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Morphometric Study and Anatomical Variation with its Incidence of Foramina Transversaria on the Lower Cervical Vertebrae

Estudio Morfométrico y Variación Anatómica con la Incidencia de Forámenes Transversos en las Vértebras Cervicales Inferiores

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SUMMARY: Anatomical variation of the foramina transversaria (FT) is associated with vertebral neurovascular symptoms and can cause complications after lower spine surgery, especially cervical pedicle screw (CPS) insertion. FT variation has been documented and classified in various populations, as this information can help increase cervical stability in subaxial vertebral surgery. Although the morphometry of the upper cervical spine in Thai populations has been reported, there have yet been no studies examining the features of FT. The FT of dried cervical spines (C3-C7; left and right side; n = 107, male = 53 and female = 54) were examined for morphological variation, and their anteroposterior (AP) and transverse (T) diameters were measured using a digital vernier caliper. Morphometric data and variations were compared by sex and lateral side. It was that the C3-C6 FT in both sexes were round, and the C7 FT was elliptical with an oblique right side. FT diameters did not differ significantly by sex except for the AP diameters of C6-C7 and for T diameters of C4 and C7. The left AP diameters of C3-C6 were significantly longer than the right, as were the T diameters of C4 and C7 FT. Additionally, T diameter was significantly longer than that of the AP, except that of the left C6 in male spines, which did not differ from the AP. Most FT examined were round. These findings should be considered in the provisional diagnosis of vertebral neurovascular symptoms caused by FT variation as well as that of neurovascular damage after cervical pedicle screw placement.

KEY WORDS: Lower cervical spine; Foramina transversaria; Variation; Cervical pedicle screw fixation.

INTRODUCTION

Foramina transversaria (FT) are commonly found in the cervical vertebrae (1st -7th) at both the left and right transverse processes, creating passages for the vertebral vessels and sympathetic nerve plexuses. Generally, the paired vertebral arteries run into the FT at the sixth or seventh levels of the cervical spine to the first vertebra before exiting to form the basilar artery at the ventral brainstem. Clinically, the variations in FT, such as narrow size and presence of osteophytes, can cause vertebral vascular or vertebrobasilar insufficiency, leading to transitory ischemia in the vertebrobasilar circulation (Kaya *et al*., 2011; Zibis *et al*., 2016). As a result, patients with FT variations (especially vertebral neurovascular compression) may present with various neurological symptoms including headaches, migraine, vomit, ataxia, dizziness, vertigo, diplopia, blindness, and loss of balance (Romanov *et al*., 1973). Moreover, FT size is an important factor for radiologists and surgeons to consider during computed tomographic (CT) or magnetic resonance imaging (MRI) scanning prior to lower cervical pedicle screw (CPS) fixation (An *et al*., 1991). In addition, the FT variation can affect the vertebral neurovascular bundle after CPS insertion. The incidence and morphological features of C3-C7 FT variation have been well documented and differ by population (Taitz *et al*. 1978; Kimura *et al*., 1985; Nagar *et al*., 1999; Aydinoglu *et al*., 2001; Das *et al*., 2005). For example, the FT shapes reported

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in Japanese, Chinese, and Indian populations have been classified into 5 types, with type 3 (elliptical with transverse direction) being the most commonly observed at C3-C5 (Kimura *et al*., 1985). In contrast, the 13 types have been observed in South African populations, with type 1 being the most common found at C3-C6 (Taitz *et al*. 1978). Anatomical variations on the subaxial vertebral pedicles and morphometry of the FT in the upper cervical spine have recently been documented in the Thai population (Mahiphot *et al*., 2019; Chaiyamoon *et al*., 2021). However, no morphometric study of variation in the lower cervical FTs (C3-C7) has not been conducted. With this study, we aimed to fill this gap by investigating FT morphometry and classifying FT variation in the lower cervical spine in a Thai population in order aid in the diagnosis of vertebral neurovascular symptoms and in lower cervical pedicle spine fixation.

MATERIAL AND METHOD

Resource of dried lower cervical spine samples. Adult subaxial cervical spine vertebrae (C3-C7) excluded for any degeneration were used in this study. All lower cervical spines were collected from 107 identified Northeastern Thai's skeletons (53 males and 54 females) that they were previously donated for medical teaching and research at the Unit of Human Bone Warehouse for Research (UHBWR), Department of Anatomy, Faculty of Medicine, Khon Kaen University, Thailand. This study was approved by the office of the Ethics Committee for Human Research, Khon Kaen University, Thailand (No. HE621190).

