VIA MEDICA

ORIGINAL ARTICLE

Folia Morphol.
Vol. 82, No. 3, pp. 587–595
DOI: 10.5603/FM.a2022.0066

ISSN 0015–5659
eISSN 1644–3284
journals.viamedica.pl

Foramen magnum morphometry in children based on computed tomography examination

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[Received: 13 March 2022; Accepted: 17 May 2022; Early publication date: 8 July 2022]

Background: The foramen magnum is the largest opening at the base of the skull. The dimensions of the foramen magnum are of significant clinical importance because of the vital structures that pass through it. The aim of the study was the morphometric analysis of the foramen magnum in children based on head computed tomography (CT).
Materials and methods: The study was carried out on 84 CTs of the head of children aged 0–18 years; seven age groups were distinguished. The sagittal and transverse dimensions were measured to determine the growth rate, changes between groups, and differences in the foramen size by sex. Statistical analysis of changes was performed.
Results: The entire group's mean transverse and sagittal dimensions were 29.08 mm (standard deviation [SD] 3.4 mm) and 35.63 (SD 4.23) mm. By sex, the mean transverse dimension in girls was 28.53 (SD 3.25) mm, and in boys, 29.6 (SD 3.49) mm. The mean sagittal dimension was 35.15 (SD 3.76) mm in girls and 36.09 (SD 4.64) mm in boys. Both dimensions were higher for the male sex. A statistically significant increase in the foramen magnum size was demonstrated up to the age of 36 months in the following age groups; above that age, the increase was statistically insignificant.
Conclusions: The dimensions were similar to those described in adults a moderate dependence of the foramen magnum size on age was found. (Folia Morphol 2023; 82, 3: 587–595)

Key words: morphometry, foramen magnum, computed tomography, children

INTRODUCTION

The foramen magnum (FM) is surrounded by all parts of the occipital bone. It connects the posterior fossa with the vertebral canal allowing the correct relationship between the skull and the cervical spine. The FM research is the subject of interest to many biological sciences such as anatomy, anthropology, and forensic medicine [1, 10]. FM measurements are of great importance in skull base surgery and greatly facilitate the diagnosis of various diseases that develop in this area [6, 18]. In anthropology and forensics, the skull exhibits features of sexual variability and is used to determine gender with 80% accuracy [9, 20]. Anthropometric studies on FM concerning sex differences conducted on macerated skulls concluded that the transverse and sagittal dimensions of the FM in

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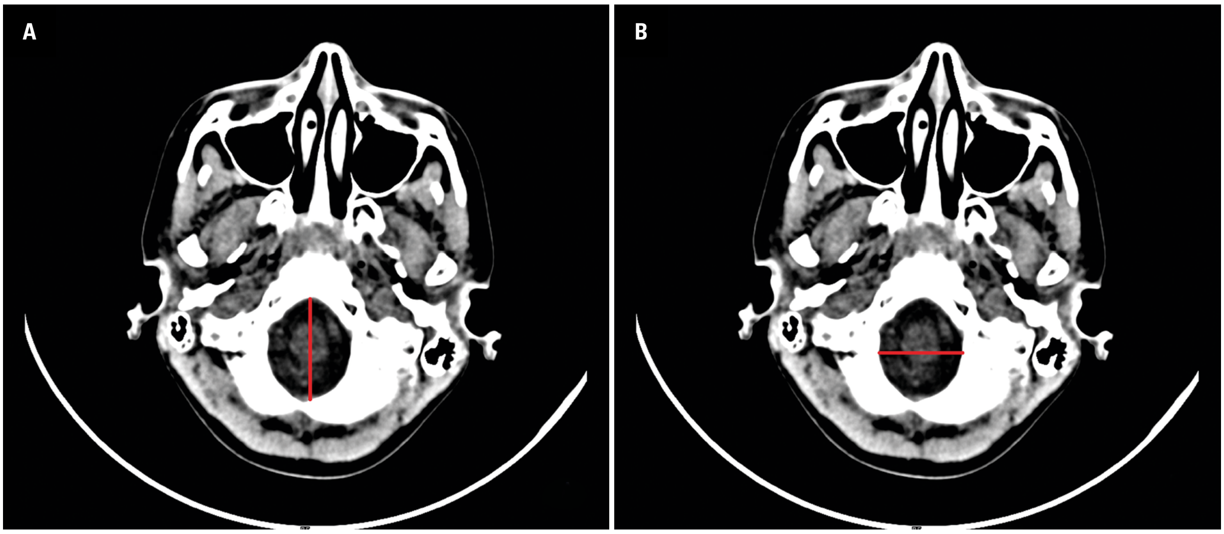

Figure 1. A. The sagittal dimension; **B.** The transverse dimension.

men were greater than in women [20]. Further studies in this field based on computed tomography (CT) and magnetic resonance imaging [15, 32] confirmed this correlation.

