A Retrospective and Prospective Observational Study to Evaluate the Jugular Bulb Anatomical Variations Using High-resolution Computed Tomography

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Abstract

Introduction: The jugular bulb (JB) is a key anatomical structure of the temporal bone that shows variability that can impact otologic surgeries and symptoms. This study aimed to assess the presence and characteristics of bulb variations with high-resolution computed tomography (HRCT) and their distribution across different demographics. **Materials and Methods:** A total of 400 patients undergoing HRCT of the temporal bone were ambispectively analyzed. JB variations, including high-riding JB, dehiscent JB, and JB diverticulum, were identified. Data were further analyzed based on gender, age, and unilateral versus bilateral presence. **Results:** High-riding JB was observed in 20% of the patients. Dehiscent JB and JB diverticulum were less frequently found in 3% and 0.25% of the cases, respectively. Significant gender differences were noted with high-riding JB more prevalent in females (27.9%) compared to males (15.9%). Age-related variations showed high-riding JB most frequently in the 10–30 year ages. The majority of JB variations were unilateral with a right-sided predominance. **Conclusion:** The presence of JB variations highlights the need for careful preoperative assessment in otologic surgeries to avoid complications. The significant findings of gender- and age-related differences in JB variations underscore the importance of personalized diagnostic approaches. This study reinforces the value of HRCT in the detailed evaluation of anatomy for optimized planning of surgeries and patient management.

Keywords: High-resolution computed tomography, jugular bulb, jugular bulb variations, preoperative imaging assessment, temporal bone anatomy

Introduction

The jugular bulb (JB) is an anatomical structure situated where the sigmoid sinus meets the internal jugular vein in the temporal bone. Typically found below the hypotympanum, the JB can show significant anatomical variations which may lead to important clinical consequences.[1] These variations commonly include high-riding (HR) JB, dehiscent JB and JB diverticulum.[2,3]

High-resolution computed tomography (HRCT) of temporal bone has become an invaluable tool for examining JB anatomy and its connections to nearby structures.[4] Research to date has shown a wide range of prevalence rates for JB variations, with HR JB occurring in 3.5%–20% of cases.[5,6] However, the reliability of these findings is often limited by small study populations or a focus on specific patient groups.

The importance of understanding JB variations lies in their potential to cause symptoms or create complications during ear surgeries. HR JBs have been linked to pulsatile tinnitus, vertigo, and conductive hearing loss.[7] In middle ear procedures, failing to identify a high or dehiscent JB can result in severe bleeding.[8] Moreover, JB variations can affect the surgical approach in procedures like cochlear implantation.[9]

Submitted: 15-Aug-2024 **Revised:** 15-Oct-2024
Accepted: 18-Oct-2024 **Published:** 16-Dec-2024

Access this article online
Quick Response Code:
Website: http://journals.lww.com/amit
DOI: 10.4103/amit.amit_105_24

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How to cite this article: Atram S, Agrawal A, Dixit Y, Manzill, Suhas KS, Dhakad H, *et al*. A retrospective and prospective observational study to evaluate the jugular bulb anatomical variations using high-resolution computed tomography. Acta Med Int 2024;11:246-51.

Some research suggests that JB variations might be more frequently one-sided (right) or in women, but the exact relationship between these anatomical differences and demographic factors is still not well understood.[3,10] There is also a lack of comprehensive data on how often JB variations occur bilaterally in individuals.

Our work hopes to provide an assessment of the prevalence and characteristics of JB anatomical variations using HRCT in a large and diverse group of patients. We will examine how these variations are distributed for side, gender, or age and also look at patterns of jugular foramen dominance. By shedding light on the epidemiology of these significant anatomical variants, we hope to improve preoperative planning and minimize the risk of complications in ear surgeries.

Materials and Methods

The study was a Ambispective, time-limited, observational project conducted at the Department of Radiodiagnosis, MGM Medical College and Hospital, India. The research received the necessary approvals from the Ethics and Institutional Scientific Review Committee (EC/MGM/SEP23/145). Spanning from May 2022 to May –2024, the study involved a total of 400 patients. Of these, 230 patients were retrospectively included, having presented between May 2022 and May 2023. The remaining 170 patients were prospectively examined from May 2023 to May 2024, all undergoing HRCT of the skull base and temporal bone at the department.