Measurements of foramen transversarium diameters. Both sides of FT diameters of each lower spine were measured at two planes of anteroposterior (AP) and transverse (T) axes by using the Digital Vernier Caliper (0.01mm precision, Mitutoyo, Kawasaki, Japan) in triplicates as shown in Figure 1. The anteroposterior (AP) diameter, direction of vertebral body facing observer, which defines from the anterior to the posterior margin of FT. For T diameter, it means the diameter from the medial to the lateral margin of FT. Such measurements of FT diameters were systematically performed by different internal and external observers on different days.

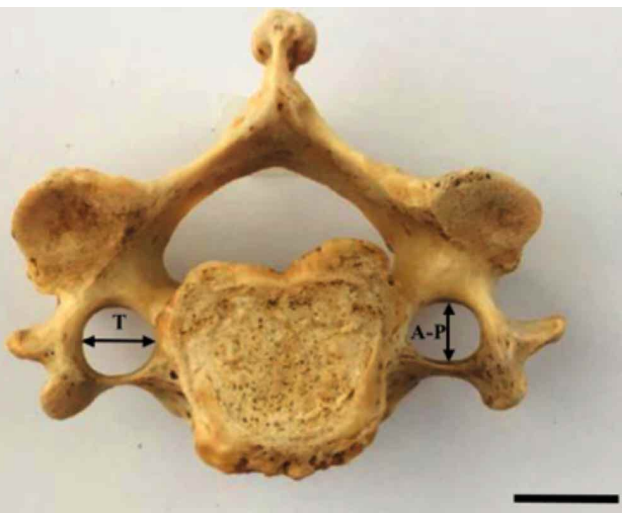

Fig. 1. Showing the representative lower cervical spine from of C4 (inferior view) and directions of measured FT diameters. AP, anteroposterior diameter; T, transverse diameter. Scale bar = 2 cm.

Classification of the foramina transversaria (FT). The types of FT belonging to lower cervical spines were classified into 5 types including the round (type 1), elliptical with anteroposterior (type 2), elliptical with transverse (type 3), elliptical with oblique from right to left (type 4), and elliptical with oblique from left to right side (type 5) as demonstrated in Figure 2 based on previous studies (Taitz *et al*., 1978; Zibis *et al*., 2016; Guerra *et al*., 2017; Abdul *et al*., 2018).

Table I. The overall morphometry of foramen transversarium of lower cervical spine (C3-C7).

Lower cervical spines	Male (n=53)				Female (n=54)			
	AP		T		AP		T	
	Left	Right	Left	Right	Left	Right	Left	Right
C3	5.38 ± 0.48	5.15 ± 0.43	6.21 ± 0.65	6.17 ± 0.66	5.27 ± 0.57	5.12 ± 0.52	6.19 ± 0.72	5.94 ± 0.68
	(4.17 – 6.53)	(4.32 – 6.16)	(4.91 – 8.82)	(4.89 – 7.77)	(3.80 – 6.45)	(4.17 – 6.43)	(4.02 – 7.31)	(4.11 – 7.26)
C4	5.48 ± 0.54	5.21 ± 0.51	6.27 ± 0.73	6.05 ± 0.70	5.36 ± 0.58	6.20 ± 0.84	5.14 ± 0.51	5.95 ± 0.69
	(4.03 – 6.60)	(3.97 – 6.32)	(4.03 – 8.09)	(4.58 – 7.46)	(3.84 – 6.34)	(4.16 – 7.92)	(4.04 – 6.70)	(4.71 – 7.46)
C5	5.71 ± 0.74	5.41 ± 0.80	5.88 ± 1.05	5.72 ± 0.72	5.57 ± 0.77	5.35 ± 0.61	5.96 ± 1.05	5.96 ± 0.88
	(2.52 – 7.79)	(3.87 – 7.80)	(2.63 – 8.48)	(3.86 – 6.88)	(2.24 – 7.21)	(4.00 – 6.63)	(2.20 – 8.75)	(3.94 – 8.27)
C6	6.16 ± 1.06	5.82 ± 1.03	6.15 ± 1.11	6.12 ± 0.94	5.83 ± 1.10	5.46 ± 0.76	5.95 ± 1.08	6.16 ± 0.92
	(2.87 – 8.17)	(2.90 – 7.70)	(3.14 – 8.60)	(3.68 – 8.35)	(2.47 – 7.86)	(3.02 – 7.37)	(2.64 – 8.16)	(3.00 – 8.47)
C7	4.54 ± 1.04	4.45 ± 0.89	5.32 ± 1.23	4.74 ± 1.07	3.95 ± 0.89	4.08 ± 1.13	4.81 ± 1.02	4.35 ± 1.11
	(2.10 – 7.07)	(1.84 – 6.42)	(2.53 – 8.58)	(2.19 – 8.60)	(1.37 – 5.64)	(1.86 – 7.52)	(2.50 – 6.96)	(2.06 – 6.86)

