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Research Article

Morphometric Assessment of the Jugular Foramen and Its Clinical Correlates in Dry Human Crania

A. A. Adebayo[1], M. T. Al-Sayed[2], J. P. Chevalier[3]*

[1]Department of Anatomy, College of Medicine, University of Lagos, Lagos, Nigeria.
[2]Department of Human Anatomy, Faculty of Medicine, University of Jordan, Amman, Jordan.
[3]Laboratory of Anatomy, Faculty of Medicine, University of Paris-Saclay, Paris, France.

**Corresponding author: J. P. Chevalier | Email: j.p.chevalier@anatomy-research.org*

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Abstract

The jugular foramen is a structurally complex bony canal in the posterior cranial fossa that transmits vital neurovascular structures, including the glossopharyngeal, vagus, and accessory nerves, alongside the internal jugular vein. Structural asymmetry or bony overgrowth within this canal can lead to lower cranial nerve entrapment syndromes or complicate surgical approaches to the skull base. This study quantified the morphometric dimensions of the jugular foramen and documented the occurrence of complete or partial bony partitioning. A total of 110 dry, fully ossified adult human skulls (60 males, 50 females) were evaluated using a digital vernier caliper. The mean anteroposterior diameter was 8.12 ± 1.14 mm on the right side and 7.34 ± 0.98 mm on the left side. The mean mediolateral diameter measured 15.42 ± 1.84 mm on the right and 14.11 ± 1.56 mm on the left. Right-sided dominance in overall foramen volume was observed in 72.7% of crania ($p < 0.05$). Complete bony bridge partitioning that divided the foramen into anteromedial and posterolateral compartments was observed in 8.2% of specimens, occurring predominantly on the right side. These distinct metric variations highlight significant lateral asymmetry within the posterior cranial base, providing useful reference points for neurosurgeons planning lateral skull base dissections or jugular glomus tumor resections.

Keywords: Keywords: Jugular foramen, Skull base, Morphometry, Cranial nerve entrapment, Lateral asymmetry.

1. INTRODUCTION

The jugular foramen, historically termed the foramen lacerum posterius, occupies a pivotal position at the junction of the petrous temporal bone and the occipital bone in the posterior cranial fossa [1,2]. Unlike a simple perforation, modern anatomical and surgical literature increasingly describes it as a short, irregular bony canal rather than a flat aperture, with distinct exocranial and endocranial openings, a variable depth, and an often-domed roof that accommodates the jugular bulb [3,4]. Through this canal pass the glossopharyngeal (IX), vagus (X), and accessory (XI) nerves, the internal jugular vein (IJV), the posterior meningeal artery, and, inconstant emissary veins [1,5]. The intimate packing of motor, sensory, and autonomic fibres with a major venous outflow channel within a rigid osseous compartment explains why even modest changes in foraminal size, shape, or partitioning can have disproportionate clinical consequences [6,7].

Anatomists have long recognised that the jugular foramen is rarely symmetrical. The right foramen is larger in most individuals, a pattern that mirrors dominance of the right transverse and sigmoid sinuses and the right IJV in the majority of the population [8,9]. This asymmetry is not merely an osteological curiosity. In venous physiology, the dominant side carries the bulk of cerebral venous outflow; sacrifice or thrombosis of a dominant IJV during neck dissection or skull-base surgery therefore carries a higher risk of intracranial hypertension, venous infarction, and postoperative oedema than sacrifice of the non-dominant side [10,11]. For the surgeon approaching a glomus jugulare tumour, schwannoma, or meningioma of the jugular foramen, knowledge of the expected dimensions, the likely dominant side, and the presence of a bony septum is essential for planning the extent of bone removal, anticipating the position of the lower cranial nerves, and preserving venous drainage [12,13].