Inclusion criteria

1. Age >2 years.

Exclusion criteria

1. Intracranial tumors distorting the JB anatomy
2. Postoperative middle ear cases.

Study protocol

- The procedure for the HRCT temporal bone scan was explained and informed written consent was taken from all of the patients/attendants
- 128 slice 5th-generation CT scanner. Multidetector CT scan machine with CPT software was used to scan patients
- HRCT temporal bone was performed with the patient positioned in the gantry in the supine position with the head reclined and the neck flexed
- Standard CT protocol is used with a tomogram length of 512 cm, 120 kV, and 250 mA
- The effective mAs defined "as the mA × the gantry cycle time/helical pitch" were adjusted according to the age and head size. At 150 effective mAs, 200 effective mAs in children ages 1–10 years, 250 effective mAs in adolescents, and 320 for adults
- Serial thin sections of the temporal bone were used to obtain axial projections. These sections were about 0.5–1 mm thin. A line connecting the infraorbital rim to the external auditory meatus was perpendicular to the table
- The images were processed using a bone algorithm. Coronal and sagittal reformatting was done to a slice thickness of 0.625 mm and was required to evaluate the JB
- It takes about 15–30 min to finish an examination for one patient.

Results

Out of 400 patients, the majority Majority had a normal JB anatomy, with only 2 (0.5%) cases showing no JB. High-riding JB was observed in 80 (20%) patients, dehiscent JB in 12 (3%) patients, and JB diverticulum in just 1 (0.25%) patient.

The distribution of JB variations between genders showed that high-riding JB was more prevalent in females (27.9%) than in males (15.9%), with a significant $P = 0.0012$, indicating a significant difference in the prevalence of high-riding JB between the genders.

High-riding JB was most prevalent in the 10–30-year age group (23.2%), whereas dehiscent JB was more common in children under 10 years (7.2%). JB diverticulum was rare and only identified in one patient within the 30–50-year age group.

High-riding JB predominantly occurred unilaterally with 40 cases on the right (10%) and 24 on the left (6%). Dehiscent JB was equally distributed between the right and left sides with 6 cases each (1.5%). JB diverticulum was found unilaterally on

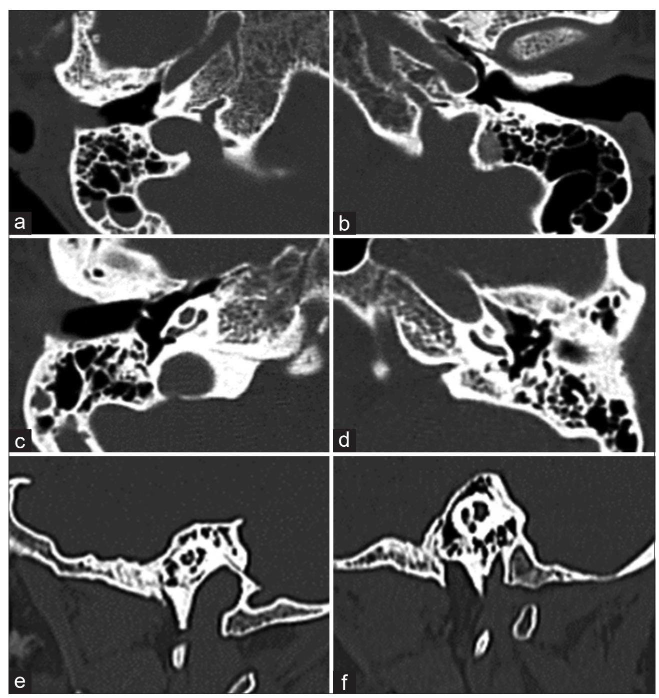

Figure 1: Right high riding and larger jugular bulb (JB). Case 1: High-resolution computed tomography B/L temporal bone of 25-year-old male patient. (a) Axial section: Right jugular bulb (b) Axial section: Left jugular bulb (c) Axial section: Right JB above the level of cochlea (d) Axial section: Left JB below the level of the cochlea (e) Saggital: Right JB above the level of basal turn of cochlea (f) Saggital: Left JB below the level of the basal turn of the cochlea

the left in one case. $P = 0.039$ indicates a statistically significant difference in the unilateral versus bilateral distribution of no JB.