Values are mean ± SD in mm. AP, anteroposterior; T, transverse.

Statistical analysis. All morphometric values were represented as mean and standard deviation (mean ± S.D.). The variable data were tested for their normality by using the Shapiro-Wilk test. IBM SPSS Statistics software (version 20, IBM Corporation, Armonk, New York) was used for statistical analyses. Differences of parameters between sexes and sides were analyzed using the independent sample t-test and a paired sample t-test. A p-value less than 0.05 (≤ 0.05) is considered a statistically significant difference.

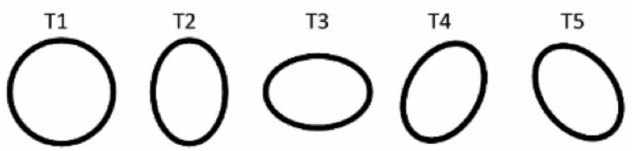

Fig. 2. Showing classifications of foramen transversarium found in C3-C7. T1, type1 (round); T2, type2 (elliptical with anteroposterior); T3, type3 (elliptical with transverse); T4, type4 (elliptical with oblique from right); and T5, Type5 (elliptical with oblique from left).

RESULTS

Morphometry of foramina transversaria (FT) of the lower cervical spines. After measurements of AP and T diameters (shown in Fig. 1), the overall morphometric features of C3-C7 FT in both sexes with left and right sides from 107 dried bones were summarized in Table I. The results showed that the diameters of both sexes and sides were shortest in C7 as compared to other levels. In male, the longest diameters were found in AP and right T diameters of C3 and in the left T of C4 (Table I). Both diameters in the left C3 were longer than those of right side. In females, left AP and right T diameters were longest in C6 and such prominence was found in right AP of C4 and left T of C3 (Table II).

Comparison of FT diameters between sexes and sides. Table II shows that the AP diameter of C6 and C7 in male was significantly longer that of female, whereas there was only T diameter of male C7 was longer than female. In both sexes, it was found that T diameters of C3-C7 were significantly longer than that of AP, except C6 of male had no difference between T and AP diameters. Compared between sides, the left AP diameter of C3-C6 was significantly longer than that of the right side. On T diameter, the left C4 and C7 showed significantly longer diameter compared to the right side. In contrast, the T parameter of C3, C5 and C6 showed no difference. In the same side, the T diameter was found to be significantly longer than that of AP diameter in each side, except on the left C6 (Table II).

Table III shows that the left AP diameter of lower cervical spines was not significantly different in both sexes, except that of C7 was significantly longer in male. The right AP diameter of C3-C5 showed no difference in both sexes, except that the diameter of male C6 and C7 was significantly longer than female. Compared between sides, the left AP diameter of C3-C5 was longer than the right side in male, whereas in female, it showed no significant difference. In C6 and C7, the diameter of both genders was not different between left and right sides, except that the left C6 was longer than the right side in

Table II. Comparisons of FT diameters (AP and T) on lower cervical spines (C3-C7) between sexes and sides.

