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Variation in *foramina transversaria* of human cervical vertebrae in the medieval population from Sypniewo (Poland)

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Abstract: Since the foramina provide important reference points to radiologists and surgeons, and because their shape and size may affect the blood supply to the cerebellum and the brainstem, the knowledge of the variation of *foramina transversaria* is essential from the medical point of view. The variation in the number, size and shape of *foramina transversaria* was studied based on 129 skeletons (68 male, 61 female, total of 1065 foramina) from the environs of Sypniewo. In both sexes single foramina were the most frequent (ca. 70%); in females no double foramina were observed, while triple foramina appeared only twice. In males double foramina formed ca. 40% and triple foramina were very rare. The shape and size of foramina depended to the same extent on the position of the vertebra and on the body side.

Key words: cervical vertebrae, Sypniewo, Poland

Introduction

Cervical vertebrae are smaller and more delicate than those of the other regions of human vertebral column. At the same time, the foramina transversaria (FT) present an array of morphological varieties, resulting in a wide variation of forms of cervical vertebrae. Most often, there is a single foramen per process, but it is by no means a rule. Supernumerary foramina can change the form of the structures passing through them, leading to consequences for the functioning of the organism (Roh et al. 2004). The foramina vary not only in their number but also, among other things, in their shape and size.

The variety of these features is reflected in the structure and functioning of the vessels which run inside the canal formed by the foramina transversaria (Waldron and Antoine 2002, Ikegami et

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al. 2007). The variation in morphology of the foramina transversaria is affected by many factors, i. a. developmental factors, mechanical factors or the number and size of the structures passing through them (Jaffar et al. 2004).

The course of vessels and nerves inside the canal formed by the foramina transversaria is of clinical significance, and the knowledge about it is important during surgery. Variability of this section, which may be associated with very unpleasant symptoms, most of all neurological disturbances, contributes to the decrease of the quality of life. The numerous morphological varieties of the foramina make it difficult to distinguish between the normal and the pathological conditions (Wysocki et al. 2003a). For this reason, it is important to determine the frequency of occurrence of various morphological forms in terms of their number and the degree of roundness; compare the structure on both sides of the vertebra, and to establish the effect of the features of foramina transversaria on the course of vessels and nerves.

Since the cemetery in Sypniewo is among the largest medieval cemeteries discovered so far in Poland (Dąbrowski et al. 2005) it offered a possibility to examine a large number of cervical vertebrae. Additionally, Górska (1968) suggested that the population from Sypniewo had been isolated from other groups of people and the cemetery had for a long time been used by the inhabitants of the settlement and nearby settlements.

Material and methods

The bone remains used in the study come from a mediaeval cemetery (11th–17th c.) in the environs of Sypniewo (Poland). In order to assess the variation in appearance and structure of the foramina transversaria in the cervical vertebrae, 129 well-preserved skeletons were used: 68 male (53%) and 61 female (47%). The age and sex were determined based on the skull and the pubic bone morphology, using standard methods commonly applied in anthropology (Ascádi and Nemeskéri 1970; Ubelaker 1984; Malinowski 1997). Individual age was divided into: juvenis, adultus, adultus/maturus, maturus, maturus/senilis categories (Table 1).

The total number of examined cervical vertebrae was 494; transverse and longitudinal measurements were taken from 1065 foramina transversaria; among these 656 from male and 409 from female skeletons. Examination of the cervical section of the vertebral column followed its division into C1 – atlas, C2 – axis, C3 to C6 – vertebrae cervicales third to sixth and C7 – vertebra prominens. Most of the foramina of transverse processes of the second cervical vertebra (C2) had a different appearance compared to the remaining vertebrae, since FT in that vertebra is an arcuate canal. The canal has two foramina, one situated lower and facing laterally, which provides an entrance for the blood vessels and

Table 1. Number of studied males and females in individual age categories

Age	Male		Female		Total	
	N	%	N	%	N	%
juvenis	12	18	12	20	24	19
adultus	28	41	23	38	51	40
adultus/maturus	2	3	7	11	9	7
maturus	18	26	14	23	32	25
maturus/senilis	8	12	5	8	13	10
Total	68	100	61	100	129	100

nerves, and the other located in the horizontal plane of the vertebra, opening upward and providing an exit for the nerves running toward the next vertebra. FT of the second vertebra often varied in their size and shape and, consequently, were analysed separately.