In males, high-riding JB was more frequently unilateral, with 7.6% on the right and 5.6% on the left. Dehiscent JB was less common, appearing in 0.7% on both sides, and no JB diverticulum was observed. $P = 0.047$ suggests a statistically significant difference in the unilateral versus bilateral distribution of no JB among males.

For females, high-riding JB was predominantly unilateral, with 14.7% on the right and 6.6% on the left. Dehiscent JB was also more common unilaterally, with 3.6% on the right and 2.2% on the left. A single case of JB diverticulum was noted on the left side. $P = 0.044$ indicates a significant difference in the unilateral versus bilateral distribution of no JB among females.

The jugular foramen was predominantly right sided in 55.6% of the patients, left-sided in 18.7%, and symmetrical in 25.7%.

By gender, right jugular foramen dominance was slightly more common in males (56.1%) than in females (54.4%). Left dominance and symmetrical formations were slightly more frequent in females, indicating minor variations in jugular foramen dominance between genders. $P = 0.76$ indicates no statistically significant difference in jugular foramen dominance between males and females.

Discussion

In the findings, Table 1 outlines the distribution of JB variations, identifying high-riding JB as the most common variation seen. Table 2 looked into the gender differences in these variations revealing a higher prevalence of high-riding JB among the females. The age distribution of JB variations in Table 3 showed a higher occurrence in younger adults. Table 4 assesses the unilateral and bilateral presence of JB variations with a notable right-side predominance. This unilateral trend is further seen in Tables 5 and 6, which analyzed the distribution specifically among male and female patients, respectively. Tables 7 and 8 focus on the dominance of the

Table 1: Distribution of patients according to jugular bulb anatomical variations (*n*=400)

Anatomical variations	Number of patients, *n* (%)
No JB	2 (0.5)
High-riding JB	80 (20)
Dehiscent JB	12 (3)
JB diverticulum	1 (0.25)

JB: Jugular bulb

Table 2: Distribution of patients according to jugular bulb anatomical variations and gender (*n*=400)

Anatomical variations	Male; frequency, *n* (%)	Female; frequency, *n* (%)	*P*
No JB	1 (0.4)	1 (0.75)	0.0012
High-riding JB	42 (15.9)	38 (27.9)	
Dehiscent JB	4 (1.6)	8 (5.8)	
JB diverticulum	0	1 (0.75)	

JB: Jugular bulb

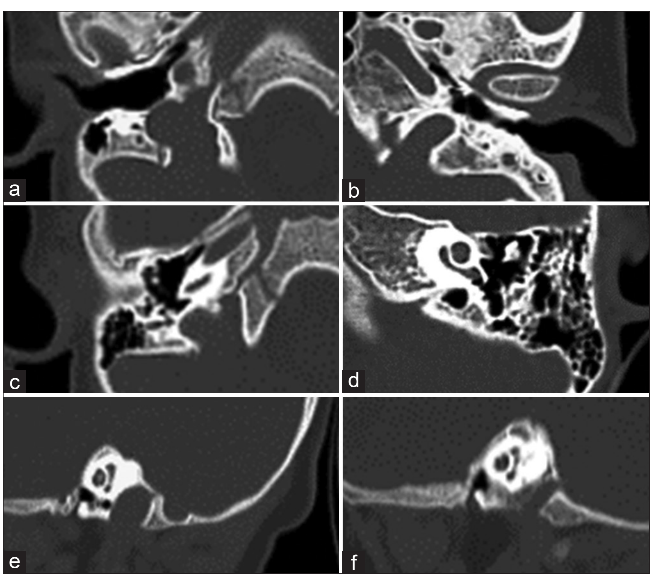

Figure 2: Right high riding and dehiscent jugular bulb (JB). Case 2: High-resolution computed tomography B/L temporal bone of 30-year-old female. (a) Axial section: Right dehiscent jugular bulb (b) Axial section: Left normal jugular bulb (c) Axial section: Right JB above the level of cochlea (d) Axial section: Left JB below the level of the cochlea (e) Saggital: Right JB above the level of basal turn of cochlea (f) Saggital: Left JB below the level of the basal turn of the cochlea

