Institute of Experimental Morphology, Pathology and Anthropology with Museum
Bulgarian Anatomical Society

Acta morphologica et anthropologica, 26 (1-2)
Sofia ● 2019

Morphological Study of Jugular Foramen in Bulgarian Adults

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Abstract

The size and shape of jugular foramen (JF) vary widely in different populations. This study aimed to investigate the size of JF in relation to sex and laterality and to establish the incidence of a domed bony roof and complete osseous bridging of the JF in Bulgarian adults. Head computed tomography scans of 148 individuals (66 males and 82 females) were used in the study. Three-dimensional surface models of the skulls were generated from the computed tomography images. The JF measurements were calculated based on the three-dimensional coordinates of definite landmarks located on the JF margin.
The JF differed significantly between males and females in its mediolateral diameter. Bilateral differences were found only in the anteroposterior diameter in males, which was greater on the right side. The domed bony roof was more common in males. The complete osseous bridging of the JF was equally frequent in both sexes.

Key words: jugular foramen, CT, 3D models, sex differences, laterality.

Introduction

The jugular foramen (JF) is a paired bony opening on the cranial base. It is located between the occipital bone and the petrous part of the temporal bone, behind the carotid canal and laterally and anterior to the *foramen magnum*. The JF is transmitted by the inferior petrosal sinus, the glossopharyngeal (IX), vagus (X), and accessory (XI) nerves, the sigmoid sinus becoming the internal jugular vein and some meningeal branches of the occipital and ascending pharyngeal arteries. The JF is conditionally divided into three portions: a smaller anteromedial (petrosal) part, which receives the drainage of the inferior petrosal sinus; a larger posterolateral (sigmoid) portion, which receives the drainage of the sigmoid sinus; and an intermediate (intrajugular) part through which the nerves pass. The structures traversing the foramen are essential for its bony configuration, since these structures develop first and the bone develops secondarily, encircling them [17].

The JF is the most important venous foramen of the skull [32] and the most complex of the foramina through which the cranial nerves pass [17]. It has irregular shape and curved course. In fact, although the JF is referred just as a foramen, it is a canal linking its endocranial to the ectocranial opening [20]. The JF has been previously studied mainly because of its clinical significance. Various congenital, vascular, and tumor lesions can involve the foramen and structures passing through it [27]. The JF could be affected by glomus jugulare tumor, paragangliomas, intracranial meningiomas, schwannomas, metastatic lesions and infiltrative inflammatory processes from surrounding structures [15, 19, 27]. Difficulties in the surgical exposure of this foramen arose from its deep location and the surrounding vital structures, such as the carotid artery, the hypoglossal nerve, the facial nerve and the vertebral artery [15]. The morphology and morphometry of JF are important for neurosurgeons dealing with lesions occupying this region [22]. Besides, morphometric analysis of the JF is crucial for radiologists to predict the chances of preserving nervous and vascular structures intact during surgical interventions [27]. Knowledge of JF dimensions is also important in the diagnosis of JF stenosis or widening [2].

The JF size and shape vary among different skulls and within the same skull from side to side and from its intracranial to extracranial opening [17]. Variations in the JF size have been mainly studied on dry skulls [2, 5, 7, 13, 14, 15, 19, 20, 22, 23, 26, 27, 28, 31, 32]. The JF has been also examined on CT images, but in search of an association between JF side dominance and hand preference [1]. However, medical CT images allow more thorough examination of the JF morphology, providing the possibility for accurate measurements and observation of the foramen from different aspects. Besides, the medical CT is a superior technique to the microsurgical anatomy with dissecting microscope, which also has been used for examination of the JF morphology and especially of its contents [29].

The JF is one of the most variable anatomical structures at the skull base [29]. Its size and shape vary in different populations and sexes [15]. There have been few studies on the sexual dimorphism in the JF size, establishing the presence of sex differences in Brazilians [23] and Poles [32], but absence of such differences in Turks [5]. In addition, some morphological traits of the JF such as dome bony roof and complete osseous bridging could be found with varying frequency among different populations. Since the extreme variations in the JF size and shape could put at risk the neurovascular structures transmitted by the foramen, it is important to know the norm and extremes in the JF morphology in different populations. However, there are no such data reported for the Bulgarian population. Therefore, the present study aimed to investigate the size of jugular foramen (JF) in relation to sex and laterality and to establish the incidence of a domed bony roof and complete osseous bridging of the JF in Bulgarian adults.

