the vertebral arteries in the transverse foramen of cervical vertebrae. a: Anterior view of cervical spine and vertebral arteries. 1: Subclavian artery. 2: Vertebral artery. 3: Basilar artery. b: Upper view of a typical cervical vertebra with the vertebral artery and veins passing through the transverse foramen.

regarding the vertebral artery, depending on whether or not it affects normal blood flow (Taitz et al., 1978). Therefore, variations in shape, size and number of TF could be implicated in the etiology of some clinical syndromes and symptoms, such as headache, migraine, fainting, blackouts due to low blood pressure in the vertebral artery, and vertebrobasilar insufficiency after certain neck movements (Bulsara et al., 2006). One of this variations is the occurrence of double transverse foramen (DTF), which consists on the presence of an abnormal accessory transverse foramen (accessory TF) posterior and smaller to the transverse foramen (primary TF) (Fig. 2) (Kaya et al., 2011). Double TF has been described in the inferior segment of the cervical spine, either unilaterally or bilaterally, and located more often in C6 (Murlimanju et al., 2011; Chandravadiya et al., 2013).

Variations on the development and course of the vertebral artery may be involved in the embryogenesis of DTF (Das et al., 2005).

Furthermore, since the TF variants of the cervical spine can place the vertebral artery at risk during surgical procedures that involve the cervical spine, it is important to understand this anatomical variant in order to properly plan surgery of the cervical spine (Peng et al., 2009).

The aim of this study is to determine the prevalence of DTF in a sample of complete sets of cervical vertebrae from a Spanish rural population of the late 17th to the early 18th centuries, as well as to determine the possible correlation between the presence of DTF and the size of the primary TF in terms of anteroposterior and lateral diameters of primary TF of cervical vertebrae with DTF compared with the TF of normal cervical vertebrae.

Material and methods

This study was approved by the Ethics Committee in Human Research of the University of Valencia, and, the corresponding authorization was granted by the local authorities at “Consellería de Cultura de la Comunidad Valenciana”.

Figure 2 - Four cervical vertebrae. a: Upper view of a normal C3 cervical vertebra. b: Upper view of a C3 cervical vertebra with double transverse foramen in the right side. c: Upper view of a normal C6 cervical vertebra. d: Upper view of a C6 cervical vertebra with bilateral double transverse foramen. Arrow heads: accessory transverse foramen.

The cervical vertebrae analyzed in this work 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 osseous remains discovered within its walls and under its floors date from the late 17th to the early 18th centuries, as has been revealed by the historical context, as well as by of the objects found in the graves. Skeletal samples were labeled according to their stratigraphic unity status, and analyzed 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 (Asociación Española de Antropología y Odontología Forense) (Serrulla, 2013). Cervical samples were 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, consolidation procedures were not necessary. The anthropological identification was based on a morphological and morphometric analysis of the skeletons

(Reverte-Coma, 1991). Adult skeletons were separated from the child ones. Gender of adult skeletons was determined by bone length of femur, tibia, humerus, and by morphological traits of skull and pelvis (Reverte-Coma, 1991). Due to the lack of old registers on age at death from each individual, the age was estimated from cranial bone synostoses and pubic symphysis morphology (Reverte-Coma, 1991), thyroid cartilage ossification (Loth and Iscan, 1989) and ribs traits and sternal extremities (Burns, 2008). Adult individuals were classified by age in either 25-40 year-old or 41-65 year-old. Finally we selected from the adult skeletons with a clear age and gender classification those cervical sets that were complete, from C1 to C7 (Puchalt-Fortea and Villalaín-Blanco, 2000).

We looked for the presence of DTF in every cervical vertebra, and annotated if it was present bilaterally, only on the right side, or on the left side. With the purpose to compare our results with previous published studies, we considered that a DTF was present only if it was complete; partial forms were excluded from the analysis.

Anteroposterior and lateral diameters of normal TF were measured, as well as those of the primary TF and the accessory TF of the vertebrae with DTF. A digital caliper Powerfix 0-150 mm was used for the measurements in triplicates, and their average was used for further analysis.