Diameters (compared between sexes)	C3		P	C4		P	C5		P	C6		P	C7		P
	Male (n=106)	Female (n=108)		Male (n=104)	Female (n=106)		Male (n=106)	Female (n=108)		Male (n=106)	Female (n=108)		Male (n=104)	Female (n=100)	
AP	5.26 ± 0.47 (4.17 – 6.53)	5.19 ± 0.55 (3.80 – 6.45)	0.329	5.35 ± 0.54 (3.97 – 6.60)	5.25 ± 0.56 (3.84 – 6.70)	0.309	5.56 ± 0.79 (2.52 – 7.80)	5.46 ± 0.70 (2.24 – 7.21)	0.316	5.99 ± 1.06 (2.87 – 8.17)	5.65 ± 0.96 (2.47 – 7.86)	0.015	4.50 ± 0.98 (1.84 – 7.07)	4.02 ± 1.02 (1.37 – 7.52)	0.000
T	6.19 ± 0.66 (4.89 – 8.82)	6.06 ± 0.71 (4.02 – 7.31)	0.169	6.16 ± 0.93 (4.03 – 8.09)	6.08 ± 0.78 (4.16 – 7.92)	0.552	5.80 ± 0.92 (2.63 – 8.48)	5.96 ± 0.96 (2.20 – 8.75)	0.210	6.14 ± 1.03 (3.14 – 8.60)	6.06 ± 1.01 (2.64 – 8.47)	0.565	5.02 ± 1.25 (2.19 – 8.60)	4.58 ± 1.09 (2.06 – 6.96)	0.007
P	0.000	0.000		0.000	0.000		0.003	0.000		0.106	0 .000		0.000	0.000	
Diameters (compared between sides)	C3		P	C4		P	C5		P	C6		P	C7		P
	Left (n=107)	Right (n=107)		Left (n=105)	Right (n=105)		Left (n=107)	Right (n=107)		Left (n=107)	Right (n=107)		Left (n=102)	Right (n=102)	
AP	5.32 ± 0.53 (3.80 – 6.53)	5.13 ± 0.48 (4.17 – 6.43)	0.005	5.42 ± 0.56 (3.84 – 6.63)	5.17 ± 0.51 (3.97 – 6.70)	0.001	5.64 ± 0.76 (2.24 – 7.79)	5.38 ± 0.71 (3.87 – 7.80)	0.004	6.00 ± 1.09 (2.47 – 8.17)	5.64 ± 0.92 (2.90 – 7.70)	0.004	4.25 ± 1.01 (1.37 – 7.07)	4.27 ± 1.04 (1.84 – 7.52)	0.712
T	6.20 ± 0.69 (4.02 – 8.82)	6.05 ± 0.68 (4.11 – 7.77)	0.058	6.23 ± 0.78 (4.03 – 8.09)	5.95 ± 0.90 (0.08 – 7.46)	0.017	5.92 ± 1.05 (2.20 – 8.75)	5.84 ± 0.82 (8.27 – 3.86)	0.426	6.05 ± 1.10 (2.64 – 8.60)	6.14 ± 0.93 (3.00 – 8.47)	0.448	5.07 ± 1.17 (2.50 – 8.58)	4.54 ± 1.16 (2.06 – 8.60)	0.000
P	0.000	0.000		0.000	0.000		0.000	0.000		0.483	0 .000		0.000	0.000	

Values are mean ± standard deviation in mm. *Statistically significant (P<0.05). AP, anteroposterior; T, transverse

female. It was found that the T diameter of the left C7 of male was significantly longer than that of the female. Moreover, the left C3 of females showed a longer T diameter compared to the right side. In similarity, the T diameter of C7 in both sexes was significantly longer on the left side (Table III).

Classification and incidence of FT types in lower cervical spine. The types of FT observed in Thai lower cervical spines were classified into 5 types including type1 (round), type2 (elliptical with anteroposterior), type3 (elliptical with transverse), type4 (elliptical with oblique from right), and type5 (elliptical with oblique from left), respectively, as drown in Figure 2. The incidence of such FT types was shown in Table IV. In male, the prevalence of FT types found in C3-C7 were type 1 (48.49 %), type 2 (1.51 %), type 3 (18.68 %), type 4 (16.04 %), and type 5 (15.28 %). In females, there were type 1 (56.30 %), type 2 (0.19 %), type 3 (17.04 %), type 4 (13.33 %), and type 5 (12.78 %), respectively. It was noted that the most incidence similarly observed in both sexes was type 1 (round shape) as shown in Table IV.

Table III. Comparisons of FT diameter difference of sexes in left and right sides of lower cervical spines