Material and Methods

A sample of 148 individuals (66 males and 82 females) was used in the study. The mean age of the males and females was 59.2±17.2 years and 59.3±18.1 years, respectively. All subjects were scanned using a Toshiba Aquilion 64 CT scanner. The scanning protocol was as follows: 32 × 0.5 mm detector configuration, tube voltage of 120 kV, tube current up to 500 mA, exposure time of 0.5 s, and total scan time of 6.5 – 7.0 s. Images were reconstructed with a 512 x 512 reconstruction matrix, 0.5 mm slice thickness and 0.3 mm reconstruction interval using convolution kernel FC81. The study sample did not include individuals with pathological lesions on the skull base. The study was approved by the Ethics Committee at IEMPAM-BAS.

The DICOM series of each individual was imported into the free software 3DSlicer [10], where the bone tissue was segmented using grayscale thresholding (226 – 3071 HU) and a bone mask was created for every image. Subsequently, the bone mask from the whole image stack was converted to a three-dimensional (3D) mask. Based on the outer contours of the mask, a surface 3D model was acquired and exported in PLY format. Afterwards, each 3D model was imported into software MeshLab [6], where the vertebrae were deleted and the skull base was exposed. The same software was used to pick landmarks located on the JF margin. The landmarks were placed on both endo- and ectocranial openings of the JF. Based on the 3D coordinates of these landmarks, the endo- and ectocranial JF measurements were calculated as Euclidean distances (**Fig. 1a-b**). The computation of these distances was performed in the software PAST [12]. The measurements of JF were calculated for both right and left side. The mediolateral diameter of JF (MLD) was measured between the most lateral (JF_{lat}) and the most medial (JF_{med}) point of the JF margin. The anteroposterior diameter (APD) was measured perpendicular to the mediolateral axis, in the widest part of the JF. An index of JF (IJF) was computed between the APD and MLD (IJF=APD/MLD*100) regarding the ecto- and endocranial measurements. Furthermore, ectocranial distances between the most lateral as well as the most medial landmarks of the right and left JF were calculated (**Fig. 1c**). An angle of inclination of the mediolateral axis of the JF (AIJF) toward the line passing through both right and left most lateral JF points was calculated for each side (Fig. 1d). The angle was computed as follows: firstly, a triangle between the most lateral and the most medial points of the JF on the one side and the most lateral point of the JF on the opposite side was constructed; secondly, its sides were reckoned as Euclidian distances; and thirdly, the angle was calculated using the Law of Cosines. In addition, the 3D coordinates of the midsagittal landmarks *basion* and *opisthion* were taken to assess the outlying of the most medial and most lateral points of the JFs from them (**Fig. 1e**).