There is no precise data on FM dimensions change with age in children. Morphometric skull examinations in children are performed when the cranial development disorders are suspected or to assess the progress of the disease or treatment. The dimensions of FM are essential in many developmental malformations [6, 22] or skull deformities resulting from various diseases [3, 12, 18, 20]. In all these cases, the dimensions of the FM are altered, overlapping the developmental changes in FM size depending on the child's age. Therefore, it seems reasonable to determine the average dimensions of FM for individual age groups and depending on sex. The aim of the study was the morphometric analysis of FM in children of different ages based on CT examination to determine the growth rate of FM with age, based on sagittal and transverse dimensions and sex differences in each age group.

MATERIALS AND METHODS

Study group

A retrospective study was conducted on 84 (41 girls and 43 boys) selected head CT scans from patients diagnosed at the Independent Public Clinical Hospital No. 6 at the Medical University of Silesia in Katowice. The research material included CT images obtained from Polish Caucasian children aged 0 to 18 years referred for imaging examinations due to various medical reasons. Patients were defined as "without any changes" in the opinion of experienced radiologists. The exclusion criteria of the morphometric analysis were; incorrect patient positioning, artefacts (patient movement, blurred scan), detected trauma in the occipital bone area, and abnormal FM shape. The CT examinations were performed using Somatom Plus 4 CT scanner in spiral technique and the standard diagnostic protocol for head examination. Morphometric analysis and linear measurements of FM on CT images were performed using the Onis Dicom Viewer. The cross-sections of the head were carried out parallel to the Frankfurt plane at the level of the FM. The following were measured: the sagittal — basion — opisthon distance (APD) and transverse dimension in its highest width (TD) (Fig. 1) [15]. Statistical analysis was performed in Statistica 13.3 StatSoft PL. The patients were divided into age groups: 0–12 months, 12–36 months, 3–6 years, 6–9 years, 9–12 years, 12–15 years, and 15–18 years. The following variables were calculated for each group, depending on sex: the minimum and maximum of both FM dimensions, mean, standard deviation (SD), and median.

Additionally, the Pearson's correlation coefficients on the growth rate with age for both dimensions were calculated. To analyse the differences between adjacent age groups and by gender, the Student's t-test was calculated, assuming that $p < 0.05$ is statistically significant. Because this is a retrospective study, it does not require the consent of the Bioethics Committee.

Table 1. The results obtained for the sagittal and transverse dimensions of foramen magnum for the study group

Variable	N	Min [mm]	Max [mm]	Mean [mm]	Median	SD
Sagittal dimension	84	24.79	43.09	35.63	36.29	4.23
Transverse dimension	84	19.27	35.62	29.08	29.53	3.4

N — number of patients; Min — minimum; Max — maximum; SD — standard deviation

Table 2. Sagittal dimension and transverse dimension values of foramen magnum obtained in a particular age group

Age group	N	Min [mm]	Max [mm]	Mean [mm]	Median	SD	P
Sagittal dimension							
0–12 months	12	24.79	32.33	29.84	30.30	2.30	
12–36 months	12	27.21	37.85	33.76	34.86	3.41	< 0.01
3–6 years	12	29.46	41.61	34.84	33.95	3.79	0.47
6–9 years	12	32.38	42.51	36.72	35.70	3.82	0.24
9–12 years	12	30.72	42.9	38.32	38.45	3.25	0.28
12–15 years	12	33.74	43.09	38.74	38.48	3.24	0.75
15–18 years	12	32.74	39.83	37.19	37.65	2.16	0.18
Transverse dimension							
0–12 months	12	19.27	27.93	23.66	23.90	2.12	
12–36 months	12	24.76	32.37	28.16	27.99	2.57	< 0.01
3–6 years	12	23.36	33.46	29.26	29.41	3.13	0.36
6–9 years	12	26.43	34.64	30.04	29.51	2.20	0.49
9–12 years	12	27.51	33.78	31.03	31.65	2.43	0.31
12–15 years	12	25.24	35.62	30.90	31.19	2.51	0.9
15–18 years	12	27.28	35.08	30.49	30.17	2.33	0.68