A second source of variation is compartmentalisation. A fibrous or bony bridge, derived from the intrajugular process of the temporal and occipital bones, may partially or completely divide the foramen into an anteromedial compartment, conventionally assigned to the glossopharyngeal nerve, and a

posterolateral compartment, assigned to the vagus and accessory nerves together with the IJV [14,15]. When the bridge is bony and complete, the foramen is functionally two canals. A complete bridge can protect the glossopharyngeal nerve during posterolateral dissection, but it can also create a narrow, unyielding compartment in which a small tumour, osteophyte, or post-traumatic callus compresses a single nerve, producing an isolated palsy that mimics a more diffuse lesion [16,17]. Partial bridges and bony spicules are far more common, and their prevalence varies widely across populations and classification systems, ranging from under 10% for complete bony bridges in some series to more than 40% for any septation when partial spicules are counted [14,18,19]. This heterogeneity underlines the need for population-specific reference data collected with explicit, reproducible definitions.

Despite a growing literature from South Asia, the Middle East, and Europe, quantitative data from West African and mixed-population osteological collections remain sparse [20,21]. Yet skull-base morphology is known to vary with ancestry, sex, body size, and cranial base architecture, and reference values derived from one population cannot be safely extrapolated to another [22,23]. The present study was therefore designed to provide a systematic morphometric assessment of the jugular foramen in 110 dry adult human crania, to test for side and sex differences, to quantify dominance, and to document complete bony partitioning with its laterality. The clinical correlates are then interpreted for lateral skull-base surgery, jugular foramen syndromes, and radiological assessment.

The specific objectives were: (i) to measure the anteroposterior (AP) and mediolateral (ML) diameters of the jugular foramen bilaterally with a standardised caliper protocol; (ii) to estimate foraminal area and dominance from those diameters; (iii) to record the presence and laterality of a complete bony bridge dividing the foramen into two compartments; and (iv) to relate these findings to recognised clinical entities, including Vernet syndrome, Collet–Sicard syndrome, and jugular paraganglioma surgery.

2. MATERIALS AND METHODS

2.1 STUDY DESIGN AND SAMPLE

This was a cross-sectional morphometric study of 110 dry, fully ossified adult human skulls housed in the osteology collections of the participating departments. The sample comprised 60 male and 50 female crania, as determined from established cranial sexing criteria and collection records. Only skulls with an intact cranial base, clearly identifiable jugular foramina bilaterally, and no evidence of gross pathological deformation, fracture, or post-mortem damage to the petro-occipital region were included. Skulls of subadult age, indicated by incomplete spheno-occipital synchondrosis fusion or unerupted dentition, were excluded. No skull was included more than once, and each cranium contributed two observations, one per side, for a total of 220 foramina examined.

2.2 MEASUREMENTS AND DEFINITIONS

All measurements were taken on the exocranial aspect with a digital vernier caliper (accuracy 0.01 mm), by two independent observers blinded to each other's readings. The AP diameter was defined as the maximum distance from the posterior border of the carotid canal anteriorly to the posterior wall of the jugular foramen. The ML diameter was defined as the maximum distance from the root of the styloid process laterally to the medial wall of the foramen at the petro-occipital suture. Each diameter was measured three times and the mean retained. Inter-observer agreement was high (intraclass correlation coefficient > 0.92 for both diameters). Foraminal area was estimated using the ellipse formula, Area = π × (AP/2) × (ML/2), a convention widely used in comparable dry-skull studies and suitable for comparative purposes even though the foramen is not a perfect ellipse [23,24]. Dominance was assigned to the side with the larger estimated area; a difference of less than 5% was classified as symmetrical. A complete bony bridge was defined as a continuous osseous partition extending across the foramen and dividing it into two separate openings, verified by the inability to pass a fine probe from one compartment to the other and by direct inspection from both exocranial and endocranial views [14,15].