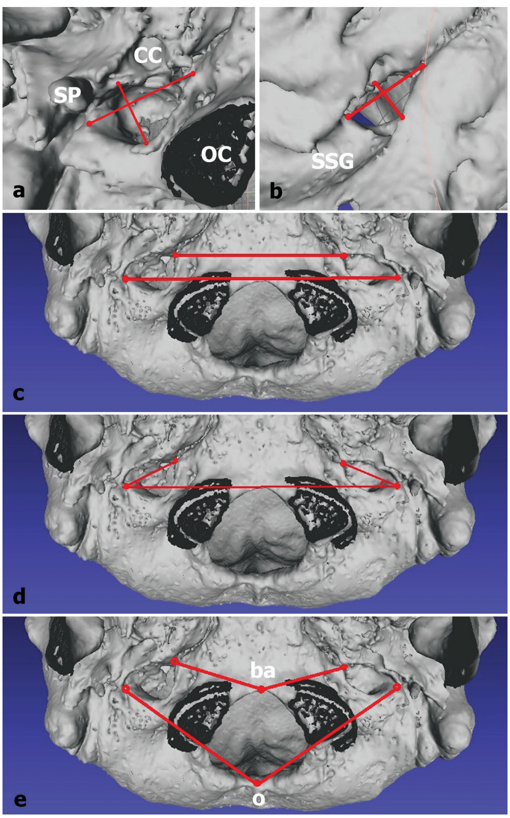

Fig. 1. Measurements: a) ectocranial mediolateral and anteroposterior diameters of the jugular foramen; b) endocranial mediolateral and anteroposterior diameters of the jugular foramen; c) interforaminal distances; d) angle of inclination of the mediolateral axis of the jugular foramen on the right and left side; e) distances from basion (ba) to the medial landmarks of the right and left jugular foramen and from opisthion (o) to the lateral landmarks of the right and left jugular foramen. CC – carotid canal; SP – styloid process, OC – occipital condyle, SSG – sigmoid sinus groove.

The incidence of a domed bony roof (**Fig. 2**) and complete osseous bridging of the JF (**Fig. 3**) was established.

Statistical analsyses

The sex and bilateral differences were evaluated for statistical significance.

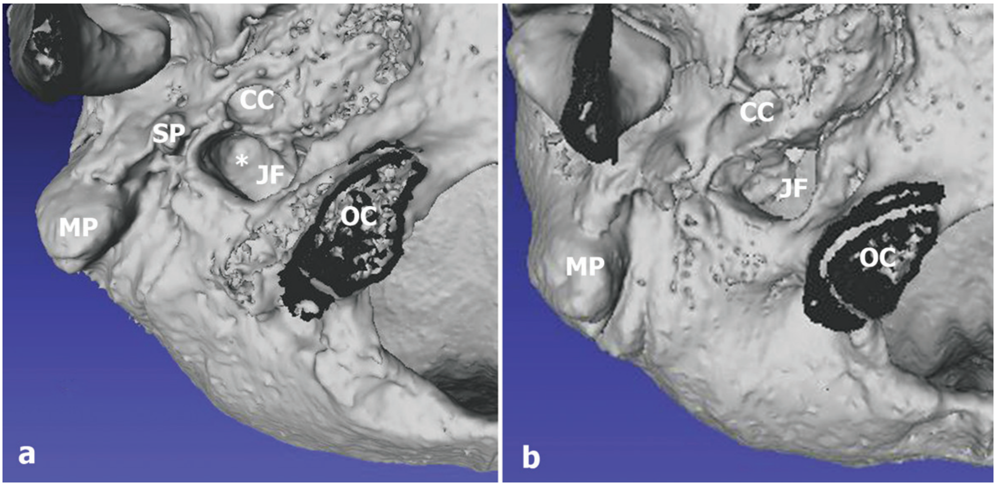

Fig. 2. Domed bony roof of the jugular fossa: a) presence; b) absence. JF – jugular foramen, CC – carotid canal, SP – styloid process, MP – mastoid process, OC – occipital condyle, * – domed bony roof.

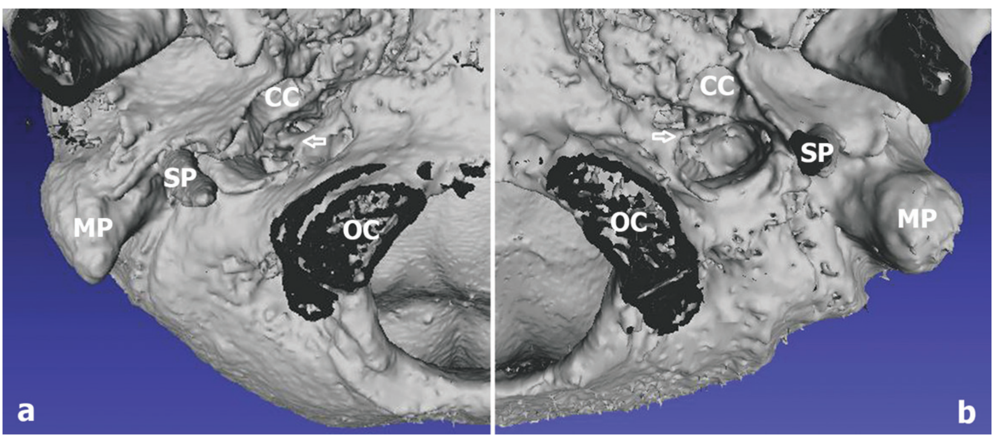

Fig. 3. Complete osseous bridging: a) of the right jugular foramen in a female; b) of the left jugular foramen in a male. CC – carotid canal, SP – styloid process, MP – mastoid process, OC – occipital condyle, ↑ – complete bridging.