N — number of patients; Min — minimum; Max — maximum; SD — standard deviation; P — statistical significance coefficient between adjacent age groups

RESULTS

The results obtained for the entire study group (n = 84) are presented in Table 1. The normal distribution of both dimensions was checked and confirmed. The mean value of both dimensions was statistically significantly higher in boys than in girls (Table 2). The mean values of both dimensions for the entire group and by gender are presented in Figure 2. The dimensions of the FM in individual age groups are presented in Table 3. Pearson's correlation coefficient for the sagittal dimension (APD) and for the transverse dimension (TD) with age was r = 0.59 and r = 0.56, respectively. Both coefficients indicated a moderate relationship between the size of FM dimensions and age. After determining the significance level for all age groups, only between groups of 0–12 months and 12–36 months, the changes for both the APD and TD were highly statistically significant ($p < 0.01$). The mean APD values in the individual age groups showed a slight increase with age up to 12 years. Only between groups of 12–15 years and 15–18 years, a decrease in the value of this dimension was observed (Fig. 3). In TD, an increase in the value of the dimension between individual age groups was observed up to the age of 12 years; however, these changes were not statistically significant, the changes between groups 9–12 years to 12–15 years and

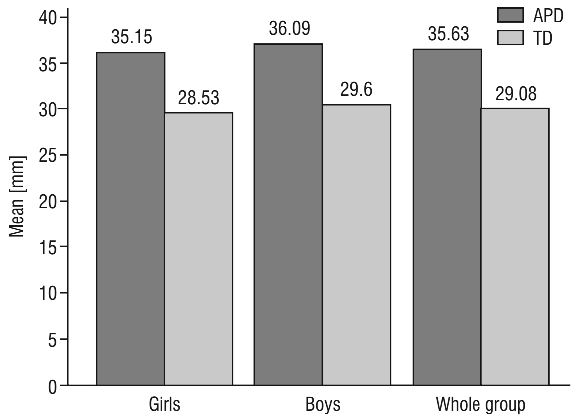

Figure 2. Mean values of sagittal dimension (APD) and transverse dimension (TD) obtained for the whole group and by sex.

Table 3. The results obtained for the sagittal and transverse dimensions of foramen magnum for the study group by sex

Variable	Sex	N	Min [mm]	Max [mm]	Mean [mm]	Median	SD
Sagittal dimension	Girls	41	28.17	42.9	35.15	35.42	3.76
	Boys	43	24.79	43.09	36.09	36.78	4.64
Transverse dimension	Girls	41	22.54	35.08	28.53	28.81	3.25
	Boys	43	19.27	35.62	29.6	30.06	3.49

N — number of patients; Min — minimum; Max — maximum; SD — standard deviation

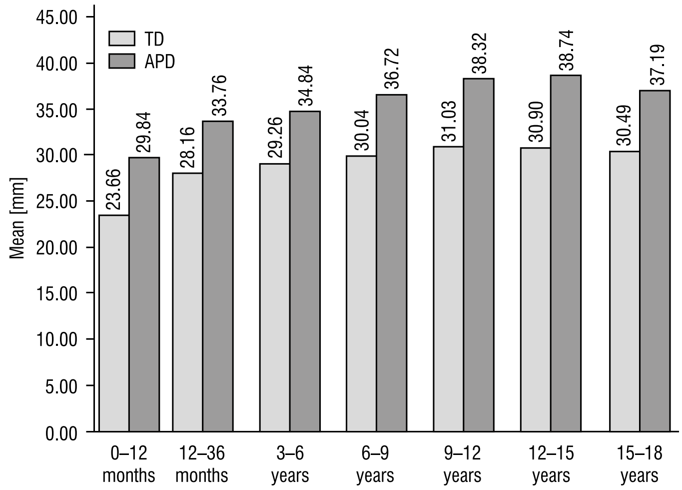

Figure 3. Mean values of the sagittal (APD) and transverse dimension (TD) obtained for a particular age group.

12–15 years to 15–18 years groups show the decrease of the value (Fig. 3).

