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Role of ethnicity in the determination of the transverse sigmoid sinus Junction (TSSJ): A prospective hospital-based radiological study in adult Sabah, East Malaysia

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ROLE OF ETHNICITY IN THE DETERMINATION OF THE TRANSVERSE SIGMOID SINUS JUNCTION (TSSJ): A PROSPECTIVE HOSPITAL-BASED RADIOLOGICAL STUDY IN ADULT SABAH, EAST MALAYSIA.

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ABSTRACT

BACKGROUND AND PURPOSE: The Transverse Sigmoid Sinus Junction (TSSJ) is a critical anatomical landmark in neurosurgery, particularly in cerebello-pontine angle (CPA) procedures. Despite its significance, there is limited research on the anatomical variations of the TSSJ, particularly regarding ethnic differences. This prospective radiological study aims to investigate the potential influence of ethnicity on the anatomical differences of the TSSJ in the adult participants from Sabah.

MATERIALS AND METHODS: This prospective hospital-based cross-sectional radiological study included 180 adult patients who underwent high-resolution CT imaging, comprising various races. Participants were categorized based on ethnicity, and detailed radiological data were collected to analyze the variations in the TSSJ across different ethnic groups. Participants recruited were between the ages of 22 and 80 and were divided into 3 major ethnic groups. The anatomical landmarks used in this study include the asterion, internal auditory canal, cranial index, and ‘key point’.

RESULTS: Preliminary findings revealed notable variations in the TSSJ among ethnic subgroups within the Sabah participants. Measurements of key anatomical points demonstrated differences that may have implications for safe burr hole placement in CPA surgery. It was observed that the left asterion to key point was higher compared to the right, with males having significantly higher asterion to key point, key point to IAC, vertical distance of key point to IAC, and cranial index ($p<0.001$), respectively. In terms of race, asterion to key point ($p=0.020$), key point to IAC ($p=0.039$), and cranial index ($p< 0.001$) were observed to be significant. Post hoc analysis revealed that Chinese had significantly higher asterion to key points than ‘others’ ($p<0.001$), and the cranial index for ‘others’ was considerably lower than Malay, Chinese, and Kadazan ($p<0.001$).

CONCLUSION: There is valid evidence to support ethnic-specific external landmarks in surgical practice, which is important for locally practicing neurosurgeons.

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ABBREVIATIONS: CPA=Cerebello-pontine angle; CT=Computer Tomography; FHP=Frankfurt Horizontal Plane; IAC=Internal Auditory Canal; IGS=Image Guided System; MITK= Medical Interaction Tool Kit; MRI=Magnetic Resonance Imaging; PACS=Picture Archiving and Communication System; PCA= Principal Coordinate Analysis; SD= Standard Deviation; SS= Sigmoid Sinus; TS= Transverse Sinus; TSSJ=Transverse Sigmoid Sinus Junction.

KEYWORDS: Transverse sigmoid sinus, key point, ethnicity, cerebello-pontine angle, radiology, navigation.

INTRODUCTION

Craniometric landmarks and neuro-navigation are essential components of modern neurosurgery, particularly in procedures involving the skull base. These landmarks, surface projections of underlying neural and vascular structures, serve as critical reference points for determining safe and accurate cranial access. However, the anatomical configuration of these craniometric points is not uniform across populations; instead, it varies among racial and ethnic groups, potentially influencing surgical approaches and outcomes (1) .

In a multicultural setting such as Malaysia, and especially in the highly diverse state of Sabah, understanding ethnic-specific cranial anatomy is crucial for neurosurgeons. Variations in skull shape and structure across ethnic groups (2) may alter the relative position of key neurovascular landmarks, thereby affecting surgical precision and patient safety. Evidence from a Thai population illustrates this point: the

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intersection of the squamosal suture and supramastoid crest was identified as a more reliable landmark for locating the transverse–sigmoid sinus junction (TSSJ) than the squamosal–parietomastoid intersection(1,3).