The sex differences were assessed using the independent samples t-test. The bilateral differences were estimated by the paired t-test.

Univariate discriminant function analysis was applied to the measurements showing significant sex differences. The sectioning point of the male and female centroids was used as a cut-off value. Applying the discriminant functions, if the resulting score was greater than the cut-off value, it was related to a male and if the score was smaller, it was considered to a female. The leave-one-out cross-validation approach was used to determine the classification accuracy of the discriminant functions. The acceptable level of accuracy was set at 70% [11].

To assess the intraobserver reliability, a sample of 15 skulls was measured twice by one observer. All metric parameters were recalculated and tested by Intraclass correlation coefficient (ICC). According to the ICC values, the reliability was assessed as poor (<0.50), moderate (0.50-0.75), good (0.75-0.90), and excellent (>0.90) [18].

The sex differences in the distribution of domed bony roof and complete osseous bridging of the JF in regard to laterality were assessed using the chi-square test.

For all statistical tests, a value of $p < 0.05$ was accepted as a statistically significant level.

Results

The intraobserver reliability was assessed as excellent for most of the measurements, except for the ectocranial MLD on the left side, endocranial MLD and APD on the left side, and both AIJF, which indicated good reliabilty.

Concerning the ectocranial JF measurements, significant sex differences were found in the MLD on both sides, but not in the APD (**Table 1**). Such differences were also established in the distances between the most lateral and the most medial points of the right and left JFs and in the distances of the JF points to *basion* and *opisthion*. The JFI also showed significant sex differences, but only on the left side, indicating considerably greater APD towards the MLD in females. The right and left AIJF did not show any significant differences between the two sexes. Regarding endocranial JF measurements, they were smaller than the ectocranial ones. Significant sex differences were established only in the MLD on the left side.

In both sexes, the right JF had greater APD than the left one. However, significant bilateral differences were established for the APD only in the male skulls. Such differences were found on both endo- and ectocranial surfaces (**Table 1**). Furthermore, bilateral difference were observed neither in the distances of both JFs to *basion* and *opisthion*, nor in the angle characterizing the inclination of the mediolateral axes of the JFs. Concerning the IJF values on both cranial surfaces, the right JFs were relatively wider than the left ones, especially in males, where bilateral differences were statistically significant.

The univariate discriminant functions including the endo- and ectocranial MLD and the distances between the right and left JFs produced relatively low accuracy rates (**Table 2**). Only the distance between the lateral points of the right and left JFs showed accuracy of nearly 71%. Most of the other studied measurements provided accuracy rates higher than 70%. The highest accuracy of 75.7% was obtained for the discriminant function including the distance from *opisthion* to the most lateral point of the left JF.

A domed jugular fossa indicating the presence of a prominent superior jugular bulb was recorded bilaterally in 27.7% and unilaterally in 43.9% of the skulls. The domed roof was most commonly present bilaterally in males, while in females it was most frequently absent (**Fig. 4**). In unilateral cases, the domed bony roof was more common on the right side in both sexes. The sex differences in the distribution of the domed roof of the jugular fossa regarding the laterality did not achieve statistical significance ($\chi^2(2, N = 148) = 3.26$, $p = .353$).

The presence of a complete osseous bridging of the JF was established in 31.7% (4.7% bilaterally and 27.0% unilaterally) of the skulls. The unilateral bridging in males was observed more frequently on the left side, while in females, it was more common on the ride side (**Fig. 5**). However, the sex differences in the distribution of this feature did not reach statistical significance ($\chi^2(2, N = 47) = 2.02$, $p = .364$).

Table 1. Descriptive statistics of the linear measurements /in mm/ and the angle of jugular foramen /in degrees/ by sex and laterality.

