FACTA UNIVERSITATIS
Series: **Medicine and Biology** Vol. 16, No 1, 2014, pp. 12–17 UC 616.714.1

MORPHOMETRIC CHARACTERISTICS OF JUGULAR FORAMEN AND SIGMOID SINUS GROOVE: THEIR POSSIBLE CONNECTIONS WITH HIGH JUGULAR BULB PRESENCE

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Abstract. *High jugular bulb represents very important variation in neurosurgery. The aim of our research was to measure certain characteristics of jugular foramen and surrounding bony structures in order to evaluate their possible significance in high jugular bulb detection. Thirty seven dried human skull sagittal sections were used as material. Sigmoid sinus groove width and depth, jugular fossa height and exocranial opening mean diameter were measured with vernier caliper. Internal auditory canal height and the distance between its inferior margin and superior margin of petrous bone, jugular foramen endocranial opening area and sino dural angle were measured with ImageJ. Cluster analysis with jugular fossa height as classification parameter was used for the classification of the analyzed skull sagittal sections. Classification analysis showed the presence of two groups: the first with predominantly low height of jugular fossa dome, the second with significantly higher values of jugular fossa dome, sino-dural angle and mean diameter of jugular fossa exocranial opening. This group predominantly included right skull sagittal sections. In addition, sigmoid sinus groove width and depth, jugular foramen endocranial opening area and jugular fossa exocranial opening mean diameter were significantly higher on the right in relation to the left side. So, it can be concluded that high jugular fossa dome is more frequently associated with sigmoid sinus groove anterior position, high values of mean diameter of jugular fossa exocranial opening and sigmoid sinus groove width and depth, especially on the right side.*

Key words: *Jugular fossa, high bulb of jugular vein, groove for sigmoid sinus, morphometry*

Introduction

Jugular foramen is hiatus located between lateral part of the occipital bone and petrous part of the temporal bone. However, today authors [1–4] more frequently describe its appearance as a canal and not as a real foramen. They describe its endocranial opening and exocranial opening, which are oriented in different planes. Its acute-angled triangular endocranial opening is by intrajugular processes divided into two or, less frequently, into three compartments. Neurovascular elements which pass through this opening are glossopharyngeal nerve and inferior petrosal sinus, which pass through its smaller anteromedial compartment, while vagus nerve, accessory nerve, posterior meningeal artery and sigmoid sinus pass through posterolateral part of the jugular foramen. Exocranial opening has alembic shape and it leads into the jugular fossa in which jugular bulb is located. The highest part of jugular fossa is its dome. Caroticojugular spine with petrosal fossula is in front, while funnel shaped pyramidal fossa with external opening of cochlear aqueduct is anteromedially located in relation to its exocranial opening [4].

In spite of numerous previous radiological and anatomical studies, there is no agreement between authors about the jugular foramen nature, its canal like appearance and its compartments nomenclature. Jugular foramen anatomical variations, such as high bulb of jugular vein, jugular bulb bony covering dehiscence, jugular bulb diverticulum, are very frequently present. Superior jugular bulb is one of them which can influence the choice of surgical approach in the treatment of primary (glomus tumor, schwannoma), secondary (meningioma, chondrosarcoma) jugular foramen lesions [5], as well as other lesions located in posterior cranial fossa [6]. It could also be the cause of complications, like profuse bleeding and air embolism during the surgical intervention [7]. Takdemir et al. [4] considered that more frequent superior sagittal sinus drainage through right transverse, then right sigmoid sinus and right jugular foramen might be associated with its more frequent presence on the right side and, consequently, with its pathogenesis.

So, since there are indirect implications about sigmoid sinus involvement in the high jugular bulb pathogenesis and there is lack of literature data about morphological and positional relationships between

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sigmoid sinus and jugular foramen, the aim of our research was to evaluate such relationships by the application of morphometric and statistical methods.