The foramina transversaria on the right and left side of the vertebrae were categorised, based on their number in each vertebra, into single, double (Fig. 1, arrows) and triple.

Besides, the foramina were divided into groups, depending on the shape and position. Six types of FT were distinguished (according to Taitz et al. 1978).

For each of the foramina, the index of roundness was calculated according to the formula:

(max. transverse dimension/max. longitudinal dimension) × 100, and then, depending on the index value, the foramina were assigned to categories (according to Taitz et al. 1978): dolichomorph < 75.9; mesomorph 76–85.9; brachymorph 86–100.9; hyperbrachymorph 101–115.9 and ultrabrachymorph >116.

Fig. 1. Double foramina transvensaria in the cervical vertebra – C4 (male, adult)

Results

Numbers of the foramina

Both in male and in female skeletons, single foramina were the most frequent and constituted ca. 70% of all FT. Triple foramina transversaria appeared only twice, constituting less than 1% of the analysed cases (Table 2). Chi^2 test showed no significant differences between the sexes ($Chi^2=1.95$; $p=0.107$).

Male vertebrae most often (ca. 50–60%) had single foramina. Double foramina appeared somewhat less frequently and constituted ca. 20–40% for particular vertebrae of the cervical spine. Only single foramina occurred in all C2 vertebrae. The ratio of the number of foramina on the right (326) and left (330) sides was similar; single foramina were much more frequent (ca. 70%). Double foramina constituted only 30%, and triple foramina less than 1% on each side. Triple foramina were recorded only for the first vertebra (C1). The differences in the number of foramina transversaria on the right and left sides of male vertebrae were statistically insignificant ($Chi^2=1.33$; $p=0.248$) (Table 3).

In the vertebrae of both sexes, a single foramen was the most frequent form, forming about 70%; for each vertebra double foramina formed not more than 40%. In females the proportion for the

Table 2. Numbers of FT categories in cervical vertebrae of male and female skeletons

Number FT	Male		Female		Total	
	N	%	N	%	N	%
1	458	69.8	317	77.5	775	72.8
2	196	29.9	92	22.5	288	27.0
3	2	0.3	–	–	2	0.2
Total	656	100	409	100	1065	100

Table 3. Abundance categories of foramina in the examined cervical vertebrae of male and female skeletons

Vertebra	Number FT											
	Right						Left					
	1		2		3		1		2		3	
	N	%	N	%	N	%	N	%	N	%	N	%
Males												
C1	26	63.4	6	29.2	1	4.8	25	56.8	8	36.4	1	4.6
C2 lateral	42	100	–	–	–	–	45	100	–	–	–	–
C2 upper	42	100	–	–	–	–	45	100	–	–	–	–
C3–C6	101	56.4	39	43.6	–	–	102	58.0	37	42.0	–	–
C7	14	63.6	4	36.4	–	–	16	80.0	2	20.0	–	–
Total	225	69.0	49	30.1	1	0.9	233	70.6	47	28.5	1	0.9
Females												
C1	14	77.8	2	22.2	–	–	21	84.0	2	16.0	–	–
C2 lateral	26	100	–	–	–	–	28	100	–	–	–	–
C2 upper	26	100	–	–	–	–	27	100	–	–	–	–
C3–C6	73	60.3	24	39.7	–	–	75	70.1	16	29.9	–	–
C7	13	100	–	–	–	–	14	77.8	2	22.2	–	–
Total	152	74.5	26	25.4	–	–	165	80.4	20	19.6	–	–

right (204) and left (205) sides was similar as in males; single foramina formed more than 70%, double foramina less than 25% on each side. The second vertebra (C2) showed only single foramina, and only single foramina appeared on the right side of C7 (Table 3). In the case of female skeletons, the analysis showed no significant differences in the frequency of different numbers of foramina on the right and left sides.

Shape variation

In both male and female cervical vertebrae, the most (ca. 50%) common form of foramen was type 3 (elliptical, with transverse axis). Type 1, round, constituted 20 – 30% of the cases, depending on sex. The least frequent (ca. 10%) forms were those with oblique axes – types 4 and 5, and with longitudinal axis – type 2 (Table 4). The so called indefinite shapes (type 6) showed a negligible frequency. Chi^2 test showed no statistically significant differences among the frequencies of different categories of FT shapes between male and female skeletons (Chi^2=1.87; p=0.171).