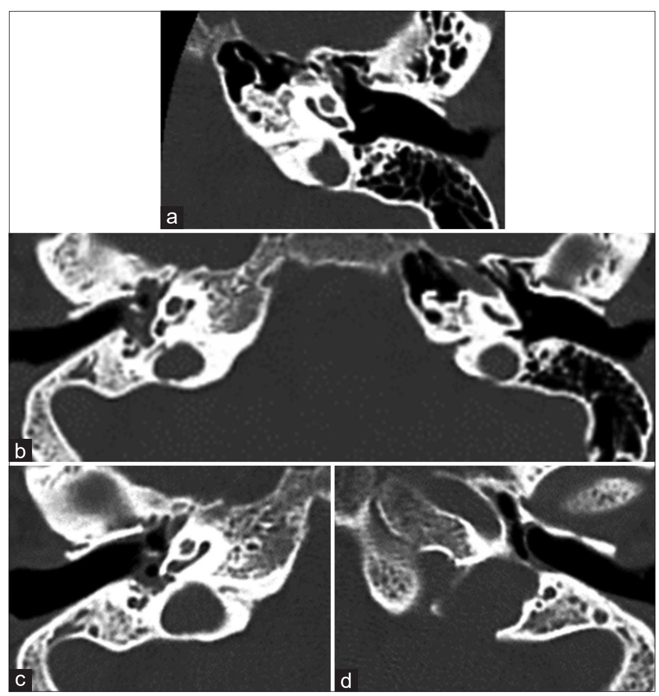

Figure 3: Bilateral high-riding jugular bulb (JB), left JB Diverticula, left JB dehiscence. Case 3: High-resolution computed tomography B/L temporal bone of 81-year-old female. (a) Axial section: Left high JB with diverticula (b) Axial section: Bilateral high jugular bulbs (c) Axial section: Right JB above the level of cochlea (d) Axial section: Left dehiscent JB

Table 3: Distribution of jugular bulb anatomical variations according to age

Anatomical variations	<10 years, *n* (%)	10–30 years, *n* (%)	30–50 years, *n* (%)	50–70 years, *n* (%)	>70 years, *n* (%)
No JB	0	1 (0.6)	1 (0.7)	0	0
High-riding JB	6 (21.4)	36 (23.2)	26 (18.1)	10 (17.8)	2 (12.5)
Dehiscent JB	2 (7.2)	6 (3.8)	2 (1.4)	2 (3.6)	0
JB diverticulum	0	0	1 (0.7)	0	0

JB: Jugular bulb

Table 4: Jugular bulb anatomical variations according to unilateral/bilateral distribution of jugular bulbs (*n*=400)

Anatomical variations	Unilateral			Bilateral, *n* (%)	*P*
	Right, *n* (%)	Left, *n* (%)	Total, *n* (%)		
No JB	0	2 (0.5)	2 (0.5)	0	0.039
High-riding JB	40 (10)	24 (6)	64 (16)	16 (4.0)	
Dehiscent JB	6 (1.5)	6 (1.5)	12 (3)	0	
JB diverticulum	0	1 (0.25)	1 (0.25)	0	

JB: Jugular bulb

Table 5: Jugular bulb anatomical variations according to unilateral/bilateral distribution of jugular bulbs in males (*n*=264)

Anatomical variations	Unilateral			Bilateral, *n* (%)	*P*
	Right, *n* (%)	Left, *n* (%)	Total, *n* (%)		
No JB	0	1 (0.4)	1 (0.4)	0	0.047
High-riding JB	20 (7.6)	15 (5.6)	35 (13.2)	6 (2.3)	
Dehiscent JB	2 (0.7)	2 (0.7)	4 (1.4)	0	
JB diverticulum	0	0	0	0	

JB: Jugular bulb

Table 6: Jugular bulb anatomical variations according to unilateral/bilateral distribution of jugular bulbs in females (*n*=136)