Material and Methods

The material included 37 sagittal sections (17 left and 20 right) of Caucasian adult dried human skulls, with completely preserved jugular foramen and sigmoid sinus groove. Skulls are the part of our Department of Anatomy collection. Petrous bones' internal auditory canal's anterior wall was removed. Vernier caliper was used for the measurement of sigmoid sinus groove vertical segment's width and depth, sigmoid sinus groove curve width and depth and its horizontal segment width and depth (Fig. 1, A). Mean sigmoid sinus groove width (SSGw) and depth (SSGd) were calculated as average of its three segments measured corresponding values. Vernier caliper was also applied for the measurement of the jugular fossa height (FJH) as a distance between the level of its exocranial opening and its dome and two jugular foramen exocranial opening diameters: one parallel to the major and the other parallel to its minor axis (Fig. 1, B). Its mean diameter (D) was calculated as average of the latter two cited diameters. Afterwards, petrous bone posterior surface, together with vernier caliper scale, was captured with digital camera and obtained images were additionally analyzed with ImageJ (http://rsb.info.nih.gov/ij/). Vernier caliper millimeter scale was used for the system's spatial calibration. Jugular foramen endocranial opening area (A), sino-dural angle (SDA) as angle between petrous bone superior margin and sigmoid sinus groove vertical segment, internal auditory canal's height (h) and the distance between internal auditory canal inferior margin and petrous bone superior margin (h') (Fig. 1, A) were measured with this software.

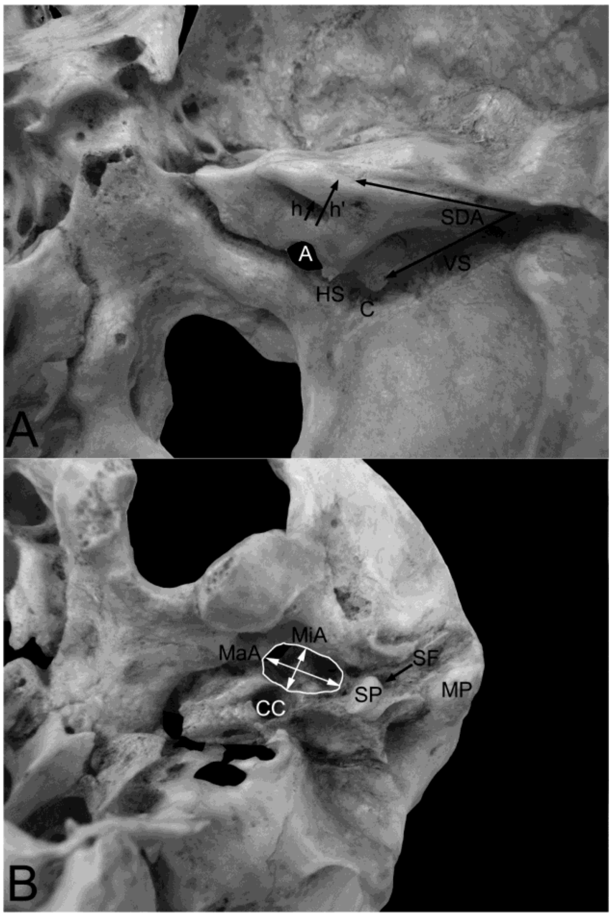

Fig. 1. View of the part of internal (A) and external (B) surfaces of cranial base. A – jugular foramen endocranial opening, sigmoid sinus groove and internal auditory canal: endocranial opening area (A), sigmoid sinus groove vertical segment (VS), curve (C) and horizontal segment (HS), sino-dural angle (SDA), internal auditory canal height (h) and the distance between internal auditory canal inferior margin and petrous bone superior margin (h'); B – inferior surface of the petrous bone: mastoid process (MP), stylomastoid foramen (SF), external opening of the carotid canal (CC), styloid process (SP), and diameter of the jugular fossa external opening along the major (MaA) and minor axis (MiA).