When comparing both FM dimensions obtained in individual age groups, an increase up to 12 years of age was noted; however, in older age groups, these values slightly decreased (Fig. 3). After analysing the descriptive statistics for the APD and TD for all age groups, the same groups were analysed by gender. In the analysis of changes in APD in individual age groups for girls, the increase in dimension was visible between the youngest 0–12 months group and 12–36 months group, as well as between 3–6 years and 6–9 years group; above this age the dimension remained at a similar level (Table 4). In boys, APD in the 0–12 months group was lower than in girls, and in the 12–36 months group, over the age of 3, the values for both sexes were similar; APD increase was visible up to the age of 12 years. In the oldest group, the mean APD values in girls and boys were identical (Table 4). The TD of the FM showed significantly lower values than APD in the corresponding age group. In girls, the increase in FM size was visible between the age groups of 0–12 months, 3–6 years, and 6–9 years, with the most significant changes between those groups, then the FM size remained at a similar level (Table 5). Although there were some exceptions, the TD dimensions measured in boys in most study groups were higher than in girls. The most significant increase in the mean in TD was visible between the age groups of 0–12 months, 12–36 months, and 3–6 years; then, the size of the foramen did not change significantly. There were also the most significant changes in dimensions between the age groups. In the oldest age group of boys (15–18 years), there was a substantial decrease in the mean extent from 35.62 to 31.1 mm (Table 5).

The differences in the dimensions of the FM between the sexes were not significant, although noticeable in most age groups. APD was higher in boys than in girls (except for the 0–12 months group). The most significant difference was observed in the 12–15 years group ($p < 0.02$), and in the other groups, the differences were not statistically significant ($p > 0.05$) (Table 4). As in the case of APD, the differences in TD between girls and boys in individual age groups were noticeable but not significant. The most remarkable differences were observed in the 12–15 years group ($p < 0.02$) and the 3–6 years group ($p < 0.05$), in the

Table 4. Sagittal dimension values of the foramen magnum obtained by sex

Age group	Sex	n/%	Min [mm]	Max [mm]	Mean [mm]	Median	SD	P
0–12 months	Girls	6/50%	28.17	32.33	30.45	30.30	1.47	0.39
	Boys	6/50%	24.79	31.93	29.24	29.75	2.93	
12–36 months	Girls	3/25%	29.99	35.68	33.7	35.42	3.21	0.97
	Boys	9/75%	27.21	37.85	33.78	34.3	3.67	
3–6 years	Girls	5/41.7%	29.46	37.52	32.47	31.7	3.02	0.06
	Boys	7/58.3%	31.73	41.61	36.54	37.45	3.5	
6–9 years	Girls	7/58.3%	32.28	42.51	35.69	34.66	3.38	0.29
	Boys	5/41.7%	32.41	42.16	38.16	39.6	4.31	
9–12 years	Girls	6/50%	30.72	42.9	37.97	38.48	4.09	0.73
	Boys	6/50%	34.54	42.09	38.66	38.45	2.48	
12–15 years	Girls	6/50%	33.74	40.59	36.69	36.63	2.49	< 0.02
	Boys	6/50%	36.65	43.09	40.79	41.61	2.61	
15–18 years	Girls	8/66.7%	32.74	39.83	37.13	37.71	2.45	0.90
	Boys	4/33.3%	35.12	39.01	37.31	37.56	1.73	

n/% — number of patients/percent; Min — minimum; Max — maximum; SD — standard deviation; P — statistical significance coefficient

Table 5. Transverse dimension values of the foramen magnum obtained by sex

Age group	Sex	n/%	Min [mm]	Max [mm]	Mean [mm]	Median	SD	P
0–12 months	Girls	6/50%	22.54	24.62	23.78	23.9	0.82	0.86
	Boys	6/50%	19.27	27.93	23.54	23.47	3.03	
12–36 months	Girls	3/25%	24.76	27.37	26.12	26.23	1.31	0.12
	Boys	9/75%	25.09	32.37	28.85	29.62	2.57	
3–6 years	Girls	5/41.7%	23.36	30.91	27.2	27.06	3.16	< 0.05
	Boys	7/58.3%	27.7	33.46	30.74	31.45	2.28	
6–9 years	Girls	7/58.3%	27.4	34.64	30.16	29.55	2.27	0.83
	Boys	5/41.7%	26.43	32.31	29.87	29.44	2.33	
9–12 years	Girls	6/50%	27.51	33.78	29.89	28.62	2.7	0.11
	Boys	6/50%	29.51	33.75	32.17	32.21	1.6	
12–15 years	Girls	6/50%	25.24	31.65	29.3	29.7	2.18	< 0.02
	Boys	6/50%	30.99	35.62	32.5	31.82	1.73	
15–18 years	Girls	8/66.7%	27.28	35.08	30.8	30.03	2.66	0.55
	Boys	4/33.3%	27.53	31.1	29.88	30.45	1.63	

n/% — number of patients/percent; Min — minimum; Max — maximum; SD — standard deviation; P — statistical significance coefficient

other groups, the differences did not show statistical significance ($p > 0.05$) (Table 5).

