MORPHOLOGY AND VARIATIONS OF THE JUGULAR BULB IN INDIVIDUALS OVER 20 YEARS OF AGE USING CONE BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

Aim: The jugular bulb (JB) forms after 2 years of age. Anatomical variations of this vascular structure are clinically important because they can cause erosion of the middle ear and internal ear and lead to symptoms such as pulsatile tinnitus, vertigo and hearing loss. This study aimed to assess the prevalence of anatomical variations of the JB in individuals older than 20 years using cone beam computed tomography (CBCT).

Materials & Method: This descriptive-analytical (cross-sectional) study evaluated CBCT scans of 200 patients (400 ears) between 20 to 78 years using On-Demand software. The position and morphology of the JB and its anatomical variations were evaluated in all three planes. Axial and coronal CBCT sections of the mid-face (ear region) were used to measure the dimensions of the JB. The position and morphology of the JB and its dimensions in the right and left sides were determined on each image. In case of observing an anomaly, the patients were questioned about clinical symptoms. The data were analyzed using chi-square test, independent t-test and ANOVA ($p<0.05$).

Results: Of all, 45 (22.5%) patients showed morphological anomalies of the JB. The frequency of high riding jugular bulb (HRJB) without dehiscence, HRJB with dehiscence and HRJB with diverticulum was 15.5%, 5.5% and 1.5%, respectively. The distance from JB to the stylomastoid foramen (SMF) in patients with abnormal JB (2.97±1.9 mm) was significantly smaller than that in those with normal JB (4±2.31 mm; $p<0.0001$). The anteroposterior and mediolateral dimensions of the JB in the right side were significantly greater than those in the left side in patients with normal JB ($p<0.0001$). These dimensions were also significantly greater in patients with abnormal JB compared to those with normal JB ($p<0.0001$). Tinnitus had the highest frequency among clinical symptoms in patients with abnormal JB and its frequency was significantly higher in patients with JB dehiscence compared to those without it ($p=0.025$).

Conclusion: The dimensions of both normal and abnormal JB in the right side are greater than those in the left side. Also, by an increase in size of JB, its distance from the SMF decreases.

Key words: Cone-Beam Computed Tomography; Jugular Bulb; Temporal Bone.

Introduction

Temporal bones are a pair of bilateral bones that form the lateral walls of the skull and are located below the parietal bones, behind the sphenoid bone and anterior to the occipital bone.[1] The jugular bulb (JB) is lodged in the jugular fossa in the inferior section of the petrous portion of the temporal bone and is the location of junction of dural venous sinuses. The transverse and sigmoid sinuses drain venous blood into the JB. The internal jugular vein is the main outlet that delivers deoxygenated blood to the right atrium of the heart. Evidence shows that the JB is a dynamic structure that forms after 2 years of age. Its size remains constant during adulthood and its exact position may be variable.[2]

Several factors including the blood flow and pneumatization of the mastoid process may affect the size and position of JB, but it has been confirmed that the size and position of JB specifically depend on postnatal events.[3] The superior border of JB is normally located below the hypotympanum of the middle ear cavity. However, in some cases, the JB may extend superiorly, elevate the floor of hypotympanum and enter into the middle ear cavity with/without invading the petrous bony septum.[4] If the JB extends above the superior ring of the tympanic part[5] or invade into the internal auditory canal by 2 mm, this anomaly is referred to as the high riding jugular bulb (HRJB).[6] In otoscopy, HRJB is seen as a blue mass behind a normal tympanic membrane and has a normal sigmoid plate, which is a thin bony plate that separates the JB from the middle ear cavity. This thin bony plate is only seen on computed tomography (CT) scans with bone algorithm. It is not visualized by magnetic resonance imaging due to excessive thinning. In case of problematic sigmoid plate, JB freely invades the middle ear cavity and is referred to as JB dehiscence.[7] The JB diverticulum is defined as irregular protrusion of the JB into the middle ear cavity and mastoid fossa, or medially towards the apex of the petrous part of the temporal bone.[8] HRJB is often detected as an incidental finding in asymptomatic individuals. The mechanisms explaining the hearing loss related to HRJB include contact of JB with the tympanic membrane and its interference with the function of auditory ossicles in the middle ear.[7] HRJB is considered a risk factor for JB dehiscence.[9]