The statistical analyses were performed using the SPSS 15.0 statistical software package (SPSS Inc., Chicago, IL, USA). Pearson's chi-squared test was used to compare the distributions of the frequencies. Student t test was used to estimate the differences of the means between two independent groups. Multivariate models for repeated measures were used to adjust for uncertain variables like age and sex. P value < 0.001 was recorded and considered significant. Categorical variables are shown as frequencies. Continuous variables are showed as average and standard deviation of the mean.

Results

A total of 331 specimens were identified as humans, 177 (53.4%) of them were adults. Since our analysis only focused on skeletons with a complete cervical spine (from C1 to C7 level), for which gender and age were able to be identified, we finally selected 88 adults: 36 men and 52 women. Most of the osseous specimens were from individuals who had died between 25-40 years of age (64.0%). The age of the women was slightly higher than that of the men (64% of men were between 25 and 40 years old and 36% were between 45 and 65 years old, while 58% of women were between 25 and 40 years old and 42% were between 45 and 65 years old), but this difference was not statistically significant.

Double TF was observed only in C4, C5, C6 and C7. After adjustment for uncertain variables like sex and age, only C7 showed a difference in DTF presence between men and women that was statistically significant ($p < 0.05$). The general prevalence of DTF considering all the cervical levels was 15.5%. The presence of DTF was most frequent in C6, followed by C5, C4 and C7 (Table 1).

There was greater prevalence of unilateral DTF than bilateral cases in C4, C5, C6 and C7, but this difference was only statistically significant in C7 ($p < 0.05$). In addition, there was a greater prevalence of DTF on the right side in comparison with the left side in C4, C6 and C7, but this difference was not statistically significant (Table 2).

Table 1 – Double transverse foramen frequency according to sex.

Cervical level	Double transverse foramen	Total (%)	Men (%)	Women (%)	p[1]
C1	Absent	88 (100.0%)	36 (100.0%)	52 (100.0%)	-
	Present	0 (0.0%)	0 (0.0%)	0 (0.0%)	
C2	Absent	88 (100.0%)	36 (100.0%)	52 (100.0%)	-
	Present	0 (0.0%)	0 (0.0%)	0 (0.0%)	
C3	Absent	88 (100.0%)	36 (100.0%)	52 (100.0%)	-
	Present	0 (0.0%)	0 (0.0%)	0 (0.0%)	
C4	Absent	77 (87.5%)	29 (80.6%)	48 (92.3%)	n.s.
	Present	11 (12.5%)	7 (19.4%)	4 (7.7%)	
C5	Absent	56 (63.6%)	21 (58.3%)	35 (67.3%)	n.s.
	Present	32 (36.4%)	15 (41.7%)	17 (32.7%)	
C6	Absent	44 (50.0 %)	17 (47.2%)	27 (51.9%)	n.s.
	Present	44 (50.0%)	19 (52.8%)	25 (48.1%)	
C7	Absent	79 (89.8%)	29 (80.6%)	50 (96.2%)	<0.05
	Present	9 (10.2%)	7 (19.4%)	2 (3.8%)	

[1] Pearson's Chi square-test; n.s. = not significant.

Table 2 – Side distribution of double transverse foramen.

Cervical level	Unilateral			Bilateral (%)	p[1]	p[2]
	Total (%)	Right (%)	Left (%)			
C4 (n=88)	6 (6.8%)	4 (4.5%)	2 (2.2%)	5 (5.6%)	n.s.	n.s.
C5 (n=88)	18 (20.4%)	9 (10.2%)	9 (10.2%)	14 (15.9%)	n.s.	n.s.
C6 (n=88)	23 (26.1%)	11 (12.5%)	12 (13.6%)	21 (23.8%)	n.s.	n.s.
C7 (n=88)	7 (7.9%)	2 (2.2%)	5 (5.6%)	2 (2.2%)	n.s.	n.s.

[1] Pearson's Chi square-test between right and left; [2] Pearson's Chi square-test between unilateral and bilateral occurrence; n.s. = not significant.

We observed sexual differences in primary TF measurements of the vertebrae with DTF (C4-C7). The lateral diameter and antero-posterior diameter were bigger in men than in women. This difference was statistically significant for the lateral diameter in C4-C7 (Table 3).

The antero-posterior diameter and lateral diameter the primary TF were bigger than the ones of the accessory TF in all the vertebrae with DTF. These differences were statistically significant at the four cervical levels where DTF was observed, except in the case of the lateral diameter and area of the primary TF of C7, in both men and women (Table 3).