Statistical analysis was performed by NCSS-PASS 2007 software (http://www.ncss.com/). Cluster analysis (k-means method), with fossa jugularis height as classification parameter, was done in order to obtain two groups of cases with its significantly different values. Significance of differences of the latter cited measured morphometric parameters of the obtained groups, as well as of the right and left skull sagittal sections, was evaluated by Student's t-test. Main effects of the side, group membership and their interaction for the evaluated morphometric parameters were analyzed by Two Way ANOVA. Additionally, the proportion of right and left skull sagittal sections as well as bony bridging in by cluster analysis obtained groups was tested with Chi-square test. Effect sizes of the established differences were calculated according to the Lipsey's and Wilson's formulas [8].

Results

Endocranial opening was in majority of the cases irregular, with approximately triangular shape and apex anteromedially directed. It was composed of two parts: smaller anteromedial and larger posterolateral, which were in most of the cases incompletely separated with temporal and occipital bones' intrajugular processes. Complete bony bridging and consequently bipartite endocranial opening was observed in 12 (5 on the left and 7 on the right side) cases (32%). Incisura which resembled glossopharyngeal recess was rarely observed. Superiorly, on the petrous bone posterior side porus acusticus internus was located. Sigmoid sinus groove beginning was placed at the level of petrous bone superior margin and transverse sinus groove junction. It extended downwards till the endocranial opening and along its course we differentiated two clearly visible segments:

longer vertical and shorter horizontal. Sigmoid sinus groove curve was located between these two segments. Generally, sigmoid sinus groove width decreased from vertical segment toward its curve and then in horizontal segment increased slightly till the endocranial opening. Exocranial opening of the jugular foramen was mostly oval in shape. Jugular fossa was above it and ended superiorly with its dome, which was present in all cases.

Morphometric and statistical analysis

The results of morphometric analysis are presented in Table 1. Generally, mean values of the internal auditory canal height, the distance between internal auditory canal inferior margin and petrous bone superior margin and sino-dural angle were not significantly different between the right and left side, respectively (Table 2). Mean jugular foramen endocranial opening area (Table 2 and Fig. 2, A), exocranial opening mean diameter (Table 2 and Fig. 2, B), mean sigmoid sinus groove width and depth (Table 2 and Fig. 2, B) were significantly higher on the right than on the left side. Latter cited differences were characterized with medium (for A) and large effect sizes (for D, SSGw and SSGd). Mean FJH was higher on the right in relation to the left side, but this difference was not statistically significant and was characterized with small to medium effect size (Table 2). So, these results did not suggest significant lateralization of the high jugular fossa.

Cluster analysis was performed in order to obtain groups with significantly different mean jugular fossa height. Its results are showed in Table 2. Two significantly different groups are obtained. Fourteen left (56%) and 11 right (44%) sagittal sections of the skull were in the first group (totally 25 sections). Second group included 12 skull sagittal sections, from which 9 were right (75%) and 3 were left (25%). Chi-square test did not show significant predominance of right or left side

Table 1. Morphometric characteristics of jugular foramen, sigmoid sinus groove and internal auditory canal