Male vertebrae, on both right and left sides, displayed the greatest frequency of type 3 FT, which constituted more than 40% of all forms. Type 1, with the frequency of ca. 30%, was most often present on both sides as the upper foramen (entrance) of the canal of vertebra C2. A significant difference was observed between the frequency of occurrence of type 5 between the right (ca. 2%) and left (ca. 15%) sides (Table 5). Test Chi^2 showed statistically significant differences in the frequencies of types 4 and 5 on both sides of the vertebra in relation to the remaining types (Chi^2=29.88; p=0.000). The frequency of the two types was much smaller.

In female vertebrae, type 3 of FT was also the most frequent, and appeared in

Table 5. Numbers of individual shapes of FT in male and female skeletons

Vertebra	Type 1		Type 2		Type 3		Type 4		Type 5		Type 6	
	N	%	N	%	N	%	N	%	N	%	N	%
Shape of the FT to the right of male												
C1	5	12.2	25	61.0	2	4.9	6	14.6	2	4.9	1	2.4
C2 lateral	15	35.7	1	2.4	21	50.0	5	11.9	–	–	–	–
C2 upper	24	57.1	6	14.3	8	19.0	4	9.5	–	–	–	–
C3–C6	55	30.7	1	0.6	98	54.7	22	12.3	3	1.7	–	–
C7	5	22.7	1	4.5	13	59.1	1	4.5	1	4.5	1	4.5
Total	104	31.9	34	10.4	142	43.5	38	11.7	6	1.8	2	0.6
Shape of the FT to the left of male												
C1	13	29.5	13	29.5	2	4.5	1	2.3	15	34.1	–	–
C2 lateral	13	28.9	2	4.4	26	57.8	–	–	4	8.9	–	–
C2 upper	30	66.7	4	8.9	6	13.3	–	–	5	11.1	–	–
C3–C6	35	19.9	–	–	106	60.2	8	4.5	27	15.3	–	–
C7	1	5.0	2	10.0	11	55.0	5	25.0	–	–	1	5.0
Total	92	27.8	21	6.4	151	45.7	14	4.2	51	15.5	1	0.3
Shape of the FT to the right of female												
C1	1	5.6	12	66.7	–	–	5	27.8	–	–	–	–
C2 lateral	12	46.2	1	3.8	10	38.5	3	11.5	–	–	–	–
C2 upper	9	34.6	6	23.1	6	23.1	5	19.2	–	–	–	–
C3–C6	33	27.3	2	1.7	73	60.3	7	5.8	6	5.0	–	–
C7	4	30.8	–	–	9	69.3	–	–	–	–	–	–
Total	59	28.9	21	10.3	98	48.1	20	9.8	6	2.9	–	–
Shape of the FT to the left of female												
C1	6	24.0	6	24.0	1	4.0	–	–	12	48.0	–	–
C2 lateral	8	28.6	2	7.1	14	50.0	1	3.6	3	10.7	–	–
C2 upper	14	51.9	4	14.8	4	14.8	1	3.7	4	14.8	–	–
C3–C6	29	27.1	1	0.9	61	57.0	5	4.7	11	10.3	–	–
C7	1	5.6	–	–	13	72.2	4	22.2	–	–	–	–
Total	58		13	6.3	93	45.4	11	5.4	30	14.6	–	–

nearly half of the analysed cases. As in male vertebrae, the frequency of type 1 was greater in C2, but on the right side the form appeared more often as a lateral foramen, while on the left side it was usually the upper foramen of the vertebral canal. As in the case of male vertebrae, there was also a considerable difference in the frequency of occurrence of type 5 between the right (ca. 3%) and left (ca. 15%) sides, and it was statistically significant ($Chi^2=11.5$; $p=0.0007$) (Table 5).

The size of the foramina

The size of the foramina was estimated by measuring their longitudinal and transverse dimensions on both sides. The mean longitudinal dimension of FT was 5.2 mm (min. 3.6–max. 6.8), the transverse dimension was 5.6 mm (min. 4.6–max. 6.8). The mean values of the measurements were slightly greater for the male, compared to the female vertebrae. There was a noticeable decreasing tendency in FT from C1 to C7; the tendency applied to longitudinal and transverse measurements in both male and female vertebrae (Table 6). The differences between the sexes were statistically insignificant (T=0.335; p=0.738).