Table 3 – Quantitative differences between the primary and the accessory transverse foramen in vertebrae with double transverse foramen, and between the primary transverse foramen of men and women.

Cervical Level			Men			Women			p^4
			Mean ± SD	Range	p^3	Mean ± SD	Range	p^3	
C4	ATF	Ø AP [1]	1.2 ± 0.5	1.1-2.5	<0.001	1.2 ± 0.3	1.0-2.2	<0.001	n.s.
	PTF		4.1 ± 1.5	3.5-6.5		3.8 ± 0.2	3.1-4.1		
	ATF	Ø lat [2]	2.3 ± 0.4	1.3-3.1	<0.001	1.8 ± 0.4	1.2-2.6	0.002	0.001
	PTF		5.3 ± 1.1	4.3-5.4		4.6 ± 1.4	3.3-4.7		
C5	ATF	Ø AP [1]	1.5 ± 0.4	0.8-2.1	<0.001	1.2 ± 0.8	0.7-1.9	<0.001	n.s.
	PTF		5.0 ± 1.2	1.2-6.1		4.7 ± 1.7	1.0-6.0		
	ATF	Ø lat [2]	2.1 ± 0.6	3.0-2.9	<0.001	1.9 ± 0.7	0.8-2.6	<0.001	0.001
	PTF		5.2 ± 1.7	2.3-6.9		4.9 ± 3.2	2.2-6.1		
C6	ATF	Ø AP [1]	1.6 ± 0.7	1.3-2.9	<0.001	1.5 ± 0.2	0.8-2.8	<0.001	n.s.
	PTF		5.3 ± 0.6	3.1-7.6		5.0 ± 0.9	2.1-6.8		
	ATF	Ø lat [2]	2.4 ± 0.5	1.3-3.8	<0.001	2.0 ± 0.6	1.2-3.6	<0.001	<0.05
	PTF		6.0 ± 0.8	3.4-7.3		5.7 ± 0.7	2.0-7.1		
C7	ATF	Ø AP [1]	2.1 ± 0.5	1.2-3.0	0.003	1.8 ± 0.4	1.0-2.1	0.002	n.s.
	PTF		4.5 ± 1.0	1.7-5.9		4.1 ± 1.1	2.1-5.1		
	ATF	Ø lat [2]	2.5 ± 1.3	1.5-4.1	0.001	2.1 ± 0.3	1.3-2.0	0.003	<0.001
	PTF		4.2 ± 0.9	2.6-7.1		3.6 ± 0.5	2.3-5.9		

SD =standard deviation; ATF = accessory transverse foramen; PTF = principal transverse foramen; [1] antero-posterior diameter (mm); [2] lateral diameter (mm); [3] Student's t-test between ATF and PTF; [4] Student's t-test between men and women; n.s. = not significant.

The comparative dimensions between the primary TF of vertebrae with DTF and the TF of vertebrae without DTF showed that the presence of DTF was accompanied by a smaller size of the primary TF in comparison with the TF of normal vertebrae. This difference was statistically significant in both men and women for the antero-posterior diameter and the lateral diameter of C4-C6 (Table 4).

Discussion

In the preceding studies about DTF, the data usually refers to the overall prevalence of this morphological variant. In our study, the overall DTF prevalence was 15.5%, in agreement with what has been previously observed (4.7-16.5%) (Taitz et al., 1978; De Boeck et al., 1984; Jovanovic, 1990; Jaffar et al., 2004; Sanchis-Gimeno et al., 2005; Sharma et al., 2010; Chandravadiya et al., 2013; Gupta et al., 2014; Patil et al., 2014). This wide range on DTF frequency reported by the previous authors could be caused by the diverse ethnic origin of the samples studied and by the dif-

Table 4 – Comparative dimensions between the primary transverse foramen of vertebrae with double transverse foramen and the transverse foramen of vertebrae without double transverse foramen.