Case	Side	Group	h (mm)	h' (mm)	A (mm^2)	D (mm)	FJH (mm)	SSGw (mm)	SSGd (mm)	SDA (^{0})
1	Left	I	3.96	6.61	67.18	8.48	11.50	6.86	4.14	59.12
2	Right	I	5.23	8.94	45.36	9.75	11.42	6.28	3.37	59.62
3	Right	I	3.92	7.46	54.40	10.53	12.06	6.54	4.48	56.28
4	Right	I	3.01	5.96	47.49	7.11	6.56	7.87	4.94	51.03
5	Left	I	3.79	7.59	39.52	8.44	9.24	8.66	5.91	61.33
6	Right	I	4.64	7.22	89.57	8.21	12.92	9.36	8.05	48.46
7	Right	I	4.83	8.03	79.75	11.32	11.48	11.10	5.34	45.64
8	Right	I	4.48	7.66	65.89	8.00	7.06	7.98	3.69	59.23
9	Left	I	4.13	7.43	41.73	5.20	10.10	5.33	2.93	66.71
10	Left	I	4.35	7.76	55.84	6.96	11.38	7.38	3.08	40.88
11	Left	I	3.92	7.82	25.59	8.72	11.48	5.79	3.98	55.57
12	Left	I	2.50	6.12	40.74	8.05	9.70	7.92	3.81	32.97
13	Right	I	4.99	8.00	50.28	6.17	10.30	6.01	5.41	53.65
14	Right	I	4.12	7.46	50.89	9.53	12.30	8.34	6.15	47.63
15	Left	I	4.32	8.05	43.25	7.11	6.60	6.33	3.75	34.97
16	Right	I	4.84	8.10	86.79	8.83	11.78	8.97	3.56	61.81
17	Left	I	3.95	5.66	57.84	9.01	13.02	7.09	5.42	39.09
18	Right	I	4.25	6.89	44.64	7.72	10.20	7.67	6.41	44.49
19	Left	I	5.45	8.50	27.99	9.87	11.78	5.70	3.95	35.85
20	Left	I	4.50	8.16	36.12	6.56	11.58	7.72	4.04	42.46
21	Left	I	2.98	6.15	37.41	6.60	12.30	6.38	5.03	58.09
22	Left	I	3.70	6.40	39.52	9.81	9.02	6.24	5.12	35.18
23	Right	I	4.17	8.75	42.41	8.35	11.42	8.43	7.09	36.63
24	Left	I	5.62	10.04	40.75	7.47	11.38	5.84	5.33	33.13
25	Left	I	5.11	9.24	79.70	4.63	12.46	4.56	3.55	50.20
26	Left	II	4.53	8.59	45.44	10.11	14.54	5.58	2.60	64.63
27	Left	II	4.72	6.69	39.96	8.47	18.12	8.29	2.73	58.83
28	Left	II	4.09	7.90	32.03	7.85	17.36	5.65	4.01	61.75
29	Right	II	4.54	8.58	66.30	9.12	14.40	6.70	2.39	68.02
30	Right	II	4.17	6.97	76.09	10.84	14.94	7.68	3.60	59.53
31	Right	II	4.01	5.88	90.89	8.64	13.80	11.92	5.04	60.69
32	Right	II	3.69	8.01	35.82	11.80	19.82	7.33	4.95	62.35
33	Right	II	4.99	8.49	38.92	9.16	14.42	7.02	5.28	45.87
34	Right	II	4.45	8.58	36.22	7.71	13.64	7.89	6.15	49.35
35	Right	II	4.01	7.96	29.67	11.25	13.82	7.38	6.11	45.41
36	Right	II	3.54	5.90	32.05	10.49	14.10	7.19	5.69	32.97
37	Right	II	5.88	8.57	60.08	7.77	20.30	8.33	6.37	47.41

Table 2. Morphometric characteristics of jugular foramen, sigmoid sinus groove and internal auditory canal in obtained groups and on the left and right side of the skull

Side	Left (n = 17)			Right (n = 20)			t-test statistics section			
Parameter	Mean	Md	SD	Mean	Md	SD	T	DF	p	d
h (mm)	4.21	4.13	0.79	4.39	4.35	0.65	0.74*	35	0.462	0.25
h' (mm)	7.57	7.76	1.18	7.67	7.98	0.95	0.28*	35	0.778	0.09
A (mm^2)	44.15	40.74	13.86	56.18	50.59	19.73	2.11*	35	0.042	0.70
D (mm)	7.84	8.05	1.55	9.12	8.98	1.55	2.49*	35	0.018	0.83
FJH (mm)	11.86	11.50	2.85	12.84	12.61	3.34	0.95*	35	0.348	0.31
SSGw (mm)	6.55	6.33	1.15	8.00	7.78	1.48	3.29*	35	0.002	1.08
SSGd (mm)	4.08	3.98	0.99	5.20	5.31	1.39	2.78*	35	0.009	0.92
SDA (^{0})	48.87	50.20	12.44	51.80	50.19	9.06	0.83*	35	0.413	0.27
Group	I (n = 25)			II (n = 12)			t-test statistics section			
Parameter	Mean	Md	SD	Mean	Median	SD	T	DF	p	d
h (mm)	4.27	4.25	0.76	4.39	4.31	0.63	0.45*	35	0.653	0.17
h' (mm)	7.60	7.66	1.07	7.68	7.98	1.05	0.20*	35	0.840	0.08
A (mm^2)	51.63	45.36	17.48	48.62	39.44	19.98	0.47*	35	0.643	0.16
D (mm)	8.10	8.21	1.60	9.43	9.14	1.43	2.45*	35	0.019	0.86
FJH (mm)	10.76	11.42	1.84	15.77	14.48	2.45	6.96*	35	<0.001	2.44
SSGw (mm)	7.21	7.09	1.47	7.58	7.35	1.63	0.68*	35	0.498	0.24
SSGd (mm)	4.74	4.48	1.30	4.58	4.99	1.46	0.35*	35	0.731	0.12
SDA (^{0})	48.40	48.46	10.43	54.73	59.18	10.35	1.73**	35	0.046	0.61