Despite the presence of comprehensive information about the prenatal development of JB, postnatal growth of JB in adults has been less commonly studied. A better understanding of the developmental course of JB may pave the way for better perception of anatomical variations and anomalies of the JB such as HRJB and JB dehiscence. It has been shown that such anomalies are clinically important because they are capable of causing erosion of the internal and middle ears and subsequent development of symptoms such as pulsatile tinnitus, vertigo and hearing loss.[9] Identification and correct diagnosis of HRJB, which appears as a mass in the middle ear, is imperative to prevent its traumatization and subsequent hemorrhage during surgical procedures.[8] The diameter of JB is highly variable ranging from a wide bulb extending to the middle ear and posterior fossa to a small bulb similar to a diverticulum, which is susceptible to perioperative otoneurological trauma.[10,12] In some cases, the JB may even proceed to the stylomastoid foramen (SMF) and affect the facial nerve, causing severe headaches, paresthesia and facial nerve palsy in rare cases.[13]

Cone-beam computed tomography (CBCT) is an imaging modality with lower patient radiation dose (8%) than conventional CT.[14] It also has higher spatial resolution and comparable or even less metal artifacts than CT. Due to these advantages, CBCT is now considered an efficient imaging modality for evaluation of the maxillofacial structures.[15]

Considering the high prevalence of HRJB reported in previous studies using CT[5,10,16-22] and limited number of studies on the Iranian population in this respect, this study sought to assess the morphology and variations of the JB in an Iranian subpopulation using CBCT.

Materials & Method

This descriptive-analytical study evaluated 200 patients (80 males and 120 females) with a mean age of 41.1±14.7 years. Individuals with a history of ear surgery, trauma to temporal bone or its fracture and syndromic patients were excluded. This study was carried out during 2017-2018 in a private oral and maxillofacial radiology clinic in Isfahan. Radiographs of patients were studied after obtaining written informed consent of patients.

All CBCT images had been taken with Scanora 3D CBCT system (Soredex, Tuusula, Finland) using CMOS flat-panel sensor in high-resolution mode with 0.25 mm voxel size, exposure settings of 90 kVp, 12.5 mA and 4.5 s scanning time and a large field of view (130×145 mm). Both temporomandibular joints and the external auditory canal were visible on CBCT scans with optimal contrast. The radiographs were evaluated by a post-graduate student of oral and maxillofacial radiology under the supervision of an oral and maxillofacial radiologist using On-Demand 3D version 1 software. The CBCT scans on which, the temporal bone and the internal ear structures were unclear were excluded from the study.

First, the patient's head position was adjusted using axis and resliced feature of the software and then different sections were evaluated. Using CBCT scans, first the position and morphology of the JB in terms of presence of anatomical variations such as HRJB and HRJB along with dehiscence and diverticulum were assessed. The superior border of the JB is normally located beneath the hypotympanum of the middle ear cavity. If the JB extends superiorly, elevate the floor of the hypotympanum and appear in the middle ear cavity[4] or extend above the superior ring of the tympanic part[5] or intrude into the internal auditory canal by a minimum of 2 mm, this anomaly is referred to as HRJB.[6] In addition to its noticeable large size, if the superior border of the JB extends superiorly beyond the auditory canal in the sagittal plane, it is also referred to as HRJB. If a HRJB does not have a distinct bony septum separating it from the auditory canal in the axial or coronal planes, it is referred to as a HRJB along with dehiscence. If a HRJB protrudes into the middle ear or petrous part of the temporal bone in the axial or coronal planes, it is referred to as a diverticulum.

The axial and coronal CBCT sections of the mid-face area (ear region) and temporal bone with 1 mm slice thickness and 1 mm interval were used to measure the dimensions of the JB. For this purpose, the largest length of the JB in the right and left sides was measured in anteroposterior dimension on axial sections and mediolateral dimension on coronal sections and reported with 0.01 mm accuracy.[3,23] Also, the shortest distance between the JB and SMF was measured on coronal sections. [Figure 1]

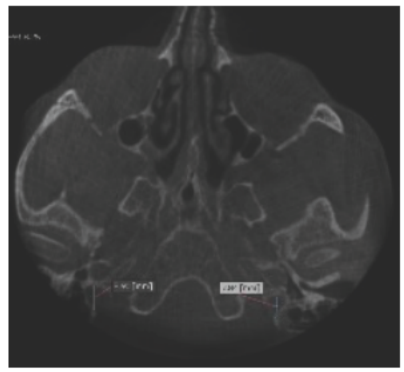

Figure 1.(A) Measuring the largest anteroposterior (AP) dimension of the JB in the right and left sides on axial section;