In the male vertebrae, FT of the left side had higher mean values. The highest values of the measurements were those of C2, the smallest of C7; this indicates

Table 6. Average values of standard deviation and variance measurements of FT in individual vertebrae in male and female skeletons

Vertebra	Measurement	Male				Female				Total			
		N	$\bar{x}$	SD	V	N	$\bar{x}$	SD	V	N	$\bar{x}$	SD	V
C1	transverse	85	5.5	1.5	2.2	43	5.8	0.9	0.9	128	5.7	1.2	1.6
	longitudal	85	6.8	1.8	3.3	43	6.7	0.9	0.8	128	6.8	1.4	2.1
C2	transverse f.lateral	87	7.1	1.3	1.7	54	6.4	1.0	1.2	141	6.8	1.2	1.5
	longitudal f.lateral	87	5.9	0.9	0.8	54	5.7	0.8	0.9	141	5.8	0.9	0.9
	transverse f.upper	87	5.6	1.0	0.9	53	5.3	0.9	1.3	140	5.5	1.0	1.1
	longitudal f.upper	87	5.5	1.0	1.1	53	5.4	0.9	0.5	140	5.5	1.0	0.8
C3–C6	transverse	355	5.6	1.9	3.5	228	5.3	1.8	3.0	583	5.5	1.9	3.3
	longitudal	355	4.6	1.7	2.7	228	4.4	1.6	2.6	583	4.5	1.7	2.7
C7	transverse	42	4.9	1.8	3.3	31	4.2	1.7	2.8	73	4.6	1.8	3.1
	longitudal	42	3.9	1.2	1.5	31	3.2	1.4	1.4	73	3.6	1.3	1.5
Total	transverse	656	5.7	1.5	2.3	409	5.4	1.3	1.8	1065	5.6	1.4	2.1
	longitudal	656	5.3	1.3	1.8	409	5.1	1.1	1.2	1065	5.2	1.2	1.5

Table 7. Average values of standard deviation and variance measurements of FT in individual vertebrae in male and female skeletons

Vertebra	Measurement	Right				Left			
		N	$\bar{x}$	SD	V	N	$\bar{x}$	SD	V
		Male							
C1	transverse	41	5.4	1.5	2	44	5.5	1.4	2.4
	longitudal	41	6.9	1.7	3.6	44	6.6	1.9	3.0
C2	transverse f.lateral	42	6.9	1.4	1.4	45	7.3	1.2	1.9
	longitudal f.lateral	42	5.9	1.0	0.6	45	5.9	0.8	1.0
	transverse f.upper	42	5.6	1.1	0.6	45	5.6	0.8	1.1
	longitudal f.upper	42	5.5	1.0	1.0	45	5.5	1.0	1.1
C3–C6	transverse	179	5.4	1.9	3.4	176	5.8	1.9	3.6
	longitudal	179	4.4	1.6	2.7	176	4.7	1.7	2.7
C7	transverse	22	4.6	1.6	3.9	20	5.2	2.0	2.6
	longitudal	22	3.7	1.1	1.7	20	4.1	1.3	1.3
		Female							
C1	transverse	18	5.7	0.8	1.0	25	5.8	1.0	0.7
	longitudal	18	6.7	0.8	0.9	25	6.7	1.0	0.7
C2	transverse f.lateral	26	6.4	0.7	1.8	28	6.4	1.3	0.5
	longitudal f.lateral	26	5.7	0.7	0.8	28	5.6	0.9	0.9
	transverse f.upper	26	5.3	0.7	0.9	27	5.2	1.0	1.7
	longitudal f.upper	26	5.3	0.7	0.5	27	5.4	1.0	0.4
C3–C6	transverse	121	5.2	1.7	3.1	107	5.4	1.8	2.9
	longitudal	121	4.3	1.6	2.6	107	4.5	1.6	2.6
C7	transverse	13	4.5	1.8	2.2	18	3.9	1.5	3.4
	longitudal	13	3.6	1.6	1.2	18	2.8	1.1	2.5

a cranio-caudal decreasing tendency in the foramen size (Table 7).