Anatomical variations	Unilateral			Bilateral, *n* (%)	*P*
	Right, *n* (%)	Left, *n* (%)	Total, *n* (%)		
No JB	0	1 (0.8)	1 (0.8)	0	0.044
High-riding JB	20 (14.7)	9 (6.6)	29 (21.3)	10 (7.4)	
Dehiscent JB	5 (3.6)	3 (2.2)	8 (5.8)	0	
JB diverticulum	0	1 (0.8)	1 (0.8)	0	

JB: Jugular bulb

jugular foramen, confirming a general one-sided dominance across the patient population. The study shows demographic-higher prevalence of high-riding JB in females [Figure 1] and unilateral right-sided dominance [Figure 2]. Age related trends in distribution in Figure 3, emphasizing the importance of tailoring preoperative assessments. Figure 4 illustrates the clinical relevance of rarer variants like JB diverticulum.

The structural differences of the JB and surrounding structures in the temporal bone have significant implications for otologic surgery and patient symptoms. This study found a prevalence of high JB (HJB) of 20% in the patient population, which is within the range of 6%–34% reported in previous studies as in Table 1.[5,6] However, some studies have found lower rates, such as 3.5% reported by Brook *et al*.[9] The higher prevalence in females as in Table 2 (27.9% vs. 15.9% in males) aligns with findings by Aksoy and Yurdaisik, who noted a female predisposition to HJB[3] In contrast, Pekcevik *et al*. found no significant gender difference in HJB prevalence.[4]

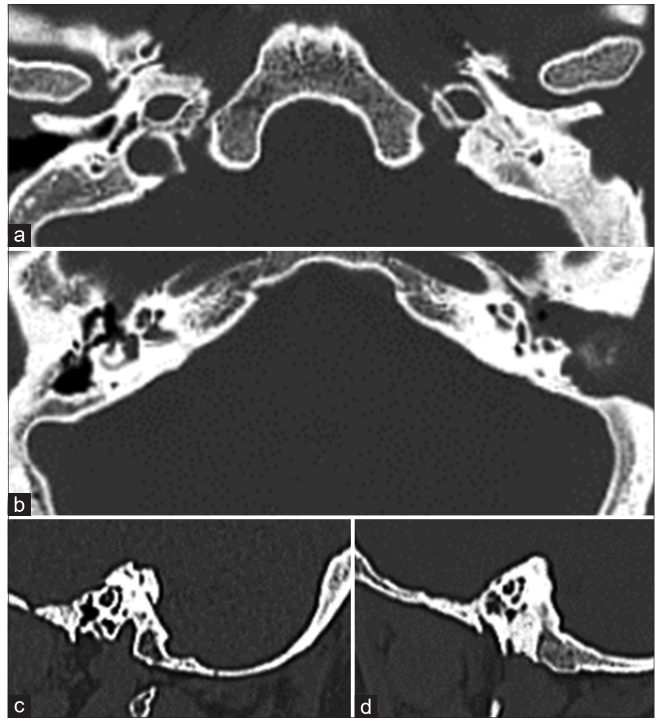

Figure 4: Left absent jugular bulb (JB). Case 4: High-resolution computed tomography B/L temporal bone of 43-year-old male. (a) Axial section: Left-sided JB not visualized, right-sided normal JB (b) Axial section at the level of the cochlea: B/L JB not visualized (c) Saggital section through right cochlea: Right JB at normal position (d) Sagittal section through left cochlea: Left JB not visualized

Unilateral variations were more common than bilateral, with a right-sided predominance. This asymmetry has been observed in other studies and may relate to the embryological development of the venous system.[5,6] In our study, 64.7% of cases had a larger right jugular foramen compared to 19.1% with a larger left foramen. This is similar to findings by Kumar *et al*., who reported a larger right foramen in 64.7% of cases.[6] However, Sturrock found a higher rate of 69% right-sided

Table 7: Distribution of patients according to jugular foramen dominance

Dominance	Number of patients, *n* (%)
Right	222 (55.6)
Left	75 (18.7)
Symmetrical	103 (25.7)
Total	400 (100)

Table 8: Distribution of patients according to jugular foramen dominance and their gender