Measurements	Males		Females		Sex differences	Bilateral differences
	Mean	SD	Mean	SD		
MLD_{ecto} (R)	18.21	2.71	16.93	2.35	t = 3.087 (p = 0.002)*	Males: t = 0.812 (p = 0.420) Females: t = 1.187 (p = 0.239)
MLD_{ecto} (L)	17.92	2.09	16.59	2.02	t = 3.899 (p = <0.001)*	
APD_{ecto} (R)	9.70	2.22	9.13	2.03	t = 1.625 (p = 0.106)	Males: t = 3.660 (p = 0.001)* Females: t = 1.878 (p = 0.064)
APD_{ecto} (L)	8.30	1.99	8.47	2.11	t = -0.494 (p = 0.622)	
IJF_{ecto} (R)	54.00	11.55	54.72	12.62	t = -0.358 (p = 0.721)	Males: t = 3.799 (p = <0.001)* Females: t = 1.885 (p = 0.063)
IJF_{ecto} (L)	46.63	12.16	51.04	11.76	t = -2.233 (p = 0.027)*	
MLD_{endo} (R)	14.67	2.10	14.25	2.11	t = 1.184 (p = 0.238)	Males: t = 0.109 (p = 0.913) Females: t = 0.993 (p = 0.323)
MLD_{endo} (L)	14.63	1.70	14.01	1.79	t = 2.142 (p = 0.034)*	
APD_{endo} (R)	7.70	2.45	7.45	2.13	t = 0.657 (p = 0.512)	Males: t = 2.478 (p = 0.016)* Females: t = 1.934 (p = 0.057)
APD_{endo} (L)	6.77	2.05	6.86	1.96	t = -0.267 (p = 0.790)	
IJF_{endo} (R)	52.77	15.99	52.93	15.16	t = -0.060 (p = 0.952)	Males: t = 2.527 (p = 0.014)* Females: t = 1.705 (p = 0.092)
IJF_{endo} (L)	46.65	14.40	49.44	14.42	t = -1.171 (p = 0.244)	
JF_{lat} (R) – JF_{lat} (L)	76.94	4.33	73.01	3.67	t = 5.989 (p = <0.001)*	-
JF_{med} (R) – JF_{med} (L)	45.11	4.38	43.06	3.40	t = 3.208 (p = 0.002)*	-
JF_{lat} (R) – opisthion	52.35	3.43	49.39	2.76	t = 5.817 (p = <0.001)*	Males: t = -1.580 (p = 0.119) Females: t = -1.281 (p = 0.204)
JF_{lat} (L) – opisthion	52.90	2.83	49.72	2.60	t = 7.097 (p = <0.001)*	
JF_{med} (R) – basion	26.70	2.44	24.82	2.01	t = 5.040 (p = <0.001)*	Males: t = 1.251 (p = 0.215) Females: t = 1.102 (p = 0.274)
JF_{med} (L) – basion	26.43	1.98	24.59	2.02	t = 5.570 (p = <0.001)*	
AIJF (R)	27.45	7.10	25.62	6.48	t = 1.634 (p = 0.104)	Males: t = -0.024 (p = 0.981) Females: t = -0.785 (p = 0.435)
AIJF (L)	27.48	7.20	26.27	7.20	t = 1.017 (p = 0.311)	

MLD – mediolateral diameter; **APD** – anteroposterior diameter; **IJF** – index of the jugular foramen; **ecto** – ectocranial; **endo** – endocranial; $\mathbf{JF_{lat}}$ – the most lateral point of the jugular foramen on the ectocranial side; $\mathbf{JF_{med}}$ – the most medial point of the foramen on the ectocranial side; **AIJF** – the angle of inclination of the jugular foramen; **R**- right; **L** – left; * – significant at p<0.05.

Table 2. Univariate discriminant functions.