DISCUSSION

The morphometry of the foramen magnum is of great clinical importance. The shape and size of FM are subject to changes in craniocervical region pathologies, which compresses the structures that pass through it and causes several undesirable symptoms [15]. Determining the dimensions of FM is vital in the case of many developmental defects [6, 22]. Knowing the dimensions of the FM is essential for diagnosing many diseases. Still, it is also invaluable in planning surgical interventions within the skull base, for example, in the case of craniovertebral stenosis or FM meningioma [3, 12]. The reduction in the size of the FM is found in patients with achondroplasia due to significantly lower skull base growth due to premature bone fusion [22]. In the case of patients with Chiari I and II malformations, the dimensions of FM were more significant than in the healthy population (mainly transverse) as a consequence of the appearance of the cerebellar tonsil herniation and the displacement of brain structures toward the spinal canal and the deformation of FM as an effect of intracranial pressure [4, 6, 19]. In anthropology, morphometric studies help to determine the anthropometric differences between populations, such as ethnicity, sex, age, genetic factors, eating habits, and regional changes related to the living environment, which may influence the shape and size of bone structures [11] but also distinguish the norm from a pathological condition [33]. In the case of forensic examinations, the skeleton is often incomplete, making it challenging to identify sex, so the dimensions of FM and other features of the skull base can be used for this purpose [11]. Analysing the function of FM, Vinutha et al. [32] stated that no muscles influence changing its shape and size. The shape and size of FM are essential parameters in determining risk factors in patients with craniovertebral anomalies [21, 26], the normal range of its APD and TD is significant.

In most FM studies, the results came from the measurements taken in adults, both with macerated skulls and with imaging studies [10, 14, 32]. Research on children is rare and therefore presented results have additional value. The mean APD calculated for the entire study group of children was 35.63 (SD 4.23) mm. The mean TD was 29.08 (SD 3.4) mm, which indicates a certain disproportion between TD and APD which is similar to the observations made by selected other authors [5, 20].

Analysing the age groups, More et al. [14] compared two age groups of children: 0–9 years and 10–19 years group using CT examination. In the study cited, in the age group 0–9 years, the mean of APD was 36.00 (SD 6.93) mm, and TD was 27.85 (SD 0.64) mm. In the 10–19 years, both dimensions were 35.70 (SD 3.38) mm and 29.45 (SD 2.86) mm, respectively. By averaging the results obtained in our study for the group of 0–9 years, the APD was 33.79 (SD 4.15) mm, TD for the same group 27.78 (SD 3.5) mm. In the 10–18 years group, the values were 39.39 (SD 2.92) mm for APD and 30.81 (SD 2.37) mm for TD. Both studies show some discrepancies, especially in APD of the foramen magnum, caused most likely by the population differences (Indian population), sample size (250 CT examinations), and the measurement technique; in TD, the differences between both studies were slight. Our study group was divided into smaller age groups covering shorter periods of a child's development, making it possible to analyse FM changes according to age.

The presented study showed a moderate dependence of the increase in FM's sagittal and transverse dimension with age (APD, $r = 0.59$; TD, $r = 0.56$). The research conducted by Samara et al. [23] found a weak negative linear correlation between the age of the subjects and both dimensions measured (APD, $r = -0.15$; TD, $r = -0.14$). In our work, slight changes were observed between adjacent age groups. However, most of these changes didn't show statistical significance ($p > 0.05$). Only for groups 0–12 months and 12–36 months the difference was highly statistically significant ($p < 0.01$), proving FM's rapid growth in this period.

The mean values of foramen magnum APD and TD presented in our work were similar to studies based on adults. In a survey by Radhika et al. [21] conducted on 150 macerated skulls of an adult Indian population, the mean APD was 35.30 (SD 2.7) mm, and the mean TD was 29.49 (SD 2.6) mm, which was close to the mean values of the entire study population obtained in our research. In similar studies conducted by Patel and Mehta [19] and Ganapathy et al. [7] on the Indian population of adults, the results were within one SD compared to the results of our work.