Dominance	Male; frequency, *n* (%)	Female; frequency, *n* (%)	*P*
Right	148 (56.1)	74 (54.4)	0.76
Left	47 (17.8)	28 (20.6)	
Symmetrical	69 (26.1)	34 (25.0)	
Total	264 (100)	136 (100)	

dominance.[7] The JB's proximity to critical structures such as the facial nerve, inner ear, and internal carotid artery underscores the importance of preoperative imaging to identify variants.[8,9]

Beyond HJB, other variations such as JB diverticulum (0.25%) and dehiscent JB (3%) were identified at lower rates in our study. These findings emphasize the spectrum of JB anatomy surgeons may encounter. As Cömert *et al*. noted, precise knowledge of these relationships is essential for safe surgical approaches to the lateral skull base.[10] Some studies have reported higher rates of dehiscent JB, such as 3.7% by Pekcevik *et al*.[4]

Age-related trends were observed, with HJB most prevalent in the 10–30-year age group in our study. This contrasts somewhat with Wang *et al*.'s findings of higher HJB prevalence in early middle age.[11] Aksoy and Yurdaışık found no significant age-related differences in HJB prevalence.[3] Further research on age-related changes in JB anatomy could clarify these discrepancies.

The clinical relevance of JB variations extends beyond surgical planning. Pulsatile tinnitus, vertigo, and conductive hearing loss have been associated with HJB.[7,8] However, many individuals with anatomical variants remain asymptomatic. Our study found JB variations in 24% of patients, higher than rates of 8%–15% reported for symptomatic presentations in some series.[12,13] This suggests anatomical variants alone do not necessarily produce symptoms. Xia *et al*. found no significant difference in JB abnormalities between patients with Ménière's disease and controls.[14]

Imaging plays a crucial role in identifying these variations. While our study utilized CT, magnetic resonance imaging (MRI) and MR venography can provide complementary information, particularly for vascular anatomy.[15,16] Schrauben *et al*. demonstrated how advanced imaging techniques like 4D flow MRI can elucidate the hemodynamics of jugular venous outflow.[17] Some researchers have advocated for routine preoperative imaging to identify variants.[18]

The relationship between JB variations and chronic otitis media remains unclear. Some researchers have hypothesized that altered venous drainage could predispose to middle ear disease.[19-22] However, our study did not find a clear association. Gökharman *et al*. found significantly higher rates of HJB and anteriorly located sigmoid sinus in chronic otitis media patients compared to controls.[23] Further investigation of potential links between vascular anatomy and otologic pathology is needed.

From a surgical perspective, awareness of JB variations is critical for avoiding complications. Techniques like infralabyrinthine approaches must be made to individual anatomy.[24,25] Endoscopic approaches may offer advantages for visualizing the complex relationships in this region.[26] By providing detailed visualizations of relationships, 3D-models enhance spatial awareness for surgeons, hence improving access during lateral skull base and middle ear surgeries and helping to reduce the risk of complications.[15,25,27]

This study provided valuable data on the prevalence and characteristics of JB variations in a large patient sample. The findings show the importance of preoperative imaging and individualized surgical planning. Future research directions could include long-term follow-up of asymptomatic individuals with variants and exploring potential associations with otologic conditions. As imaging and surgical techniques continue to progress, the understanding of the clinical significance of these structural differences will evolve ahead.

Limitations of this study include its retrospective nature and reliance on imaging findings without surgical correlation in all cases. The single-center design may limit generalizability, While CT provides excellent bony details, soft tissue and vascular imaging is limited compared to MRI. Future prospective studies correlating imaging, surgical findings, and clinical outcomes across multiple centers would be valuable. Longitudinal studies examining age-related changes in JB anatomy could also provide important insights.

Conclusion

Thus, JB anatomical variations highlight their significant prevalence and clinical implications. The study found a 20% incidence of HJB, with higher rates in females and on the right side. These variations can impact surgical approaches and patient symptoms. Preoperative imaging is crucial for identifying variants and planning appropriate interventions. While some variations may be asymptomatic, others can cause pulsatile tinnitus, vertigo, or hearing loss. Understanding these anatomical nuances is essential for otolaryngologists and neurosurgeons to optimize patient care and minimize surgical complications.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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