Diameters	C3 Male (n=53)	C3 Female (n=54)	*P*	C4 Male (n=52)	C4 Female (n=53)	*P*	C5 Male (n=53)	C5 Female (n=54)	*P*	C6 Male (n=53)	C6 Female (n=54)	*P*	C7 Male (n=52)	C7 Female (n=50)	*P*
AP-Lt	5.39 ± 0.49	5.27 ± 0.57	0.276	5.48 ± 0.55	5.37 ± 0.59	0.324	5.72 ± 0.75	5.58 ± 0.78	0.341	6.17 ± 1.07	5.84 ± 1.11	0.122	4.54 ± 1.04	3.97 ± 0.90	0.004
AP-Rt	5.15 ± 0.44	5.12 ± 0.53	0.788	5.19 ± 0.51	5.15 ± 0.52	0.644	5.41 ± 0.81	5.35 ± 0.61	0.642	5.82 ± 1.04	5.47 ± 0.77	0.048	4.51 ± 0.86	4.09 ± 1.16	0.043
P	0.016	0.122		0.011	0.045		0.031	0.055		0.087	0.013		0.786	0.490	
Dimeters	C3 Male (n=53)	C3 Female (n=54)	*P*	C4 Male (n=52)	C4 Female (n=53)	*P*	C5 Male (n=53)	C5 Female (n=54)	*P*	C6 Male (n=53)	C6 Female (n=54)	*P*	C7 Male (n=52)	C7 Female (n=50)	*P*
T-Lt	6.22 ± 0.66	6.19 ± 0.73	0.844	6.24 ± 0.70	6.21 ± 0.84	0.881	5.89 ± 1.06	5.97 ± 1.06	0.693	6.15 ± 1.12	5.96 ± 1.09	0.362	5.32 ± 1.27	4.86 ± 1.00	0.045
T-Rt	6.17 ± 0.67	5.94 ± 0.69	0.078	6.06 ± 0.71	5.96 ± 0.70	0.469	5.72 ± 0.76	5.96 ± 0.88	0.128	6.13 ± 0.95	6.16 ± 0.93	0.850	4.79 ± 1.15	4.36 ± 1.14	0.063
P	0.693	0.027		0.116	0.077		0.294	0.976		0.890	0.198		0.002	0.004	

Values are mean±SD in mm. *Statistically significant (P<0.05). AP, anteroposterior; T, transverse; Lt, left; Rt, right.

Table IV. Incidence of FT types and variations found in Thai lower cervical spines.

Cervical vertebrae	Classification of type: Male (%) N=106					Female (%) N=108				
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 1	Type 2	Type 3	Type 4	Type 5
C3	60.38 (64/106)	0	35.85 (38/106)	1.89 (2/106)	1.89 (2/106)	67.59 (73/108)	0	32.41 (35/108)	0	0
C4	57.55 (61/106)	1.89 (2/106)	33.96 (36/106)	3.78 (4/106)	2.83 (3/106)	69.44 (75/108)	0	30.56 (33/108)	0.93 (1/108)	0.93 (1/108)
C5	50.94 (54/106)	0	8.49 (9/106)	17.92 (19/106)	22.64 (24/106)	68.52 (74/108)	0.93 (1/108)	10.19 (11/108)	11.11 (12/108)	9.26 (10/108)
C6	55.66 (59/106)	5.66 (6/106)	5.66 (6/106)	18.87 (20/106)	14.15 (15/106)	64.81 (70/108)	0	12.04 (13/108)	12.96 (14/108)	10.19 (11/108)
C7	17.92 (19/106)	0	9.43 (10/106)	37.74 (40/106)	34.91 (37/106)	11.32 (12/108)	0	0	41.67 (45/108)	43.52 (47/108)
Total	48.49 (257/530)	1.51 (8/530)	18.68 (99/530)	16.04 (85/530)	15.28 (81/530)	56.30 (304/540)	0.19 (1/540)	17.04 (92/540)	13.33 (72/540)	12.78 (69/540)

DISCUSSION

FT variation is clinically significant to radiologists and surgeons planning posterior operations at the lower cervical spine (C3-C7). The morphometry (such as type and diameter) and rates of variance of FT have been found to differ by population, with previous studies being conducted in Israel, Japan, China, India, Italy, Turkey, the US, Greece, Spain, Chile, South Africa, and Korea (Taitz *et al*. 1978; Kimura *et al*., 1985; Sangari *et al*., 2015; Zibis *et al*., 2016; Quiles-Guiñau *et al*., 2017; Guerra *et al*., 2017; Abdul *et al*., 2018; Malla *et al*., 2018; Gupta & Agarwal, 2019). Ours was the first study to report the incidence of variance and morphometric features of the lower cervical spine FT in a Thai population. We found that the AP and T diameters at C3, C4, C6, and C7 were significantly longer in males than females. This may explain the finding of insufficiency in vertebral basal artery circulatory in Thai women (unpublished data), in that the condition could be due to narrowness

of the FT causing compression of the vertebral neurovascular bundle. In addition, the recent study showed significantly higher AP diameters of C6-7 and T diameter of only C7 in male, indicating that such parameters could be used to be very helpful in forensic identification of complete cervical vertebral FT remains. These findings were similar to those of previous reports in Korean (Malla *et al*., 2018) and Spanish populations (Quiles-Guiñau *et al*., 2017) but differed in that the C5 T diameter in females in our study was significantly longer than in the males.