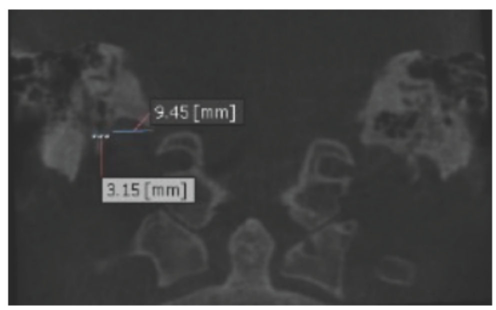

Figure 1.(B) measuring the largest mediolateral (ML) dimension of the JB and the shortest distance between the JB and SMF in the right side on coronal images;

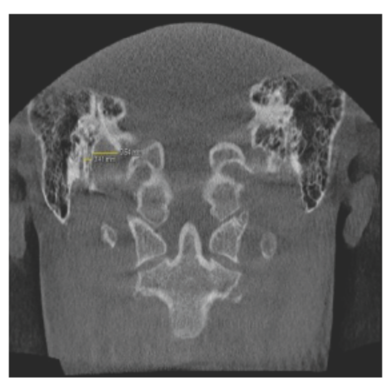

Figure 1. (C) coronal section (mediolateral) of the right side in another patient

Data were analyzed by chi square test, t-test and ANOVA using SPSS version 22 (SPSS Inc., IL, USA).

Results

Evaluation of the frequency distribution of different anomalies and side of involvement revealed that 45 of 200 patients (22.5%) had morphological anomalies of the JB; HRJB without dehiscence was the most common anomaly, and the right side was more commonly involved (64.4%).

Of 45 patients with morphological anomalies of the JB, 30 (66.7%) were females and 15 (33.3%) were males; males and females were not significantly different in terms of frequency distribution of morphological variations (p=0.194, Table 1).

Variable	Males Number (percentage)	Females Number (percentage)	*p* value
HRJB without dehiscence	9(29.0%)	22(71.0%)	0.194
HRJB with dehiscence	5(45.5%)	6(54.5%)	
HRJB with diverticulum without dehiscence	1(50.0%)	1(50.0%)	
HRJB with diverticulum and dehiscence	0(0.0%)	1(100.0%)	
Total	15(33.3%)	30(66.7%)	

HRJB High riding jugular bulb

Table 1: Frequency distribution of morphological variations of the JB in males and females.

The frequency distribution of morphological anomalies of the JB was not significantly different in different age groups (p=0.282, Table 2).

Age group (years)	Normal JB Number (percentage in age group)	JB variations Number (percentage in age group)	Total Number (percentage in age group)	*p* value
20-29	38(74.5%)	13(25.5%)	51(100.0%)	0.282
30-39	36(70.6%)	15(29.4%)	51(100.0%)	
40-49	27(77.1%)	8(22.9%)	35(100.0%)	
50-59	35(89.7%)	4(10.3%)	39(100.0%)	
60 and older	19(79.2%)	5(20.8%)	24(100.0%)	
Total	155(77.5%)	45(22.5%)	200(100.0%)	

Table 2: Frequency distribution of different anatomical variations of the JB in different age groups

According to the independent t-test, the size of anteroposterior and mediolateral dimensions of the JB in normal individuals was significantly different in the right and left sides (p<0.0001). But the JB-SMF distance was not significantly different in the right and left sides in these subjects (p=0.381, Table 3).

	Gender	Number (temporal bone)	Anteroposterior dimension of JB Mean± SD		Mediolateral dimension of JB Mean± SD		JB-SMF distance Mean± SD	
			Right	Left	Right	Left	Right	Left
Normal JB	Male	65(130)	7.46±1.65	6.66±1.39	7.55±1.85	6.68±1.27	3.95±1.18	4.09±1.23
	Female	90(180)	7.36±1.57	6.77±1.53	7.56±1.74	6.86±1.80	3.86±1.47	3.99±1.36
	Total	155(310)	7.40±1.60	6.72±1.47	7.56±1.78	6.79±1.59	3.90±1.35	4.03±1.30
p value between the right and left sides			0.0001		0.0001		0.381	

JB Jugular bulb; SMF Stylomastoid foramen; SD Standard deviation

Table 3:Mean anteroposterior dimension of the JB on axial section, mediolateral dimension of the JB on coronal section and mean of shortest distance between JB and stylomastoid foramen on coronal section in males and females with normal JB in the right and left sides

According to ANOVA, the mean of the largest anteroposterior and mediolateral dimensions of the JB in subjects with abnormal JB was significantly greater than that in normal individuals (p<0.05). No significant difference was noted in mediolateral dimension of the JB in subjects with HRJB and diverticulum and without dehiscence (p=0.132, Table 4).