*Two – tailed T-test
**One – tailed T-test
DF, degrees of freedom; d, effect size

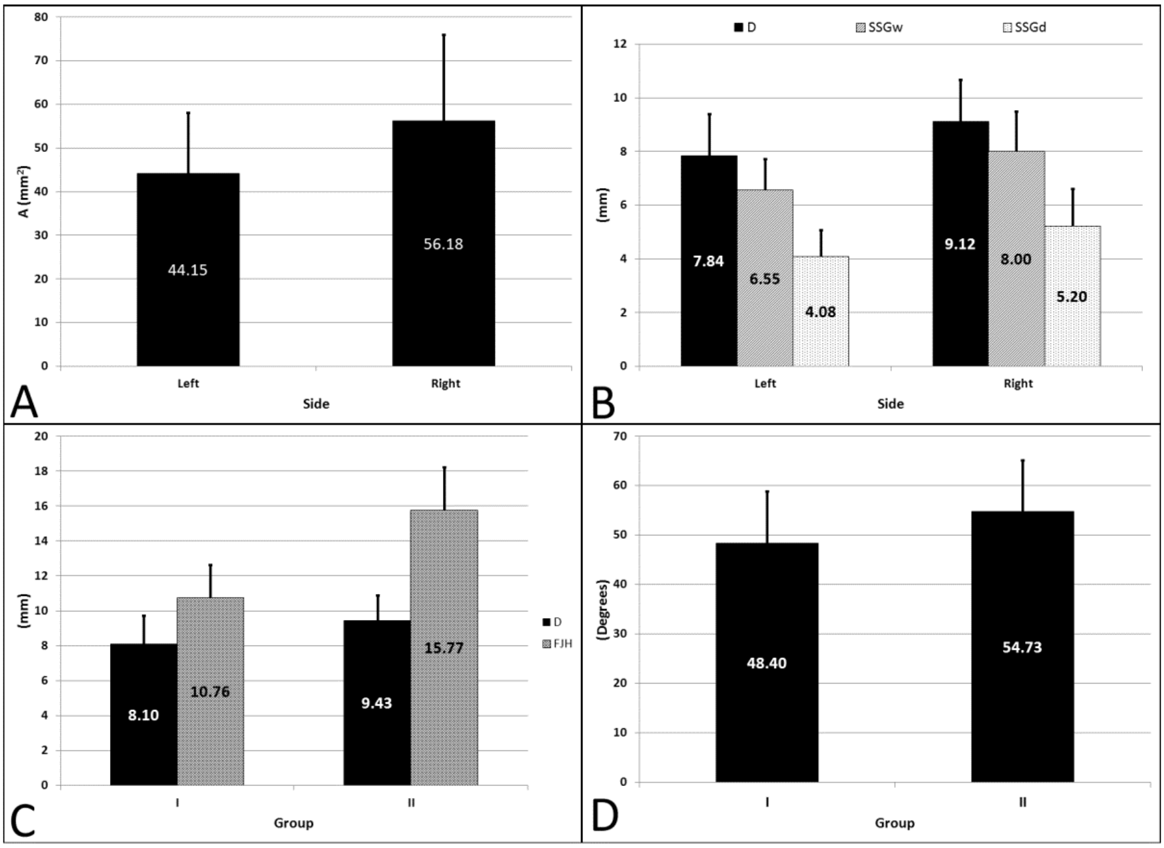

Fig. 2. Mean jugular foramen endocranial opening area on the left and right sides and sigmoid sinus groove morphometric parameters. A – jugular foramen morphometric parameters; B – mean sigmoid sinus groove width and depth and mean diameter of the jugular foramen exocranial opening on the left and on the right side; C – mean fossa jugularis height and exocranial opening diameter in by cluster analysis obtained groups; D – mean sino-dural angle in obtained groups.