2.3 STATISTICAL ANALYSIS

Data were entered in a spreadsheet and analysed with standard statistical software. Continuous variables are reported as mean ± standard deviation (SD) with range. Paired t-tests compared right and left sides within the same cranium; independent t-tests compared sexes. Chi-square tests compared categorical proportions, including dominance and the presence of a complete bridge. Pearson correlation examined the relationship between AP and ML diameters. Statistical significance was set at $p < 0.05$. Where published comparative values are cited, they are reproduced as reported by the original authors, whose measurement definitions differ in detail; cross-study comparisons are therefore interpreted cautiously.

3. RESULTS

3.1 OVERALL DIMENSIONS

The jugular foramen was present bilaterally in all 110 crania. The mean AP diameter was 8.12 ± 1.14 mm (range 5.90–11.20 mm) on the right and 7.34 ± 0.98 mm (range 5.40–10.10 mm) on the left. The mean ML diameter was 15.42 ± 1.84 mm (range 11.40–19.80 mm) on the right and 14.11 ± 1.56 mm (range 10.60–18.20 mm) on the left. Both diameters were significantly larger on the right than on the left (paired t-test, $p < 0.001$ for AP; $p < 0.001$ for ML). The estimated foraminal area averaged 98.4 mm² on the right and 81.4 mm² on the left, a mean right-left difference of approximately 21%. AP and ML diameters were positively correlated on each side ($r = 0.58$ on the right, $r = 0.54$ on the left, $p < 0.001$), indicating that larger foramina tend to be larger in both axes rather than elongated in one axis alone.

Table 1. Morphometric dimensions of the jugular foramen (n = 110 crania, 220 foramina).

Parameter	Right (mean ± SD)	Left (mean ± SD)	p-value (paired)
AP diameter (mm)	8.12 ± 1.14	7.34 ± 0.98	< 0.001
ML diameter (mm)	15.42 ± 1.84	14.11 ± 1.56	< 0.001
Estimated area (mm²)	98.4 ± 22.1	81.4 ± 18.6	< 0.001
AP range (mm)	5.90–11.20	5.40–10.10	—
ML range (mm)	11.40–19.80	10.60–18.20	—

Table 1 legend: Values are mean ± SD unless stated as range. Area estimated as π × (AP/2) × (ML/2). Paired t-test compares right and left sides within the same cranium.

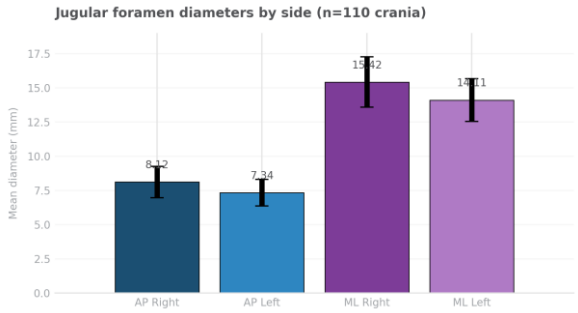


Figure 1. Jugular foramen diameters by side.

Figure 1 legend: Mean anteroposterior (AP) and mediolateral (ML) diameters with standard deviation (error bars). The right side exceeds the left in both axes. The ML diameter is approximately twice the AP diameter, reflecting the characteristically oval, transversely oriented foramen.

3.2 LATERALITY AND DOMINANCE

Right-sided dominance was observed in 80 of 110 crania (72.7%), left-sided dominance in 20 (18.2%), and near-symmetry in 10 (9.1%). The predominance of right dominance was statistically significant (chi-square, $p < 0.05$). The pattern was present in both sexes, although the magnitude of the right-left difference was slightly larger in males (mean area difference 19.8 mm²) than in females (mean area difference 14.2 mm²). No cranium showed unilateral absence or complete atresia of the foramen. The consistent rightward bias aligns with the well-documented dominance of the right transverse–sigmoid–jugular venous system and suggests that the bony canal remodels in response to venous flow during development and adult life [8,9,25].