Consideration of lateral size differences may help prevent left vertebral neurovascular damage during spinal surgery. Previous studies in South Africa (Abdul *et al*., 2018) and Israel (Taitz *et al*., 1978) have reported longer C3-C6 AP and T diameters on the left side than on the right. In our study, while this was true for C3-C5 (Table V), the right T diameter at C6 was longer than on the left side, as was the AP diameter at C7. By contrast, a study in a Greek population found that C3, C5, and C6 FT diameters on the left side were longer than those on the right, except for the T diameter

Table V. Comparison FT diameters of subaxial cervical spine between Thais and other populations.

FT diameters		Sexes & sides	Populations							
			South Africa[15]	American[16]	Greek[1]	Israeli[6]	Spenish[11]	Korean[17]	Indians[18]	Present study
C3	AP	M	AP (Lt) = 4.60 ± 1.67 AP (Rt) = 4.34 ± 1.63 T (Lt) = 5.43 ± 2.00 T (Rt) = 5.03 ± 1.97	AP (Lt) = 5.13 ± 0.79 AP (Rt) = 5.17 ± 0.89 T (Lt) = 5.87 ± 0.89 T (Rt) = 5.69 ± 1.04	NR	NR	NR	5.48 ± 0.67	NR	5.26 ± 0.47
		F			NR	NR	NR	5.09 ± 0.65	NR	5.19 ± 0.55
	T	M			NR	NR	NR	6.50 ± 0.87	NR	6.19 ± 0.66
		F			NR	NR	NR	5.81 ± 0.70	NR	6.06 ± 0.71
	AP	Lt			4.75 ± 0.88	6.80 ± 0.77	NR	NR	4.72 ± 0.49	5.32 ± 0.53
		Rt			4.61 ± 0.82	6.22 ± 0.66	NR	NR	5.03 ± 0.58	5.13 ± 0.48
	T	Lt			5.57 ± 0.88	5.15 ± 0.51	NR	NR	6.36 ± 0.54	6.20 ± 0.69
		Rt			5.40 ± 0.83	4.89 ± 0.49	NR	NR	6.22 ± 0.93	6.05 ± 0.68
C4	AP	M			NR	NR	5.60 ± 1.10	5.52 ± 0.65	NR	5.35 ± 0.54
		F			NR	NR	5.00 ± 0.50	5.19 ± 0.62	NR	5.25 ± 0.56
	T	M			NR	NR	6.50 ± 1.00	6.46 ± 0.98	NR	6.16 ± 0.93
		F			NR	NR	6.30 ± 0.90	5.96 ± 0.90	NR	6.08 ± 0.78
	AP	Lt			4.93 ± 0.93	6.58 ± 0.80	NR	NR	5.03 ± 0.84	5.42 ± 0.56
		Rt			4.80 ± 0.75	6.21 ± 0.73	NR	NR	4.88 ± 0.88	5.17 ± 0.51
	T	Lt			5.40 ± 0.81	5.27 ± 0.56	NR	NR	5.94 ± 0.84	6.23 ± 0.78
		Rt			5.42 ± 0.71	4.99 ± 0.61	NR	NR	6.10 ± 0.92	5.95 ± 0.90
C5	AP	M			NR	NR	5.40 ± 0.70	5.80 ± 0.82	NR	5.56 ± 0.79
		F			NR	NR	5.00 ± 1.20	5,43 ± 0.50	NR	5.46 ± 0.70
	T	M			NR	NR	5.90 ± 0.90	6.17± 0.82	NR	5.80 ± 0.92
		F			NR	NR	5.60 ± 1.50	5.86 ± 0.67	NR	5.96 ± 0.96
	AP	Lt			5.41 ± 0.97	6.41 ± 0.81	NR	NR	5.28 ± 0.92	5.64 ± 0.76
		Rt			5.30 ± 0.82	6.14 ± 0.95	NR	NR	5.01 ± 0.91	5.38 ± 0.71
	T	Lt			5.55 ± 0.83	5.57 ± 0.96	NR	NR	5.96 ± 1.00	5.92 ± 1.05
		Rt			5.34 ± 0.76	5.15 ± 0.86	NR	NR	6.00 ± 1.17	5.84 ± 0.82
C6	AP	M			NR	NR	5.6 ± 0.5	6.09 ± 0.83	NR	5.99 ± 1.06
		F			NR	NR	5.4 ± 1.1	5.51 ± 0.67	NR	5.65 ± 0.96
	T	M			NR	NR	6.5 ± 1.6	6.63 ± 0.67	NR	6.14 ± 1.03
		F			NR	NR	5.7 ± 0.70	5.89 ± 0.65	NR	6.06 ±1.01
	AP	Lt			6.27 ± 1.00	6.40 ± 1.74	NR	NR	5.20 ± 1.27	6.00 ± 1.09
		Rt			6.07 ± 1.22	6.29 ± 1.08	NR	NR	5.25 ± 1.01	5.64 ± 0.92
	T	Lt			5.89 ± 0.91	5.51 ± 1.35	NR	NR	5.74 ± 1.33	6.05 ± 1.10
		Rt			5.81 ± 1.04	5.04 ± 1.00	NR	NR	5.67 ± 1.10	6.14 ± 0.93
C7	AP	M	NR	NR	NR	NR	5.50 ± 1.40	NR	NR	4.50 ± 0.98
		F	NR	NR	NR	NR	4.20 ± 1.00	NR	NR	4.02 ± 1.02
	T	M	NR	NR	NR	NR	4.90 ± 1.00	NR	NR	5.02 ± 1.25
		F	NR	NR	NR	NR	4.00 ± 0.80	NR	NR	4.58 ± 1.09
	AP	Lt	NR	NR	5.13 ± 1.93	6.30 ± 1.05	NR	NR	4.12 ± 1.77	4.25 ± 1.01
		Rt	NR	NR	5.37 ± 1.83	6.31 ± 2.01	NR	NR	4.04 ± 1.42	4.27 ± 1.04
	T	Lt	NR	NR	4.93 ± 1.58	4.58 ± 1.28	NR	NR	5.18 ± 2.06	5.07 ± 1.17
		Rt	NR	NR	4.87 ± 1.38	4.37 ± 1.35	NR	NR	5.27 ± 1.85	4.54 ± 1.16