in the obtained groups (H = 3.14, n = 37, DF = 1, p = 0.077). Nevertheless, obtained effect size for this test was moderate to large (d = 0.61), which might point to the conclusion that above cited absence of significance is probably due to the sample's size and that there could be mild predomination of the left in the first and right sagittal sections in the second group. Chi-square test did not show more frequent presence of complete jugular foramen endocranial opening bony bridging in the latter cited groups (H = 0.007, n = 37, DF = 1, p = 0.935, d = 0.03). As far as jugular fossa characteristics are concerned, its height and external opening mean diameter were significantly higher in the second group than in the first and these differences were characterized with large effect sizes (Table 2 and Fig. 2, C). Sino-dural angle's mean value of the second group was significantly higher than the same one of the first group and this difference was characterized by medium to large effect size (Table 2 and Fig. 2, D). Differences between all other evaluated morphometric parameters (h, h', A, SSGw and SSGd) of the above cited groups were not statistically significant (Table 2).

Finally, in order to evaluate main effects of the group membership and side, as well as their interaction for evaluated morphometric parameters, we conducted Two Way ANOVA. Results of this analysis confirmed significant main effect of the side for the mean jugular foramen endocranial opening area ($F(1,33) = 3.99$, $p = 0.05$, $\eta = 0.33$) and sigmoid sinus groove's width ($F(1,33) = 7.46$, $p = 0.01$, $\eta = 0.43$) and depth ($F(1,33) = 9.89$, $p = 0.004$, $\eta = 0.48$) with values of the right side being significantly higher than the same of the left side. Significant main effect of the group membership was established for the mean jugular fossa height ($F(1,33) = 42.85$, $p < 0.001$, $\eta = 0.75$) and sino-dural angle ($F(1,33) = 4.43$, $p = 0.043$, $\eta = 0.34$) with values of the second group being significantly higher in relation to the first group, too. Significant interaction between the side and group membership was not established for any of the evaluated morphometric parameters.