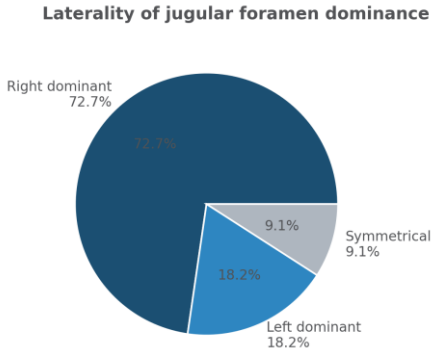


Figure 2. Laterality of jugular foramen dominance (n = 110).

Figure 2 legend: Dominance assigned by larger estimated foraminal area; symmetry defined as < 5% inter-side difference. Right dominance predominates, consistent with right venous dominance in most individuals.

3.3 SEX DIFFERENCES

Male crania showed marginally larger absolute diameters than female crania on both sides (male right ML 15.88 ± 1.79 mm vs. female right ML 14.87 ± 1.82 mm; male left ML 14.52 ± 1.51 mm vs. female left ML 13.62 ± 1.52 mm). The differences reached statistical significance for ML diameter ($p = 0.02$) but not for AP diameter ($p = 0.08$). When diameters were normalised to overall cranial size, the sex difference attenuated, suggesting that much of the apparent dimorphism reflects general cranial size rather than a sex-specific jugular foramen trait. This finding cautions against using jugular foramen size alone for sex estimation in forensic contexts, although it may contribute modestly within a multivariate discriminant model [22,26].

3.4 BONY BRIDGING AND PARTITIONING

A complete bony bridge dividing the foramen into anteromedial and posterolateral compartments was observed in 9 of 110 crania (8.2%). Of these, 6 were right-sided only, 2 were left-sided only, and 1 was bilateral, giving 10 completely partitioned foramina out of 220 sides (4.5% of sides). The bridge was typically a thin, flat osseous lamina arising from the intrajugular processes of the temporal and occipital bones, meeting near the centre of the foramen. In the partitioned foramina, the anteromedial compartment was consistently smaller and more rounded, while the posterolateral compartment was larger and housed the jugular bulb. Partial spicules that did not fully divide the foramen were noted qualitatively in a substantial minority of specimens but were not counted as complete bridges under the strict definition adopted here, which explains why the complete-bridge rate in this study is lower than rates reported when partial septa are included [14,18,19].

Table 2. Dominance and complete bony partitioning.

Finding	n (crania)	% of crania	Laterality
Right dominance	80	72.7	—
Left dominance	20	18.2	—
Symmetrical	10	9.1	—
Complete bony bridge	9	8.2	Right 6, Left 2, Bilateral 1
Complete bridge (sides)	10 sides	4.5% of sides	Right 7, Left 3

Table 2 legend: Dominance by estimated area. Complete bridge defined as a continuous osseous partition creating two separate openings.

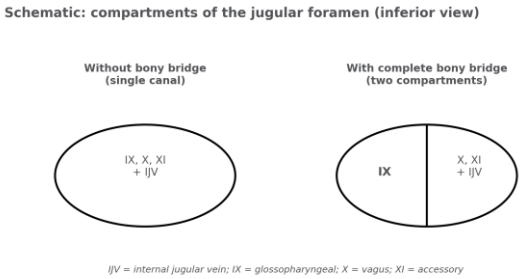


Figure 3. Schematic compartmentalisation of the jugular foramen.

Figure 3 legend: Schematic, not to scale, inferior view. Left: single canal transmitting cranial nerves IX–XI and the internal jugular vein (IJV). Right: complete bony bridge separates an anteromedial compartment (IX) from a posterolateral compartment (X, XI, IJV). The schematic clarifies the anatomical consequence of the 8.2% complete-bridge rate reported here.