AP, anteroposterior; M, male; F, female; T, transverse; Lt, left; Rt, right; NR, not recorded.

Table VI. Comparison FT types of subaxial cervical spine between Thai and other races.

Populations	Numbers	Type C3 (%)					Type C4 (%)					Type C5 (%)					Type C6 (%)					Type C7 (%)				
		Type 1	Type 2	Type 3	Type 4	Type 5	Type 1	Type 2	Type 3	Type 4	Type 5	Type 1	Type 2	Type 3	Type 4	Type 5	Type 1	Type 2	Type 3	Type 4	Type 5	Type 1	Type 2	Type 3	Type 4	Type 5
Israeli	480	14.7 (Rt), 11.4 (Lt)	0 (Rt), 2.8 (Lt)	67.8 (Rt), 74.3 (Lt)	17.6 (Rt), 0 (Lt)	0 (Rt), 11.4 (Lt)	9.1 (Rt), 0 (Lt)	0 (Rt), 3 (Lt)	75.7 (Rt), 51.5 (Lt)	15.1 (Rt), 3 (Lt)	0 (Rt), 15.1 (Lt)	29.4 (Rt), 35.29 (Lt)	0	55.88 (Rt), 35.29 (Lt)	8.82 (Rt), 11.76 (Lt)	5.88 (Rt), 14.70 (Lt)	37.14 (Rt), 54.28 (Lt)	2.85 (Rt), 5.71 (Lt)	37.14 (Rt), 8.57 (Lt)	11.42 (Rt), 8.57 (Lt)	11.42 (Rt), 22.85 (Lt)	16.12 (Rt), 8.33 (Lt)	0	29.03 (Rt), 29.16 (Lt)	6.45 (Rt), 54.10 (Lt)	48.38 (Rt), 4.16 (Lt)
Japanese, Chinese, Indian	200	13.50	0	68	10	8.5	8.5	0	65.5	2.5	23.5	21	0	45.5	5.5	28	57	1.5	27	8	24.5	4.5	0.5	12	82.5	1
South Africa	126											Type 1 = 32.93 Type 2 = 0 Type 3 = 18.29 Type 4 = 2.44 Type 5 = 18.29										2.27 (Rt), 0 (Lt)	0	0 (Rt), 2.27 (Lt)	0 (Rt), 18.18 (Lt)	11.36 (Rt), (0)
Chilean	47	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	33.3	0	0	11.1	11.1
Present study	214	61.02	0	34.11	0.93	0.93	63.55	0.93	32.24	2.34	1.87	59.81	0.47	9.35	14.49	15.89	60.28	2.80	8.88	15.89	39.25	8.88	0	4.67	39.72	39.25