Variable	Number	Anteroposterior dimension of JB on axial section (mm) Mean± SD	Mediolateral dimension of JB on coronal section (mm) Mean± SD	*p* value Normal versus AP and ML
Normal JB	348	7.03±1.55	7.13±1.71	
HRJB without dehiscence	36	9.68±1.35	10.11±1.59	0.0001(AP) 0.0001(ML)
HRJB with dehiscence	13	9.73±1.56	10.34±1.40	0.0001(AP) 0.0001(ML)
HRJB with diverticulum without dehiscence	2	11.66±0.86	9.90±1.41	0.0001(AP) 0.132(ML)
HRJB with diverticulum and dehiscence	1	10.02	9.25	

AP Anteroposterior ; ML Mediolateral

Table 4: Mean anteroposterior dimension of the JB on axial section and largest mediolateral dimension of JB on coronal section for different anatomical variations of the JB

According to the independent t-test, the mean of shortest JB-SMF distance in subjects with normal JB was significantly greater than that in subjects with abnormal JB (p<0.0001, Table 5).

Group	Number	JB-SMF distance (mm)	Standard deviation	*p* value
Normal JB	348	4.00	1.31	0.0001
Abnormal JB	52	2.97	1.19	

Table 5. Mean shortest distance between JB and SMF on coronal section in subjects with normal and abnormal JB

Assessment of the frequency distribution of different complications in individuals with JB variations revealed that tinnitus had the highest frequency (24.4%), and the frequency of tinnitus in subjects with HRJB along with dehiscence was significantly higher than that in patients with HRJB without dehiscence (p=0.025). However, no difference was noted among individuals with different anomalies of the JB regarding the frequency of hearing loss (p=0.48) or vertigo (p=0.10, Table 6).

Symptom	Frequency	HRJB without dehiscence	HRJB with dehiscence	Total	*p* value
Tinnitus	Number	5	6	11	0.025
	Percentage	15.20%	50.00%	24.40%	
Hearing loss	Number	5	1	6	0.48
	Percentage	15.20%	8.30%	13.30%	
Vertigo	Number	2	3	5	0.10
	Percentage	6.10%	25%	11.10%	

HRJB: High riding jugular bulb

Table 6: Frequency distribution of different complications in our study population

Discussion

This study assessed the morphology and anatomical variations of the JB in individuals over 20 years of age using CBCT.

Most studies on this topic have used CT and to the best of our knowledge, only Guldner *et al.*[24] used CBCT to assess the visibility of anatomical structures of the middle ear and adjacent structures such as the JB in normal and pathological conditions. Studies on this topic have reported a wide range of prevalence rates for HRJB varying from 3.5% to 65%. The afore-mentioned studies either used dry skulls or CT scans of patients for this purpose[5,10,17,18,19,20,21,22,23] Such a wide range of prevalence rates for a particular morphological anomaly can be due to many reasons such as variability of vascular structures, lack of a consensus among researchers regarding the definitions of diagnostic parameters of JB variations on images, false results of studies on dry skulls due to fragility of the skulls and racial and geographical differences among the study populations.

In the current study, the prevalence of anatomical variations of the JB was 22.5% (n=45); out of which, 14.5% (n=29) were in the right side, 4.5% (n=9) were in the left side and 3.5% (n=7) were bilateral. However, the prevalence rate of HRJB reported in previous studies has been widely variable.[3,16,17,19,22,25,26] Our findings in this respect were close to those of Savic *et al*,[19] Sonmez *et al*,[25] and Sayit *et al.*[26] The two latter studies have been conducted in Turkey and the similarity between their results and ours may be attributed to the relatively close geographical and racial conditions.

The current findings revealed that the anteroposterior and mediolateral dimensions of the JB in patients with a normal JB were significantly greater in the right side compared to the left side. The morphology of the dural venous sinuses in the posterior cranial fossa and the JB is highly variable. The vascular anatomy of this region relates not only to embryology and postnatal growth and development of the brain, but also to hemodynamic alterations in cerebral circulation.[10] Superiority of the venous structures of the right side including the JB compared to the left side is seen in 70% to 80% of individuals.[2] In the current study, in line with that of Friedmann *et al*,[3] JB dimensions in the right side were greater than those in the left side.

According to the current findings, anatomical variations of the JB were significantly different among different age groups. The prevalence of anatomical variations of the JB in the first two decades of life (i.e. 20-29 years and 30-39 years) was greater than that in other decades. The first increase in prevalence of morphological variations of the JB is seen between the ages of 11 and 20 years, and may occur concomitantly with general growth and development of the body and sexual maturity. Subsequently, an abrupt increase occurs in the prevalence of variations of the JB with over two-fold increment in this rate between the ages of 31 to 40 years and 41 to 50 years with an unknown etiology. After the age of 50 years, its prevalence rate remains constant around 10%.[3] The JB is not present at the time of birth and appears at 2 years of age. It increases in size up to 40 years of age and remains almost unchanged afterwards. Therefore, morphological variations of the JB primarily occur during the growth phase of JB.[2] This hypothesis can explain the increase in variations of the JB between 20 to 40 years of age in our study.