Discussion

According to Roche et al. [7] high jugular bulb presents the structure which is a connecting link between the sigmoid sinus and internal jugular vein. It is located in the jugular fossa at the inferior and medial side of the petrous bone. Jugular bulb upper extremity is at the level of jugular fossa dome. Its wall is thinner than the wall of sigmoid sinus, as well as internal jugular vein, because of the absence of sinus dural and vein's adventitial layer in it, respectively. The position of jugular bulb exhibits numerous variations. The most important variation is its high position, whose incidence varies from 6% to 65% [9]. After the development of translabyrinthine and retrolabyrinthine approaches in the cerebellopontine angle tumors exposure and surgical treatment, this variation acquired great importance. Its presence increases the possibility of the intraoperative complications like profuse bleeding, or air embolism, due to its unintentional injuring [10]. High jugular bulb also impedes surgical operative area and reduces the exposure and removal of cerebellopontine tumors [7,9]. Its position can be lateral when it protrudes into the middle ear cavity above the level of inferior rim of tympanic ring. Another possibility is its high and medial position when it is in relation with internal auditory canal [7]. Different anatomical landmarks, such as inferior tympanic annulus, round window, basal turn of cochlea and internal auditory canal, were used for its definition. From the surgeon's point of view, internal auditory canal is the best landmark [9]. According to Roche et al. [7] jugular bulb is in high position when its dome is less than 6.5 mm below the inferior margin of internal auditory canal. Jugular bulb is in very high position when its dome reaches the level of internal auditory canal and overtakes its floor. This anatomical variation is termed overlapping high jugular bulb. During our research we evaluated the location and height of internal auditory canal. We did not find significant differences between obtained groups for the internal auditory canal's height and the distance from internal auditory canal inferior margin and petrous bone superior margin. In such way, we tried to exclude the possibility that internal auditory canal's lower position or its increased height could be the cause for the reduction of distance between the dome of jugular fossa and internal auditory canal inferior wall. There were numerous attempts by other authors to explain the presence of high jugular bulb by reduced mastoid pneumatization and size, but these attempts failed [11,12]. Today, general opinion is that the right jugular foramen is larger than the left one [4]. Authors also agree that the incidence of high jugular bulb increases with age and is higher on the right than on the left side [6,7,9,12,13] They considered that the large superior sagittal sinus drains through the right transverse, then right sigmoid sinus and right jugular foramen [4]. Navsa and Kramer [2] found during their jugular foramen morphometric analysis that the area of its endocranial and exocranial opening and jugular fossa dome height and jugular fossa volume were significantly higher on the right side. We also observed significantly higher values of the jugular fossa endocranial opening area and exocranial opening mean diameter on the right side, while jugular fossa dome was higher on the right side but this difference was not significant. This can be explained by differences in evaluated samples size and by different racial structure of the analyzed material. Firstly, our sample size (n = 37) was smaller than the ones of Navsa and Kramer [2]. The influence of the sample's size on our results can be additionally confirmed by the fact that in our group with significantly higher jugular fossa height the frequency of the right skull sagittal sections was higher than the left ones with medium effect size. In such way, significant right sided asymmetry of the higher jugular fossa dome cannot be excluded in our study, too. Secondly, study of Navsa and Kramer [2] included skulls of black and white racial origin, while we used only Caucasian skulls' sagittal sections. The influence of the different racial structure in the analyzed material can be additionally supported by the finding of the latter cited authors that significantly higher right jugular fossa was observed only in skulls of black, but not in the ones of white racial origin. Wysocki [12] cited in his paper that the sigmoid sinus characteristics are very important in high jugular bulb formation. Sarmiento and Eslait [14] and Wysocki [12] also cited that the sigmoid sinus anterior position is associated with the high jugular bulb presence, while posterior position of the sigmoid sinus in the mastoid is associated with so called flat jugular bulb and its low position. Significantly higher values of sino-dural angle in the group with higher jugular fossa dome in our study may be in accordance with above cited assumption. It can be said that higher values of this angle are associated with steeper and more anteriorly positioned sigmoid sinus groove and hence might have the role in the increase of blood pressure in its terminal part and consequently high bulb formation. This is in agreement with the positions of the Sarmiento and Eslait [14] and Wysocki [12] about the mechanism responsible for the high jugular bulb genesis. Significantly higher values of the sigmoid sinus groove width and depth detected on the right side during our research may additionally support the hypothesis that together with the anterior position, larger sigmoid sinus dimensions on the right side might be responsible for the increase of the blood pressure in the jugular fossa region, which will finally result in increased height of its dome and high jugular bulb presence.

Conclusion

It can be concluded that sigmoid sinus groove width and depth and jugular foramen endocranial opening area were higher on the right in relation to the left side. Higher jugular fossa dome was more frequent on the right side. This phenomenon was rather associated with higher values of jugular foramen exocranial opening diameter and sino-dural angle than with the latter cited sigmoid sinus groove and jugular foramen endocranial opening morphometric parameters.

In our opinion, acquisition of the sino-dural angle, jugular fossa exocranial opening diameter and additionally sigmoid sinus width and depth, could be potentially useful for more precise interpretation of *High-Resolution Computed Tomography* images in high jugular bulb preoperative diagnosis. High values of sino-dural angle, jugular fossa exocranial opening mean diameter and wider and deeper sigmoid sinus, especially on the right side may also represents signs which should draw the surgeons attention to more thoroughly evaluate the possibility of this potentially dangerous anatomical variation presence.

Acknowledgments. Contract grant sponsor: Ministry of Science and Technological Development of Republic of Serbia; contract grant number: 175092.

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