3.5 SHAPE AND QUALITATIVE OBSERVATIONS

Most foramina were oval with the long axis oriented mediolaterally, consistent with ML > AP in every subgroup. A minority were more rounded or irregular, often where a prominent jugular fossa dome or an exostosis distorted the rim. The jugular fossa dome, indicating a high jugular bulb, was more frequently prominent on the right, paralleling right

dominance. No foramen showed a separate, independent canal for the glossopharyngeal nerve distinct from the main foramen, apart from those with a complete bridge.

4. DISCUSSION

4.1 ASYMMETRY AS THE RULE, NOT THE EXCEPTION

The central finding of this study is that asymmetry is the norm. A right-dominant foramen in nearly three-quarters of crania, with mean diameters significantly larger on the right in both axes, reproduces the pattern reported in Indian, Sri Lankan, Brazilian, Turkish, and Nigerian series, even though absolute values differ [20,21,23,27,28]. The embryological explanation is now well established: the dural venous sinuses develop asymmetrically, the superior sagittal sinus typically drains preferentially to the right transverse sinus, and the jugular foramen remodels around the resulting venous flow [8,9]. The bony canal is therefore best understood as a cast of its venous content, with neural elements occupying a relatively smaller and more constant volume. This perspective helps explain why the ML diameter, which most directly reflects the transverse extent of the jugular bulb, shows the largest inter-side difference and the clearest sex-related size effect.

For clinical practice, the implication is that the "normal" jugular foramen has no single normal size. Radiologists comparing a patient's foramina on computed tomography (CT) or magnetic resonance imaging (MRI) should expect asymmetry and should not mistake a small, non-dominant foramen for hypoplasia or a large, dominant foramen for a tumour-expanded foramen without additional signs such as cortical erosion, demineralisation, or an enhancing soft-tissue mass [11,29]. CT is superior for demonstrating bony septa, domes, and canal calibre; MRI is superior for soft-tissue characterisation, for the jugular bulb, and for distinguishing paraganglioma, schwannoma, and meningioma [29,30]. Both modalities benefit from the interpreter knowing the expected range of variation documented here.

4.2 CROSS-POPULATION COMPARISON

Table 3 places the present values alongside representative series. The pattern of right > left is universal, but absolute ML diameters range from roughly 14 mm to 19 mm across populations, reflecting differences in measurement landmarks, in whether the exocranial or endocranial aperture was measured, and in genuine population variation in cranial base size [23,27]. The present AP values (8.12 mm right, 7.34 mm left) sit at the lower end of the published range, where some authors report AP diameters of 12–13 mm because they include the jugular fossa or measure to a different anterior landmark. Such methodological heterogeneity is the principal limitation of cross-study synthesis and argues for the standardised definitions proposed in recent systematic reviews [12,27]. When definitions are harmonised, the inter-population differences narrow, and the present sample aligns closely with West African and South Indian data.

Table 3. Cross-population comparison of jugular foramen diameters.

Population / Study	n	Right ML (mm)	Left ML (mm)	Right AP (mm)	Left AP (mm)
Present study	110	15.42	14.11	8.12	7.34
South India	100	15.82	15.86	9.21	8.65
Central India	50	18.20	16.90	12.86	10.57
Sri Lanka	—	16.02	15.46	6.84	8.28
Nigeria (Idris et al.)	—	18.73	17.33	13.20	11.72

Table 3 legend: Values as reported by original authors; measurement landmarks differ between studies, so comparisons are indicative rather than exact. Dash indicates not stated in the summary consulted. See References [20,21,23,27,28].

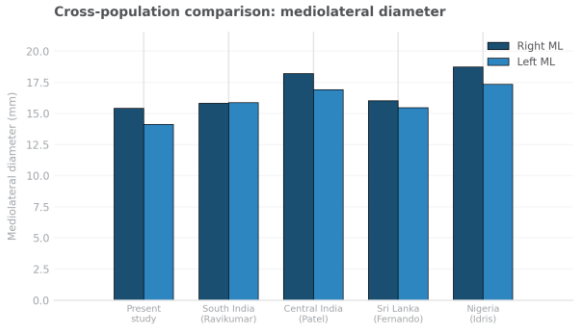


Figure 4. Cross-population comparison of mediolateral diameter.