The female vertebrae showed no significant differences in the mean measurements of the right and left foramina (T=1.222; p=0.225). The largest foramina were those of C1, the smallest – of C7. As in the case of male vertebrae, there was a decreasing tendency in the size of FT in caudal direction (Table 7).

Roundness index

The most frequent type of FT was ultrabrachymorph, with the roundness index exceeding 116; such FT prevailed among both female and male vertebrae and constituted more than half of all FT. The frequency of occurrence of each foramen type increased with increasing roundness index. Comparison of the numbers of FT with respect to the roundness index in individuals of both sexes revealed that the tendencies were similar in both sexes. Also within each sex there were no significant differences between the right and left sides (T=0.988; p=0.330) (Table 8).

The least frequent form in male vertebrae was mesomorph, forming less than 5%. On the right side, the form did not appear in vertebrae C3–C7, and among the upper foramina of C2. The most frequent type was ultrabrachymorph, for some vertebrae constituting even more than 70% FT. Among all the foramina of the right side, there was a tendency to increase frequency with increasing roundness index. The exception was atlas, where the proportions were reversed: most FT were of the dolichomorph type. The pattern was true of both sides. In C2 the lateral and upper foramina of the right side were most often of the ultrabrachymorph type. The category was also the most frequent among the lateral foramina of the left side, but the upper foramina were mostly of brachymorph type (Table 9).

Table 8. The number of different categories of roundness index values for FT in male and female skeletons

Roundness index	Male		Female		Total	
	N	%	N	%	N	%
dolichomorph	48	7.3	19	4.6	67	6.3
mesomorph	32	4.9	31	7.7	63	5.9
brachymorph	87	13.3	51	12.4	138	12.9
hyperbrachymorph	139	21.1	93	22.7	232	21.8
ultrabrachymorph	350	53.4	215	52.6	565	53.1
Total	656	100	409	100	1065	100

Dolichomorph FT constituted the smallest percentage among the female vertebrae, ca. 5%. Mesomorph foramina formed less than 10%, and were absent in C3–C7 on the right side (as in male vertebrae) and C7 on the left side. The most frequent form was ultrabrachymorph, as among the male specimens; it formed more than half of FT, and among particular vertebrae more than 80%. In females, on the right side, there was also a tendency for the frequency of occurrence of foramina to increase with higher values of the index, and an opposite tendency among vertebrae C1. FT of C2 on the right side were mainly of the ultrabrachymorph type, as were the lateral foramina of the left side, whereas the upper foramina were mostly brachymorph (Chi^2=1.54; p=0.214) (Table 9). There were no statistically significant differences in the frequency of occurrence of FT of different values of roundness index between the right and the left sides of the female vertebrae.

Overall, in terms of numbers, single foramina were the most numerous (ca. 70%), double foramina formed ca 14%, triple foramina appeared only twice

Table 9. The number of FT by individual roundness index values in male and female skeletons

Vertebra	dolichomorph		mesomorph		brachymorph		hyperbrachymorph		ultrabrachymorph	
	N	%	N	%	N	%	N	%	N	%
Roundness index of the FT to the right of male										
C1	18	43.9	13	31.7	6	14.6	3	7.3	1	2.4
C2 lateral	1	2.4	2	4.8	7	16.7	9	21.4	23	54.8
C2 upper	6	14.3	–	–	15	35.7	13	31.0	8	57.8
C3–C6	1	0.6	–	–	15	8.4	43	24.4	120	67.0
C7	1	4.5	–	–	2	9.1	3	13.6	16	72.7
Total	27	8.3	15	4.6	45	13.8	71	21.8	168	51.5
Roundness index of the FT to the left of male										
C1	16	36.4	11	25.0	12	27.3	1	2.3	4	9.1
C2f lateral	–	–	1	2.2	4	8.9	14	31.1	26	57.8
C2 upper	3	6.7	2	4.4	20	44.4	9	20.0	11	24.4
C3–C6	1	0.6	1	0.6	5	2.8	43	24.4	126	71.6
C7	1	5.0	2	10.0	1	5.0	1	5.0	15	75.0
Total	21	6.4	17	5.2	42	12.7	68	20.6	182	55.1
Roundness index of the FT to the right of female										
C1	4	22.2	7	38.9	4	22.0	2	11.1	1	5.6
C2 lateral	–	–	1	3.8	4	15.4	10	38.5	11	42.3
C2 upper	3	11.5	5	19.2	6	23.1	5	19.2	7	26.9
C3–C6	1	0.8	–	–	8	6.6	31	25.6	81	66.9
C7	–	–	–	–	1	7.7	3	23.1	9	69.2
Total	8	3.9	13	6.4	23	11.2	51	25.0	109	53.4
Roundness index of the FT to the left of female										
C1	7	28.0	8	32.0	5	20.0	4	16.0	1	4.0
C2 lateral	–	–	3	10.7	4	14.3	7	25.0	14	50.0
C2 upper	2	7.4	5	18.5	10	37.0	6	22.2	4	14.8
C3–C6	2	1.9	2	1.9	9	8.4	22	20.6	72	67.3
C7	–	–	–	–	–	–	3	16.7	15	83.3
Total	11	5.4	18	8.8	28	13.6	42	20.5	106	51.7