NR, not recorded.

at C4 (Zibis *et al*., 2016). Another study in American population found T diameters at C3-C6 to be significantly longer on the left side, whereas those of AP were longer on the right (Sangari *et al*., 2015). Our morphometric data may be beneficial in the interpretation of vertebral neurovascular compression from FT radiographic images to confirm and remove osteophytes or spurs that may cause reductions in FT diameter and compression of the vertebral vessels prior to operation.

In our study, type 1 was the most common FT shape found at C3-C6, similar to previous results from South African (Abdul *et al*., 2018) as shown in Table VI. However, type 4 was most common at C7, which was comparable to findings in Japanese, Chinese, Indian (Kimura *et al*., 1985) Chilean (Guerra *et al*., 2017), and South African (Abdul *et al*., 2018) populations. By contrast, a study in an Israeli population by Taitz *et al*. (1978) found only type 5 FT at C7. Of the five FT types, type 2 (elliptical with anteroposterior direction) is associated with the highest risk of compression. Such type may need for surgery of the vertebral artery to remove osteophytes. By contrast, type 3 (elliptical with transverse direction) carries the lowest risk of interruption of the vertebral artery, which occupies about two-thirds of the smallest FT diameter and just over half of the largest (Xu *et al*., 1995). In contrast to a recent study, the most common type was type 1 (approximately 60 %), with type 2 accounting for 2 % and type 3 for 20 %.

CONCLUSIONS

We conclude that the shape and morphometric parameters of FT observed in the lower cervical spine in Thais were unique and mostly different from other populations. All diameter parameters were longer in male except the T diameter of C5. The most common type of FT found in Thai lower cervical spine is type 1.

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SAMRID, R.; IAMSAARD, S.; KASAI, Y.; POODENDAN, C.; YANNASITHINON, S.; SAE-JUNG, S. & CHAIYAMOON, A. Estudio morfométrico y variación anatómica con la incidencia de forámenes transversos en las vértebras cervicales inferiores. *Int. J. Morphol., 41(1)*:111-117, 2023.

RESUMEN: La variación anatómica del foramen transverso (FT) se asocia con síntomas neurovasculares vertebrales y puede causar complicaciones después de la cirugía de columna cervical inferior, especialmente la inserción de tornillos pediculares cervicales (TPC). La variación del FT se ha documentado y clasificado en varias poblaciones, ya que esta información puede ayudar a aumentar la estabilidad cervical en la cirugía vertebral subaxial. Aunque se ha informado sobre la morfometría de la columna cervical superior en poblaciones tailandesas, aún no se han realizado estudios que examinen las características de FT. Se examinó la variación morfológica del FT de vértebras cervicales secas (C3-C7; lado izquierdo y derecho; n = 107, hombres = 53 y mujeres = 54), y se midieron sus diámetros anteroposterior (AP) y transverso (T) usando un pie de metro digital. Se compararon datos morfométricos y variaciones por sexo y lado. Los FT de C3-

a C6 en ambos sexos eran redondos, y el FT C7 era elíptico con el lado derecho oblicuo. Los diámetros del FT no difirieron significativamente por sexo excepto para los diámetros AP de C6-C7 y para los diámetros transversos de C4 y C7. Los diámetros AP izquierdos de C3-C6 eran significativamente más largos que los del lado derecho, al igual que los diámetros transversos de C4 y C7. Además, el diámetro transverso fue significativamente mayor que el AP, excepto el C6 izquierdo en las vértebras de hombres, que no difirió del AP. La mayoría de los FT examinados eran redondos. Estos hallazgos deben ser considerados en el diagnóstico provisional de síntomas neurovasculares vertebrales causados por la variación del FT, así como en el de daño neurovascular tras la colocación de tornillos pediculares cervicales.

PALABRAS CLAVE: Columna cervical inferior; Forámenes transversos; Variación; Fijación con tornillos pediculares cervicales.

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