Additional studies reinforce the significance of cranial anatomical variability. Asymmetry of the transverse sinuses has been reported, including aplasia and hypoplasia of the transverse sinuses (4). The volume of the lateral sinuses has been shown to correlate closely with occipital bone markings(5), and ethnic differences in cranial size and shape are also well documented (6). Notably, racial differences appear to exert a greater influence on cranial morphology than sex-based differences(7). For example, Western populations exhibit a larger petrous angle compared with Chinese individuals, necessitating relatively larger craniotomies for adequate surgical exposure(8).

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Malaysia’s population comprises Malays (70.1%), Chinese (22.6%), and Indians (6.6%)(9), while Sabah, in East Malaysia, is predominantly home to indigenous groups. Sabah has over 50 ethnic communities(10), including Kadazan-Dusun, Bajau, Murut, Rungus, and many others. Genetic studies show that these indigenous groups form a distinct ancestry cluster similar to Austronesian populations in Taiwan and the Philippines. The Kadazan-Dusun group alone comprises about 30% of Sabah’s population. A genetic study confirmed a unique "North Borneo" ancestry, which could influence cranial morphology(11).

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Given these distinct genetic and cultural profiles, the current study aims to determine whether ethnic differences influence the anatomical location of the TSSJ in the adult Sabah's study cohort. Specifically, it seeks to identify whether ethnicity affects the location of the "key point" used in burr hole placement during cerebellopontine angle (CPA) surgery. The “key point” here is defined as per Teranashi et al (12) which is the intersection between the medial edge of the sinus and the bisector angle of two lines, which is a transverse line (A transverse line drawn as tangent, rostral to the transverse sinus) and a sigmoid line (A line drawn tangent, lateral to the curve of the sigmoid sinus(Figure 5A). It differs from surface landmarks as it is obtained via two drawn imaginary lines and can not be felt.

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Although neuro-navigation has become widely integrated into contemporary neurosurgical practice, reliance on anatomical surface and radiological landmarks remains clinically relevant in specific contexts(13)(14). Navigation systems may be unavailable in resource-limited settings like in our centre, impractical during emergency procedures, or subject to inaccuracies related to registration error and intraoperative brain shift(15). Consequently, a sound understanding of surface anatomy continues to play an essential role in surgical planning and intraoperative orientation(16).Traditional landmarks for localizing the transverse–sigmoid sinus junction (TSSJ), such as the asterion, have been shown to exhibit significant anatomical variability and limited reliability, with several studies reporting a substantial risk of sinus

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violation when used as a sole reference point(13). These limitations have prompted continued efforts to refine alternative landmarks that demonstrate more consistent correlation with underlying venous sinus anatomy(17). In this context, the proposed “key point” is not intended to replace neuro-navigation, but rather to function as a complementary anatomical reference with potential utility in pre-navigation planning, radiological assessment, anthropological studies, and surgical settings where advanced navigation systems are unavailable (17). By situating this landmark within a clearly defined clinical and anatomical niche, its relevance is preserved despite ongoing advances in image-guided neurosurgery. Navigation based exclusively on preoperative imaging becomes increasingly inaccurate over the course of surgery, necessitating updated imaging, either continuous or iterative, to ensure maximal accuracy during brain tumor procedures. Thus, surface craniometrics as well as integrated multimodality radiological techniques are still relevant and important, which can improve the safety and efficacy of the surgery(18).

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MATERIAL AND METHODS

This cross-sectional radiological study was conducted between September 9, 2022, and September 9, 2023, at Queen Elizabeth Hospitals I and II, Kota Kinabalu, Sabah. Eligible computed tomography (CT) scans consisted of high-resolution adult studies (≥18 years) suitable for three-dimensional reconstruction. The study was purely radiological and did not involve dry skulls or cadaveric specimens.