According to the results, the mean of anteroposterior and mediolateral dimensions of the JB was greater in cases with HRJB with and without dehiscence compared to normal individuals; this finding was in agreement with the results of Friedmann *et al.*[3] Therefore, it appears that in the process of enlargement of the JB to turn into an abnormal HRJB, first its mediolateral dimension and then its anteroposterior dimension increase.[3]

Based on the present results, the mean mediolateral dimension of the JB was larger than the mean anteroposterior dimension of the JB in both normal and abnormal (morphological variants) cases of JB. Considering the mean of anteroposterior and mediolateral dimensions of the JB, significant differences existed in this respect between normal individuals and those with HRJB with/without dehiscence. However, cases with HRJB plus diverticulum and without dehiscence were different from cases of normal JB in only the anteroposterior dimension, and no significant difference was found between the two groups in mediolateral dimension of the JB. This finding may be due to small sample size for this particular anomaly (n=2) or protrusion of the JB in anteroposterior, rather than mediolateral, dimension in diverticulum. This finding was slightly different from the results of Friedmann *et al*,[3] which may be attributed to differences in grouping of patients (inclusion of individuals over 2 years of age in their study), method of measurements and possible errors in this regard and racial and geographical differences among the study populations.

The distance from the JB to facial nerve has been variable in previous studies.[23,27,28] The current results revealed that the sum of shortest distance from the JB to SMF was not significantly different in the right and left sides of individuals with normal JB. The mean of shortest distance between JB and SMF was significantly different in normal and abnormal JB groups, which indicates that by an increase in size of the JB, this distance decreases and risk of compression of facial nerve and its subsequent complications exists in cases with severe enlargement of the JB.

HRJB along with dehiscence was noted in 11 (5.5%) patients; it was in the right side in 9 (81.8%) and bilateral in 2 (18.2%) patients. The prevalence of this condition has been different in previous studies.[5,26,29] HRJB along with diverticulum was seen in 3 (1.5%) patients in our study; among which, one also had dehiscence. Totally, this condition was seen in the left side in 2 (1%) and in the right side in one patient (0.5%). The prevalence of JB diverticulum ranges from less than 1% to 7.9% in the literature.[5,29] Diverticulum is often more common in the left side and a number of genetic factors, bone remodeling and hemodynamic patterns of cerebral circulation are responsible for its occurrence.[8,10,30]

Evaluation of complications due to JB anomalies revealed that tinnitus had the highest frequency, and its frequency was significantly higher in patients with HRJB and dehiscence compared to patients with HRJB without dehiscence; this finding was in agreement with the results of Friedmann *et al*, and Sayit *et al*.[9,25,26,31] Also, in the current study, similar to that of Hourani *et al*, no significant correlation existed between hearing loss and vertigo with abnormal JB.[5] In general, the prevalence of symptoms in patients with HRJB and dehiscence was higher than that in patients with HRJB without dehiscence, which highlighted the significant effect of JB dehiscence on development of the triad of symptoms. Furthermore, evidence shows that patients with morphological variations of the JB have high risk of developing symptoms mimicking those of Meniere's disease; although half of these patients are asymptomatic.[32,33]

The clinical significance of HRJB is that it is susceptible to trauma during surgical procedures of the auricular area. Thus, preoperative imaging plays a fundamental role in identifying different variations of the JB and preventing hemorrhage. Since knowledge about such morphological variations can clinically help the surgeon in decision making, treatment planning and prognosis, CBCT can be used as an efficient imaging modality for this purpose due to its high spatial resolution, the ability for multiplanar image reconstruction (similar to CT) and lower patient radiation dose compared to CT.

Conclusion

The prevalence of JB anomalies was found to be 22.5% in individuals over 20 years of age. The dimensions of normal and abnormal JB in the right side were larger than those in the left side. Furthermore, by enlargement of the JB, its distance from the SMF decreases. The clinical significance of anatomical variations of the JB is that they are susceptible to trauma and subsequent hemorrhage during surgical procedures of the auricular region. Thus, CBCT can greatly help in this respect due to its multiplanar image reconstruction (similar to that of CT) and lower patient radiation dose compared to CT.

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