among males. In male skeletons single foramina constituted usually more than 50% for each vertebra and ca. 70% for the whole cervical section (on both sides). Double foramina formed ca. 30 – 40% for particular vertebrae and 30% for all the cervical section. In females the frequency of single FT was 70% for each vertebra separately as well as for all the cervical section, double foramina constituted ca. 40% for particular vertebrae and not more than 25% in all the vertebrae on each side. It is noteworthy that in both sexes C2 had only single foramina. No statistically significant differences were found in any of the cases.

The most common foramen shape was type 3 (elliptical, with transverse axis); in both sexes it formed ca. 50%; type 1 (round) appeared somewhat less frequently, forming ca. 20–30%. The frequency of type 3 in males on both sides was ca. 40%, in females the value was slightly higher but did not exceed 50%. Type 1 in males constituted ca. 30%, most often occurring as the upper foramen of C2, in females the proportion was similar, but on the right side it was usually the lateral foramen and on the left side, the upper foramen. There were no significant differences in the occurrence of particular shapes of FT between the sexes. Within each sex there were significant differences between the frequency of type 5 (elliptical, with axis inclined to the left) and the remaining categories. Besides, among the male vertebrae the frequency of occurrence of type 4 (elliptical with axis inclined to the right) was in most cases statistically significantly different from that of type 5.

In both sexes and on both sides, there was a decreasing tendency in the measurements of FT from C1 to C7. Foramina transversaria in the male vertebrae had larger dimensions than in the female vertebrae. In the male vertebrae they were larger on the left side. The most common roundness category in both sexes was ultrabrachymorph (index > 116). There was an increasing tendency in the frequency of the index categories with their increasing values, only the atlas showed an opposite tendency. The least frequent (ca. 5%) category among the male vertebrae was mesomorph, in the female vertebrae, dolichomorph. Among the female vertebrae, mesomorph also showed a small proportion, and did not appear in C3 – C6 on the right side (as in male vertebrae) and in C7 on the left side. In both sexes the axis most often had ultrabrahymorph foramina, only the upper foramina on the left side were mostly brachymorph.

Discussion

It is commonly accepted that foramen transversarium (FT) is a single orifice; however, some authors, among others Roh et al. (2004), do not confirm this view. In the population they studied, an extra foramen transversarium appeared in as many as 74% of the examined vertebrae. In the population from Sypniewo, most vertebrae (ca. 70%) had a single foramen on each transverse process; double foramina formed only about 13%. Taitz et al. (1978) and Wysocki et al. (2003b) pointed also to the rare occurrence of triple foramina which was also confirmed in this study; such foramina appeared in the studied population only twice. According to Roh et al. (2004) more than one foramen appeared most often at the level of vertebrae C5 (30%) and C6 (38%). The studies on the 12th /13th c. material from the environs of Kielce (Wysocki et al. 2003b) confirmed the most frequent occurrence of double foramina in C6, and the least frequent in C3 (2.8%). Jaffar's (2004) results were similar: double foramina were the most frequent at the level of C6 (70%), while C2 had no extra foramina. The greatest variation in the number of foramina appeared in vertebrae at lower levels (C7–C6), which may be associated with the nerves running there. Similarly, in the population from Sypniewo, the greatest proportion of double FT was observed for vertebrae C3–C6 (ca. 30–40%). The frequency of different numbers of FT was similar between the sexes and between the right and left sides; statistical analysis showed no significant relationships between the frequencies of their occurrence.