Cervical level		Men			Women		
		PTF Mean ± SD	TF Mean ± SD	P-value [3]	PTF Mean ± SD	TF Mean ± SD	P-value [3]
C4	Ø AP [1]	4.1 ± 1.5	5.6 ± 1.1	<0.001	3.8 ± 0.2	5.0 ± 0.5	<0.001
	Ø lat [2]	5.3 ± 1.1	6.5 ± 1.0	<0.001	4.6 ± 1.4	6.3 ± 0.9	0.001
C5	Ø AP [1]	5.0 ± 1.2	5.4 ± 0.7	<0.001	4.7 ± 1.7	5.0 ± 1.2	0.002
	Ø lat [2]	5.2 ± 1.7	5.9 ± 0.9	<0.001	4.9 ± 3.2	5.6 ± 1.5	<0.001
C6	Ø AP [1]	5.3 ± 0.6	5.6 ± 0.5	0.010	5.0 ± 0.9	5.4 ± 1.1	0.029
	Ø lat [2]	6.0 ± 0.8	6.5 ± 1.6	0.017	5.7 ± 0.7	5.9 ± 0.6	0.032
C7	Ø AP [1]	4.5 ± 1.0	5.5 ± 1.4	0.008	4.1 ± 1.1	4.2 ± 1.0	0.011
	Ø lat [2]	4.2 ± 0.9	4.9 ± 1.0	0.018	3.6 ± 0.5	4.0 ± 0.8	0.020

PTF = principal transverse foramen; DTF = double transverse foramen; TF = transverse foramen (single); SD = standard deviation; [1] antero-posterior diamenter (mm); [2] lateral diameter (mm); [3] Student's t-test between PTF and TF.

ferent methodologies used by other authors. While our work has focused in a sample of complete cervical sets, other studies have analyzed only cervical segments. Sharma et al. (2010) and Agrawal et al. (2012) analyzed complete segments from C3 to C6, and Jovanovic (1990) from C6 to C7. Hence, their results are not comparable to ours, since the prevalence observed by them do not refer to the full complete cervical spine. Even more, other authors report about the overall prevalence of DTF in the cervical spine, but their results are normalized to individual vertebrae included in the study, not to full cervical spines (Nagar et al., 1999; Aydinoğlu et al., 2001; Das et al., 2005; Kaya et al., 2011; Murlimanju et al., 2011; Chaudhari et al., 2013; Rathnakar et al., 2013; Katikireddi and Setty, 2014; Mishra et al., 2014; Murugan and Verma, 2014; Ramachandran et al., 2014; Shah et al., 2014; Yadav et al., 2014; Dofe et al., 2015; Kumari et al., 2015; Patra et al., 2015). The even wider variability of DTF overall prevalence reported by these studies (1.4-42.6%) is probably a consequence of the diverse origin of the cervical vertebrae studied (Table 5). Therefore, due to the different methodology used in the selection of the vertebrae analyzed by these authors, their results are not comparable with ours.

In our study, we have not only analyzed the overall prevalence of DTF, but also the prevalence of DTF at every cervical level. We observed the presence of DTF at C4-C7 levels, and it was more frequent in C6, followed by C5, C4 and C7. In this regard, other authors gave results for different cervical levels (Taitz et al., 1978; De Boeck et al., 1984; Jovanovic, 1990; Wysocki et al., 2003; Jaffar et al., 2004; Sanchis-Gimeno et al., 2005; Sharma et al., 2010; Agrawal et al., 2012; Chandravadiya et al., 2013; Gupta et al., 2014; Kwiatkowska et al., 2014; Patil et al., 2014; Ramachandran et al., 2014) (Table 5). In some cases, the different methodology applied may have influenced on the results. So, in the study by Taitz et al. (1978) the prevalence of DTF in C6 and C7 was reported together as one datum, while in the studies by Kwiatkowska

Table 5 – Summary of double transverse foramen frequencies observed by other authors.