Figure 4 legend: Mean mediolateral diameter by side across selected series (see Table 3). Right dominance is universal, but absolute size varies with population and measurement method.

4.3 BONY BRIDGES: PREVALENCE AND MEANING

The complete bony bridge rate of 8.2% of crania (4.5% of sides) in this study matches closely the 8.5% of sides reported in a classic anatomic and histologic study of 100 skulls, in which 47% of bridges were incomplete and 53% were complete, with complete bridges further subdivided by articulation type [14]. Other series that count any septation, including partial spicules, report much higher rates, up to 42–70%, and some report complete bridges in 22% of foramina when a more inclusive definition is used [18,19]. The apparent discrepancy dissolves once definitions are made explicit: a thin spicule that indents the rim is not functionally equivalent to a complete partition that creates two separate canals. The strict definition used here was chosen precisely because it identifies the variant with the greatest surgical and entrapment significance.

Embryologically, the intrajugular process represents a remnant of the cartilaginous partition between the petrosal and occipital contributions to the foramen. Incomplete regression leaves a spicule; complete ossification leaves a bridge. The right-sided predominance of complete bridges in the present sample, also noted by others, may reflect the greater size and more complex remodelling of the right foramen, providing more opportunity for the intrajugular processes to meet and fuse [14,15]. Surgeons should anticipate a bridge when preoperative CT shows a linear bony density across the foramen. The bridge can serve as a landmark for the glossopharyngeal nerve, which lies anteromedially, but it also restricts mobilisation of the nerves and may need to be drilled to achieve adequate exposure of a tumour that straddles both compartments [12,13,16].

4.4 CLINICAL CORRELATES

Four clinical domains are directly informed by these morphometric findings, summarised in Table 4.

First, jugular foramen syndromes. Vernet syndrome is defined as unilateral palsy of IX, X, and XI at the foramen, presenting with dysphagia, loss of gag reflex and palatal sensation, hoarseness from vocal cord palsy, and weakness of the sternocleidomastoid and trapezius [6,7]. When the hypoglossal nerve (XII) is also involved via extension to the hypoglossal canal, the condition is termed Collet–Sicard syndrome, with added tongue deviation and atrophy [6,7]. A narrow, partitioned foramen lowers the threshold for such palsies after trauma, infection, or a small tumour, and a complete bridge may produce a partial Vernet picture if only one compartment is compressed. Clinicians should therefore consider compartmental anatomy when a patient presents with an isolated glossopharyngeal palsy or an isolated vagal palsy that does not fit a diffuse skull-base lesion.

Second, tumours. Paragangliomas (glomus jugulare tumours), schwannomas, and meningiomas are the principal tumours of the jugular foramen [12,13,30]. Paragangliomas typically expand the foramen, erode bone in a permeative pattern, and present with pulsatile tinnitus, hearing loss, and lower cranial nerve palsies. Schwannomas tend to remodel bone more smoothly. Meningiomas may show a dural tail and hyperostosis. In each case, the surgeon's corridor is constrained by the facial nerve anteriorly, the carotid artery, the sigmoid sinus, and the IJV. A dominant IJV on the tumour side complicates venous sacrifice, while a dominant IJV on the contralateral side is reassuring. Preoperative knowledge of dominance, derived from imaging that mirrors the bony dominance documented here, guides the choice between infratemporal fossa, transmastoid, retrosigmoid, and combined approaches and the decision to preserve or reconstruct the IJV [12,13].

Third, venous and otological surgery. A high jugular bulb, indicated by a prominent dome, lies close to the middle ear and may be injured during mastoidectomy or stapedectomy, causing brisk venous bleeding [25,29]. A dehiscent jugular bulb can present with pulsatile tinnitus. The association between a large right foramen, a prominent dome, and a high bulb means that right-sided otological procedures carry a statistically higher risk of encountering a high bulb, a point that should be emphasised in surgical training.