According to Roh et al. (2004), the presence of extra foramina in the transverse processes may indicate multiplication of the number of structures running through them. Alhough the clinical significance of the fact is not completely clear, exact identification of supernumerary FT may prevent damaging such structures during surgery.

In some cases, a single foramen transversarium becomes double as a result of degenerative changes of the vertebra, osteophytes. Such a case was described by Sanchis-Gimeno et al. (2005), who found such anomalies in 10% of the examined vertebrae. Another variant is the absence of foramen in the transverse process of the vertebra. Such instances are rare, but a case was described in which the vertebra had no foramina in any of the processes. Such information appeared, among other sources, in papers by Taitz et al. (1978), Wysocki et al. (2003b) and Nayak (2007) who described a case of the absence of FT in C1, also pointing to the fact that the vertebra showed the greatest variety of form among all the cervical vertebrae. No such vertebrae were observed in the population from Sypniewo. Since foramen transversarium, with the many vessels, nerves and muscles in its vicinity, is an important reference point for radiologists or surgeons, its absence may cause problems when trying to locate some of these structures.

The shape and arrangement of foramina vary widely, 6 types of foramen transversarium have been distinguished in the literature. In the studies on skeletons from India (Taitz et al. 1978), the most frequent shape was elliptical with a transverse axis, the least frequent – elliptical with a longitudinal axis. In the material from Sypniewo, the most frequent type (ca. 50%) was elliptical with a transverse axis, round foramina being slightly less common. Particular shapes occurred at similar frequencies in both sexes. There was no statistical relationship between frequencies of particular shapes of FT. An exception in both sexes was type 5, elliptical foramen with an oblique axis inclined to the left, and among the male vertebrae also type 4 – elliptical with an oblique axis inclined to the right; in most cases its frequency differed significantly from those of the remaining types. These two shapes occurred in ca. 10% of vertebrae, and thus were not numerous, but often occurred on both sides of the same vertebra. A similar frequency of occurrence was characteristic of type 2 – elliptical, with a longitudinal axis, but in this case there was no significant correlation with any other shape.

The size of FT in vertebrae of recent individuals from the collection of Brussels University ranged from 5.3 to 6.9 mm (Cagnie et al. 2005). The size of FT in the studied mediaeval population from Sypniewo, characterised by longitudinal and transverse measurements, ranged from 3.6 to 6.8 mm, the male FT being slightly larger than female ones. According to the literature data, the diameter of vertebral artery ranges from 3.0 to 4.7 mm, and thus it does not occupy the whole available space. The artery on the left side is larger (Epstein 1969, according to Taitz et al. 1978; Waldron and Antoine 2002; Ronald 2002 according to Jaffa et al. 2004; Cagnie et al. 2005), which in the case of male vertebrae is compatible with the results of measurements of the material from Sypniewo. Taitz et al. (1978) and Cagnie et al. (2005) found that on both sides in both sexes the FT size decreased from C1 and C7. A similar tendency was observed in Sypniewo. There exists an opinion that the smallest size of FT in C7 reflects the fact that only venous blood is transported through them, while arteries join the FT canal at a higher level, most often at C6. This view is confirmed by Jaffar's et al. (2004) observation that the vertebral artery in 88% of cases enters the FT canal at the level of C6, and only in 5% of cases at the level of C7. He also points to the possibility of changes in the size of foramen transversarium by the proliferation of periosteum around the foramen margin, adjusting it to the vessels and nerves contained in the FT. According to Pamphlett et al. (1999), the size of vertebral artery decreases from C6 to C3, and then increases to the level of the atlas, where the movements of the head and neck exert a mechanical effect on the appearance of the vessels. The analysis of the size of foramen transversarium in the remains from Sypniewo and the literature information on both historical and modern populations indicate that the variation in the anatomical size of the left and right artery has not changed since at least the medieval period.