Authors and publication year	C1	C2	C3	C4	C5	C6	C7	Total
Taitz et al. (1978)	0.0%	0.0%	0.0%	0.0%	14.7%	43.9%	14.3%	
De Boeck et al. (1984)	1.6%	0.0%	5.0%	5.0%	17.0%	23.0%	15.0%	NR
Jovanovic (1990)	NA	NA	NA	NA	NA	NR	14.2%	NR
Nagar et al. (1999)	NR	NR	NR	NR	NR	NR	NR	8.6%
Aydinoğlu et al. (2001)	0.0%	0.0%	18.5%	35.2%	14.4%			
Jaffar et al. (2004)	NR	0.0%	NR	NR	NR	70.0%	NR	NR
Das et al. (2005)	0.0%	0.0%	NR	NR	NR	NR	NR	1.5%
Sanchis et al. (2005)	0.0%	0.0%	2.6%	14.2%	30.3%	41.9%	10.7%	10.0%
Sharma et al. (2010)	NA	NA	2.0%	6.0%	8.0%	16.0%	NA	8.0%
Kaya et al. (2011)	NR	NR	NR	NR	NR	NR	NR	22.7%
Murlimanju et al. (2011)	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	1.4%	
Agrawal et al. (2012)	NA	NA	3.7%	NA	3.7%			
Chandravadiya et al. (2013)	0.0%	0.0%	0.0%	0.0%	6.6%	20.0%	6.6%	4.7%
Chaudhari et al. (2013)	0.0%	0.0%	16.9%	41.6%	16.5%			
Rathnakar et al. (2013)	NR	NR	NR	NR	NR	NR	NR	5.7%
Gupta et al. (2014)	NR	0.0%	NR	NR	NR	60.0%	NR	16.5%
Katikireddi and Setty (2014)	NR	NR	NR	NR	NR	NR	NR	3.0%
Mishra et al. (2014)	NA	NA	14.0%	NA	14.0%			
Murugan and Verma (2014)	0.0%	0.0%	NR	NR	NR	NR	NR	12.6%
Patil et al. (2014)	0.0%	0.0%	0.0%	12.0%	12.0%	12.0%	4.0%	5.7%
Ramachandran et al. (2014)	0.0%	0.0%	3.7%	41.9%	12.5%	50.0%	10.2%	15.8%
Shah et al. (2014)	NR	NR	NR	NR	NR	NR	NR	16.1%
Yadav et al. (2014)	NA	NA	6.6%	NA	6.6%			
Kumari et al. (2015)	NR	NR	NR	NR	NR	NR	NR	9.8%
Patra et al. (2015)	NA	NA	0.0%	0.0%	NR	NR	36.6%	22.0%
Present Study (2016)	0.0%	0.0%	0.0%	12.5%	36.4%	50.0%	10.2%	15.5%

NR = Not reported; NA = Not analyzed.

et al. (2014) and Wysocki et al. (2003) the prevalence of DTF was not referred to the number of vertebrae examined for each cervical level, but to the total number of TF.

According to our results, other authors also reported the absence of DTF in C1 (Taitz et al., 1978; Aydinoğlu et al., 2001; Das et al., 2005; Sanchis-Gimeno et al., 2005; Murlimanju et al., 2011; Chandravadiya et al., 2013; Chaudhari et al., 2013; Gupta et al., 2014; Murugan and Verma, 2014; Patil et al., 2014; Ramachandran et al., 2014) and C2 (Taitz et al., 1978; De Boeck et al., 1984; Aydinoğlu et al., 2001; Das et al., 2005; Sanchis-Gimeno et al., 2005; Murlimanju et al., 2011; Chandravadiya et al., 2013; Chaudhari et al., 2013; Gupta et al., 2014; Murugan and Verma, 2014; Patil et al., 2014; Ramachandran et al., 2014). Only De Boeck et al. (1984) and Wysocki et al. (2003) found accessory TF in C1. However, their findings refer to another anatomical variant, the retrotransverse foramen, instead of an actual DTF (Quiles et al., 2016). Also, we did not observed DTF in C3, as in the studies by De Boeck et al. (1984), Wysocki et al. (2003), Sanchis-Gimeno et al. (2005), Sharma et al. (2010) and Ramachandran et al. (2014). Conversely, other authors have reported about the presence of DTF at this cervical level, although at a much lower prevalence, between 2.0% and 5.0% (Taitz et al., 1978; Murlimanju et al., 2011; Chandravadiya et al., 2013; Patil et al., 2014; Patra et al., 2015). Finally, in coincidence with the results of other authors (Taitz et al., 1978; De Boeck et al., 1984; Sharma et al., 2010; Chandravadiya et al., 2013; Patil et al., 2014), we have observed the highest prevalence in C6, followed by C5, C4 and C7. In addition, regarding DTF distribution by sex, there was a statistically significant difference between men and women only in C7 (Table 1). Unfortunately, few studies report about DTF frequency differences based on sex (De Boeck et al., 1984; Wysocki et al., 2003; Kaya et al., 2011; Kwiatkowska et al., 2014), and none of them informed whether any statistically significant difference was observed between men and women.