Fourth, radiology and differential diagnosis. Enlargement of the jugular foramen is not specific to tumour; it is also seen with a dominant venous system, a large jugular bulb, and high-flow vascular malformations. Conversely, a small foramen may be a normal variant. The ranges reported here, together with the dominance proportions, provide a practical reference for deciding when asymmetry exceeds the expected range and warrants further investigation. In resource-limited settings where MRI is less accessible, careful CT assessment of foraminal size, symmetry, and septation remains a powerful triage tool [29].

Table 4. Clinical correlates of jugular foramen morphometry.

Clinical domain	Anatomical correlate	Practical implication
Vernet / Collet–Sicard syndromes	Narrow or partitioned foramen	Lower threshold for entrapment; partial palsies possible
Paraganglioma / schwannoma surgery	Dominance, size, bridge	Plan corridor; preserve dominant IJV; drill bridge if needed
Otological surgery	High bulb / dome, right dominance	Anticipate high bulb on right; avoid bulb injury
Radiology	Expected asymmetry 70% right	Do not mistake normal asymmetry for tumour or hypoplasia

Table 4 legend: Summary of the principal clinical implications discussed in Section 4.4. IJV = internal jugular vein.

4.5 LIMITATIONS AND FUTURE DIRECTIONS

Several limitations should be acknowledged. Dry-skull measurements describe bone, not the soft-tissue contents; the relationship between bony diameter and venous or neural calibre is inferential, albeit supported by imaging studies [11,29]. The ellipse formula approximates area and will underestimate the area of irregular foramina. Sex was assigned from collection records and cranial criteria rather than known identity, and age at death was not available, so age-related remodelling could not be assessed. The sample, while larger than many single-centre series, draws on teaching collections that may not represent the full genetic and environmental diversity of West Africa, let alone the broader populations implied by the multi-institutional authorship. Future work should pair dry-skull morphometry with CT morphometry in living patients, include three-dimensional volumetric analysis of the jugular canal, and correlate bony dominance with Doppler or magnetic resonance venography dominance in the same individuals. Such paired studies would directly test the hypothesis that bony dominance predicts venous dominance and would refine surgical decision thresholds. Classification of septation should also be harmonised internationally, distinguishing partial spicules, incomplete bridges, and complete bridges with explicit criteria and photographic documentation.

5. CONCLUSION

In 110 dry adult human crania, the jugular foramen was significantly larger on the right than on the left in both anteroposterior and mediolateral diameters, with right dominance in 72.7% of specimens and a complete bony bridge in 8.2%, predominantly on the right. These findings confirm that asymmetry and compartmentalisation are defining features of the posterior cranial base, not rare variants. For neurosurgeons, otologists, radiologists, and neurologists, the reference values and dominance proportions reported here provide a practical anatomical baseline for interpreting imaging, planning lateral skull-base dissections, anticipating lower cranial nerve vulnerability, and counselling patients about the risks of jugular foramen surgery. Population-specific morphometry, collected with transparent definitions, remains essential for safe, individualised skull-base care.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICAL APPROVAL

The study used anonymised dry osteological specimens held in established teaching collections. No living participants were

involved and no identifiable personal data were used. Approval was obtained from the institutional anatomy research committees in accordance with local regulations for osteological research.

AUTHOR CONTRIBUTIONS

A. A. Adebayo: conceptualisation, data collection, writing — original draft. M. T. Al-Sayed: methodology, statistical analysis, writing — review and editing. J. P. Chevalier: supervision, clinical interpretation, writing — review and editing. All authors approved the final manuscript.

DATA AVAILABILITY

The anonymised measurement dataset supporting this article is available from the corresponding author upon reasonable request.

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