Discriminant functions	Wilks' lambda	Group centroids		Sectioning point	Classification accuracy (%)		
		♂	♀		♂	♀	Overall
0.398 x $\mathbf{MLD_{ecto}(R)}$ - 6.957	0.939	0.283	-0.228	0.028	62.1	59.8	60.8
0.487 x $\mathbf{MLD_{ecto}(L)}$ - 8.361	0.906	0.357	-0.288	0.035	54.5	61.0	58.1
0.572 x $\mathbf{MLD_{endo}(L)}$ - 8.175	0.970	0.196	-0.158	0.019	59.1	58.5	58.8
0.251 x $\mathbf{JF_{lat}(R)–JF_{lat}(L)}$ - 18.802	0.803	0.549	-0.442	0.054	68.2	73.2	70.9
0.259 x $\mathbf{JF_{med}(R)–JF_{med}(L)}$ - 11.376	0.934	0.294	-0.237	0.029	59.1	59.8	59.5
0.325 x $\mathbf{JF_{lat}(R)}$**–opisthion** - 16.481	0.812	0.533	-0.429	0.052	68.2	72.0	70.3
0.370 x $\mathbf{JF_{lat}(L)}$**–opisthion** - 18.903	0.743	0.650	-0.523	0.064	75.8	75.6	75.7
0.453 x $\mathbf{JF_{med}(R)}$**–basion** - 11.621	0.846	0.472	-0.380	0.046	62.1	72.0	67.6
0.500 x $\mathbf{JF_{med}(L)}$**–basion** - 12.712	0.825	0.510	-0.411	0.050	69.7	70.7	70.3

$\mathbf{MLD_{ecto}}$ – ectocranial mediolateral diameter of the jugular foramen; $\mathbf{MLD_{endo}}$ – endocranial mediolateral diameter of the jugular foramen; $\mathbf{JF_{lat}}$ – the most lateral point of the jugular foramen on the ectocranial side; $\mathbf{JF_{med}}$ – the most medial point of the jugular foramen on the ectocranial side; **R** – right; **L** – left.

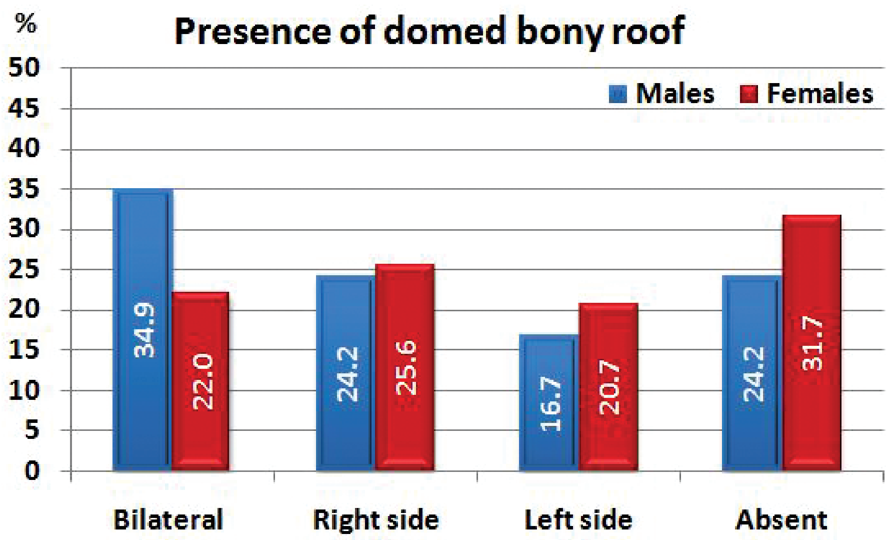

Fig. 4. Frequency of the domed bony roof of the jugular fossa in males and females.