The study by Osunwoke et al. [17] showed results very close to ours in the skulls of the African population of adults, the same as Natsis et al. [16] in their studies conducted on the Greek people of adults and Pires et al. [20] in the Brazilian population. In the studies by Gruber et al. [8] carried out on the skulls of adults in the European population, the mean APD was 36.6 (SD 2.8) mm and the TD 31.1 (SD 2.7) mm, which were higher than the values obtained in our study, but still in the range of one SD. The results of Chethan et al. [5] obtained in the Turkish population in adults showed results slightly lower than those presented in our study, the same as Tubbs et al. [29] in the Caucasian population. At the same time, they didn't notice any significant differences in the dimensions of FM between different sexes. The study of Ulcay et al. [30] conducted in the Turkish population showed the mean APD at 35.81 mm and TD at 28.14 mm, which were similar to our results. Additionally, they suggested evaluating the shape of the FM predicted from the primary cranial index and measurements.

Based on the data presented above, it can be concluded that the results obtained by us in children did not differ significantly from the results obtained by other authors in adults. In some cases, the FM dimensions of adults [5, 9, 25, 29, 30] were lower or higher than the mean values obtained by us in children. The differences from the presented data could be due to race differences, the measurement method used, or the sample size.

The increase of both measured dimensions in the present study was observed up to the age of 12, the changes were slight, and the most significant growth was visible up to the age of 3 and then slowed down. Shepur et al. [25] and Shmeltzer [24], in their study, stated that FM reaches its maximum size in early childhood, which is in line with our results if we take into consideration statistically significant changes; however, slight changes are still visible up to the age of 12 years. On the other hand, those studies confirmed that FM does not undergo significant secondary sexual changes during adolescence [24, 25] which is in line with our research. This may indicate that the size of FM increases to this age and then does not change; the same changes between individual age groups did not show statistically significant differences over the age of 3 years old.

In the case of the sex division in most analysed studies [5, 19], there was no certainty about the sex of the examined skulls, so they were studied together, or there were no sex differences in the FM dimensions described [5]. In our studies, taking gender into account, the mean APD value for girls was 35.15 (SD 3.76) mm, and for boys, it was slightly higher, reaching the value of 36.09 (SD 4.64) mm. The mean TD was lower for girls, 28.53 (SD 3.25) mm, while 29.6 (SD 3.49) mm for boys. Due to the lack of studies on children available in literature, the obtained results were compared, as before, with the results of adults. The results are similar to those obtained in our work, with differences within one SD from the mean. Manoel et al. [11], in the studies of Brazilian adult skulls, showed that APD in women was 35.1 (SD 3.3) mm and in men 35.7 (SD 2.9) mm, TD was in the range of 29.4 (SD 2.3) mm in women and 30.3 (SD 2.0) mm in men, obtained results were similar to our results. Samara et al. [23] and Moodley et al. [13] showed identical results. Studies by Shepur et al. [25], carried out in 150 adult skulls, presented results lower than ours obtained in children. Another study conducted by Murshed et al. [15] showed slightly higher results than the results obtained in our study. The results in women were lower but in men were higher than ours. Studies on skulls in the Polish adult population by Tomaszewska et al. [28] also confirmed smaller dimensions of FM in women compared to men, which was consistent with the correct sex classification of skulls in 90% of cases.

The examination of the skulls based on CT also confirmed sexual dimorphism of FM in terms of both measured morphometric dimensions, confirming their higher values in men than in women. Burdan et al. [2], in a study based on CTs of Polish adults, noted statistically significant differences in the dimensions of APD and TD between women and men; however, their results were higher than the values obtained in the presented study. Results of Tellioglu et al. [27] based on CT of adults in the Turkish population also showed results that go along with ours in women and men for both dimensions measured. Uthman et al. [31] showed results lower than ours, obtained in the Arabic population of adults; however, the study by Ilgüy et al. [9] on the European population presented the results a little higher than ours both for women and men.

Considering the results of all the studies mentioned above, it can be concluded that the results obtained in this study and the data available in the literature are comparable. In adults, the shape of FM shows interpersonal changes, and its determination is difficult to assign to strict classification [27]. However, it should be noted that sex differences in FM dimensions and their shape should be considered when performing clinical and radiological diagnostics and during preparation for surgical procedures [15].

CONCLUSIONS

Based on the results obtained and data from the analysed literature, it has been shown that the FM has the shape of an oval, where the sagittal dimension is greater than the TD. Both the sagittal and the TDs of the FM correlate poorly with age, so age is not a criterion for determining the dimensions of FM above 12 months of age. There are visible differences in FM dimensions depending on gender; higher values of FM dimensions were found in men, both children and adults.

Conflict of interest: None declared

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