With respect to the unilaterality or bilaterality of DTF, and the possible predominance of side, again few studies focused on this aspect (Jovanovic, 1990; Aydinoğlu et al., 2001; Murlimanju et al., 2011; Agrawal et al., 2012; Rathnakar et al., 2013; Gupta et al., 2014; Katikireddi and Setty, 2014; Kwiatkowska et al., 2014; Ramachandran et al., 2014; Shah et al., 2014; Patra et al., 2015). Although it was only statistically significant in C7, we observed a greater prevalence of unilateral cases in C4, C5 and C7 (Table 2), in line with the results of preceding authors (Jovanovic, 1990; Aydinoğlu et al., 2001; Murlimanju et al., 2011; Agrawal et al., 2012; Rathnakar et al., 2013; Gupta et al., 2014; Katikireddi and Setty, 2014; Ramachandran et al., 2014; Shah et al., 2014), except for Patra et al. (2015), where the bilateral form (11.33%) was more frequent than the unilateral one (10.67%), although this work did not provide statistical analysis of the results. In addition, we observed that TF was more frequent on the right side in C4, C6 and C7, although this difference was not statistically significant (Table 2). This agrees with the results from Kwiatkowska et al. (2014), but Murlimanju et al. (2011) observed a statistically significant greater prevalence on the right side.

We observed sexual differences in primary TF measures of vertebrae with DTF (C4-C7). The lateral and antero-posterior diameters were wider in men than in women, and this difference was statistically significant for the lateral diameter from C4 to C7 (Table 3). There is no previous published data on sexual differences TF size in vertebrae with DTF. There are only studies based on general samples of cervical vertebrae, without distinguishing between normal vertebrae and vertebrae with DTF (Zhao et al., 2008; Malik et al., 2009; Evangelopoulos et al., 2012). In any case, the results reported by Malik et al., 2009 and Evangelopoulos et al. (2012) are similar to ours. On the contrary Zhao et al. (2008) found no sexual differences, which may be explained by the diverse ethnic origin of the samples studied.

Regarding the dimensions of the accessory TF, our work shows that the antero-posterior and lateral diameters were both smaller than those of the primary TF at all the cervical levels affected with DTF. These results were statistically significant (Table 3) and consistent with the preceding ones (Mishra et al., 2014; Murugan and Verma, 2014; Patra et al., 2015).

Since the size of the TF may affect the caliber and vascular flow of the vertebral artery (Taitz et al., 1978), and the presence of an accessory TF may affect the size of the primary TF, we analyzed if vertebrae with DTF presented a smaller size of primary TF compared with the TF of the normal vertebrae. We observed that the primary TF was smaller than the TF of normal vertebrae. This difference was statistically significant, in both men and women, for the antero-posterior diameter and the lateral diameter of C4-C6. Among the authors who have investigated DTF previously, none of them analyzed this possible influence. In our opinion this correlation is relevant for the compressive pathology of the vertebral artery at the C4-C6 levels, and vertebral arterial surgery.

In conclusion, our work contributes with new data on the prevalence of DTF at each cervical level from complete cervical sets. Moreover, we have verified that this anatomical variant may determine a smaller size of the primary TF in comparison with normal vertebrae. In this context, in order to verify a possible correlation between DTF and vertebrobasilar insufficiency, it would be interesting to perform a further analysis of the DTF prevalence in present-day samples based on CT images of the cervical spine. This extended study would allow a precise analysis of the area of the TF and the vertebral artery depending on the presence of DTF. Details are not available in the literature regarding the content of accessory TF. It is unclear whether it contains vertebral artery or veins, neither, or some combination. Further analysis based on cadaver dissection or radiological imaging may help to clarify this question. Nonetheless, the accurate knowledge of this anatomical variant is relevant for medical professionals, especially radiologists, neurosurgeons and orthopedic surgeons, in order to improve the safety, precision and efficacy of surgical procedures in the cervical spine.

Conflict of interest

The authors have no conflict of interest to declare.

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