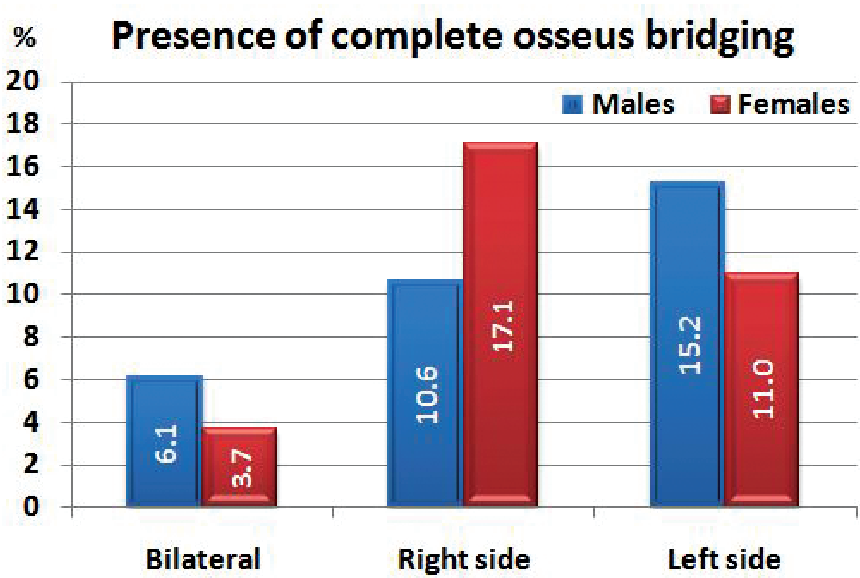

Fig. 5. Frequency of the complete osseous bridging of the jugular foramen in males and females.

Discussion

The JF provides the main venous outflow from the skull [32]. It frequently demonstrates asymmetry [27], which is most prominent in the posterolateral sigmoid portion [17]. The JF size and shape have been related to the size of the internal jugular vein and the presence or absence of a prominent superior bulb [28]. The difference in size of the right and left internal jugular veins is visible in human embryo as early as at the 8th gestation week and probably caused by differences in the pattern of development of the right and left brachiocephalic veins [21]. The variability in JF size from side to side has been also attributed to the difference in size of the sigmoid sinus on the right and left side [17]. The right JF has been frequently found to have larger size [2, 13, 14, 15, 19, 31, 32] with significantly greater measurements of the right JF established in a number of previous studies [5, 7, 20, 22, 26, 28]. Pereira et al. [23] found bilateral differences only in the APD in males, which is observed in our study as well. Significant relationship has been found between sagittal sinus drainage laterality and larger JF size with a statistical association found between the larger JF and the ipsilateral sagittal sinus groove [8]. The larger size of the right foramen have been described with the more common draining of the superior sagittal sinus into the right transverse sinus and the right sigmoid sinus respectivly [4, 8, 16]. Unlike the ectocranial APD, the endocranial diameter has not been established to show such explicite predominance for the right side, which is probably due to the exocranial location of the superior jugular bulb [20]. However, our results show bilateral differences in the WJF in males not only on the ectocranial surface, but also on the endocranial one, which could be related to the size of the sigmoid sinus. The smaller size of the left JF has implied greater susceptibility to compression of the neurovascular structures passing through it [7]. However, the diameters of the JFs from the opposite skull sides have been established to correlate significantly [5, 15], while such correlations have not been found between the JF dimensions on each side [15], suggesting coordinated deveopment of the JFs on the opposite skull sides with regard to the optimal venous otflow.

The sex differences in the JF size have been discussed in few previous studies. Çiçekcibaşi et al. [5] established no sex differences in both JF diameters, whereas Pereira et al. [23] reported significantly greater MLD in males, which is in line with our results. Significant sex differences have been also found in the JF area [32]. According to Das et al. [7], the smaller area of the JF in females might be a risk factor for compression of neurovascular structures passing through it in cases of tumors invading this region. In our study, the right JFs of females have smaller APD than males, while the left ones have slightly greater one, unlike the MLD, which is constatnly greater in males on either side.

The sex differences in the ecto- and ednocranial measurements of the JF have been established to show population specificity. The ectocranial dimensions have demonstrated significant differences between Caucasian males and females, while the endocranial measurements have indicated significant differences between Negroid males and females [20]. In our study, the sex differences on the ectocranial surface are related to the MLD on the right and left sides, while on the endocranial surface, they concern the same measurement but only on the left side.