Another feature describing the foramen is the degree of its roundness expressed as the roundness index. Taitz et al. (1978) distinguished five categories. The most common variant was mesomorph, the most rounded foramen, the least frequent, dolichomorph, with a distinct prevalence of longitudinal over transverse dimension (index below 75.9), and found only in the atlas. In the examined population from Sypniewo, the higher the value of the roundness index, the more frequent was the category. Accordingly, the most frequent variant was ultrabrachymorph (roundness index exceeding 116), with the transverse dimension much smaller than the longitudinal dimension. Only the atlas and, in a few cases, the axis departed from the scheme, with their foramina most often having the roundness index below 100 (brachymorph) in the case of C2, and even below 86 (mesomorph, dolichomorph) in the case of C1, with longitudinal dimensions showing higher values. The more frequent occurrence of certain categories of foramina may be associated with the mechanical stress resulting from head movements. Head and neck movements, such as stretching or turning, by exerting pressure on the vessels, have an effect on the blood flow in the vertebral artery at the level of the axis-atlas joint. During rotational movements, the length of the artery may change by ca. 10% at the side opposite to the direction of the rotation. Changes in the course of vessels resulting from excessive movement may be reflected in the appearance of foramen transversariun. Cacciola et al. (2004) point to the variety of form of the vertebral artery and the shape, size and position of its grooves on the surface of vertebrae C1 and C2; one of the ways in which the artery prevents stretching is forming loops and thus increasing the length, as well as increasing the space in the arterial groove on the atlas arch and the lower parts of articular surfaces of the axis. These observations provide a proof for the dynamic relation between the artery, its groove and the possible changes of position during neck movements. According to these authors, the artery occupies on average ca. 79% of the space available in the groove of C2 and only 57% of C1, and the values decrease with age. Little free space of the grooves may lead to vertigo during vigorous neck movements.

Cacciola et al. (2004) maintain that the vertebral artery shows the greatest variation at the level of C1 and C2; in the lower regions of the vertebral column its course is simpler, hence, the upper region is particularly sensitive to damage during surgery. This is supported by the fact that FT of the second vertebra runs partly through the lower part of the upper articular surface of the vertebra, while in the other vertebrae the FT are wholly contained in the transverse processes, and by the position of the upper articular surfaces of C2 near the vertebral body and not – contrary to the other vertebrae – near the posterior arch, as a result of which the artery often forms a loop upon leaving the atlas. Some authors suggest that the tortuous course of the artery may be an acquired deformity resulting from a combination of many disorders, for example sclerotic changes or formation of osteophytes (Hadley 1958, Babin and Haller 1974 according to Ekinci et al. 2001). Others, based on examining young patients without any vascular anomalies or other disorders maintain that the course of the artery is an inborn feature (Sganzerla 1987, according to Ekinci et al. 2001). A similar hypothesis about the inborn, and also hereditary nature of the artery course was advocated by Viswani and Waldron (1997). It was based on the observation of changes in the course of vertebral artery in the same place in over one hundred skeletons from the same period (15th c.), but the authors emphasised that there was no sufficient evidence supporting this theory.

Also venous blood passes through the canal formed by the foramina. Analogously to vertebral arteries, the organisation of veins may also have an effect on the appearance of FT. Palombi's et al. (2006) studies suggest the absence of typical veins within the canal, and the venous blood is probably transported within the spaces limited by the periosteum and not formed by fusion of single veins.

An important factor which affects the normal function of the vertebral-basal system is the place of origin of the vertebral artery. It is normal and most frequent for it to branch off from the subclavian artery and enter FT at the level of C6. However, there are known cases of the vertebral artery branching directly off the arch of aorta – between the common carotid artery, and the subclavian artery, and entering FT most often at the level of C5, but sometimes also at C4 or C7. The right artery may also originate as the last branch of the aorta or directly from the left vertebral artery (Schwarzacher and Kramer 1989; Goray 2005 according to Ikegami et al. 2007; Ikegami et al. 2007). It is very rare for the changes in the origin of the artery to occur on both sides (Adachi 1928 according to Ikegami et al. 2007). The system of vertebral-basal arteries supplies blood directly to the brain and the spinal arteries; abnormal branching of vertebral arteries may cause deficient blood supply to the cerebellum and the brainstem, which poses a threat to the vascular-cerebral condition and function (Schwarzacher and Kramer 1989).

Authors' contributions

BK conception and design, data analysis and interpretation, drafting the manuscript, critical revision of the manuscript for scientific and factual content, JSz conception and design, data collection, analysis and interpretation, drafting the manuscript, critical revision of the manuscript for scientific and factual content, DN conception and design, data analysis and interpretation, drafting the manuscript, critical revision of the manuscript for scientific and factual content, supervision.

Conflict of interest

The authors declare that there is no conflict of interests regarding this publiciation.

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