As far as we know, the discriminating power of the JF measurements in the sex estimation has not been previously studied. The discriminant functions for the JF measurements developed in the present study achive accuracy rates comparebale with those obtained for the *foramen magnum* in the same population [30], suggesting that the measurements of the cranial base foramina are mediocre sex indicators. However, the functions based on dimensions measured between the right and left JFs as well as between the JF points and midsagittal landmarks, such as *basion* and *opisthion*, achieve higher accuracy results, most of them exeeding 70%, and thus, useful as supportive tools for sex estimation purposes. The sex differences observed in the last-mentioned distances could be explained with the generally larger male skull. The lack of bilateral differences in the measurements between the JF points and midsagittal landmarks as well as between the right and left AIJF indicates the symmetric position of the right and left JFs in the skulls of both sexes.

The presence of a domed bony roof of the JF is related to the presence of a prominent superior jugular bulb [28], while its absence indicates that the bulb is absent or poorly developed [22]. When well-developed, the bulb has rounded upper part which lies in the dome of the jugular fossa [20]. The presence of a domed bony roof on both sides has been the most common reported combination [3, 7, 13, 19, 20, 23, 26, 28] reaching up to 100% in the study of Hossain et al. [14]. However, in some studies, the bilateral absence of domed jugular fossa has been reported as a more common variant [2, 22]. In our study, the domed bony roof is most commonly present bilaterally in males, while it is more frequently absent in females. In cases of unilateral presence of the domed roof, it has been more common on the right side [2, 7, 13, 19, 20], which is confirmed by our results. Besides, no statistically significant sex differences have been reported in the presence of this feature [7], which is established by the present study as well.

Another main morphological trait of the JF is its division by complete osseous bridging. The sigmoid and petrosal parts of the JF are separated by the intrajugular processes of the occipital and temporal bones, which are usually connected by a fibrous bridge, which may occasionally ossify [17]. The bridging of the JF is usually established by the end of fetal development suggesting the existence of genetic factors in the expression of this feature [9]. Some authors found neither sex [9] nor bilateral [9, 28] differences in the incidence of complete JF bridging. However, Kumar et al. [19] observed that it is more frequent on the right side, while Aseta et al. [2] found it more common on the left one. Our observations show that the unilateral bridging in males is more frequent on the left side, while in females, it is more common on the rigth one, although significant sex differences are not established according to this trait. Skrzat et al. [27] noticed that the division of the JF by complete osseous bridging is a rare finding. Notwithstanding, the incidence of complete septation varies in different population groups and has been found between 1% and 24% [7, 13, 15, 22, 23, 31]. In this regard, Hossain et al. [14] reported very high incidence of complete JF septation of 76% on the right and 91% on the left side in Bangladesh skulls. Thus, our results are most close to those of Serbians (24%), reported by Vlajković et al. [31]. In addition, Athavale [3] established that the JF bridging is more common on the endocranial side, which contradicts to our observations.

The variations in JF compartmentalization have been attributed to variability in bone formation around the primitive foramen lacerum posterior [24], which is observed in the early human fetal skull and persists as JF in adults [25]. In this regard, Athavale [3] suggested that JF compartmentalization could be a part of ongoing evolutionary process. However, some compartmentalization patterns can compress the structures passing through the JF and thus could mimic the clinical manifestations of glomus jugulare tumor and cause multiple cranial nerve palsies, i.e. jugular foramen syndrome (Vernet's syndrome). Das et al. [7] observed that the JF bridging is more common in males and put them at a higher risk of these manifestations than females. However, according to our results, this feature is equally frequent in both sexes (males: 31.8%; females: 31.7%), so both Bulgarian males and females could be related to the same risk category.

Altogether, the extreme variations in the JF morphology might put the passing vessels and nerves at risk during surgical procedures in this region [26]. The high variability in the size and shape of the JF enforces a compulsory preoperative imaging with thorough examination of the foramen morphology to avoid injuries to its content and surrounding structures during surgical operations.

Conclusions

The size of the JF differs significantly between males and females in its MLD. However, the JF dimensions are mediocre sex indicators for forensic purposes. Bilateral differences are found only in the APD in males, since the right JFs have greater size than the left ones. The domed bony roof is more frequently observed in males, while the complete osseous bridging is equally common in both sexes.

Acknowledgements: The study was supported by the Bulgarian National Science Fund, Grant number DN11/9-15.12.2017 and Grant number DN01/15-20.12.2016.

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