No direct patient participation occurred. Only imaging datasets and accompanying information from imaging request forms were reviewed. Ethnicity data were obtained from these request forms and were based on information recorded in the patient's national identification card (IC), which is routinely verified (scanned) during hospital admission and is therefore considered reliable. Inclusion criteria comprised adult patients (>18 years) with high-resolution CT images suitable for three-dimensional reconstruction. The CT imaging used here was a Class 2 Laser Hitachi with a wavelength of 600-700nm, and it may perform 64 slices per scan. To highlight the venous structures, the scan performed used a helical technique with intravenous contrast given, and the scan was delayed to 45 minutes. Exclusion criteria included pathological conditions affecting the venous sinuses, cranial bone deformities, or any abnormalities involving the regions of interest. Image suitability was

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verified through the hospital's Picture Archiving and Communications System (PACS).

Sample size was calculated a priori using G*Power version 3.1.9.7 **(Figure 1).** In the absence of region-specific data on inter-ethnic cranial variation, an effect size of 0.25 (small to medium) was assumed, producing a required minimum sample size of 180 subjects. The study cohort included multiple ethnic groups: Kadazan, Bajau, Malay, Chinese, Indian, Dusun, Brunei, Murut, Kedayan, and Sungai. For statistical analysis, the three most represented groups (Kadazan, Malay, and Chinese) were analysed individually, while the remaining groups were combined into an "Others" category. Participants ranged in age from 22 to 80 years.

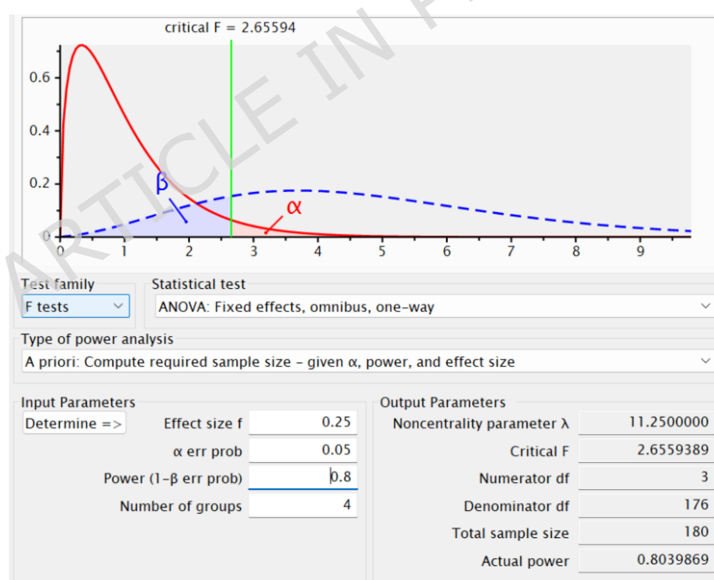

Figure 1: Calculation of Sample Size using G Power Software, which indicated at least a 180 sample size based on an effect size of 0.25

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A cross-sectional radiological design was adopted to provide a snapshot of anatomical variation within the study cohort at a single time point. This design is appropriate for describing the prevalence and distribution of anatomical characteristics, including the transverse–sigmoid sinus junction (TSSJ), within a defined cohort. It also enabled simultaneous evaluation of multiple variables, including ethnicity, sex, cranial morphometry, and clinical indications for CT imaging.

Image processing and analysis were performed using the hospital PACS. Three-dimensional reconstructions were generated using Medical Imaging Interaction Toolkit (MITK) version 2022.04, with venous sinus overlays incorporated into the reconstructions. Morphometric measurements were subsequently performed using 3-Matic version 9.0. This workflow enabled volume-rendered modelling and superimposition of the venous sinus system onto three-dimensional skull reconstructions **(Figure 2).** Skull reconstruction resolution was reduced to 50% to enhance rendering efficiency, while venous sinus structures were enhanced to 100% to optimise anatomical delineation.

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Before measurement, each reconstructed skull with segmented venous structures was positioned in the “primary position.” Subsequent craniometric measurements were conducted using 3-Matic software (version 9.0.0.231) **(Figure 3).** Each skull was assessed bilaterally to identify the surgically relevant “key point” at the junction of the transverse and sigmoid sinuses **(Figure 4).** This “primary position” orientation involved rotating the skull such that the transverse and

sigmoid sinuses were perpendicular to the observer's line of sight **(Figure 4 and Figure 5a).**

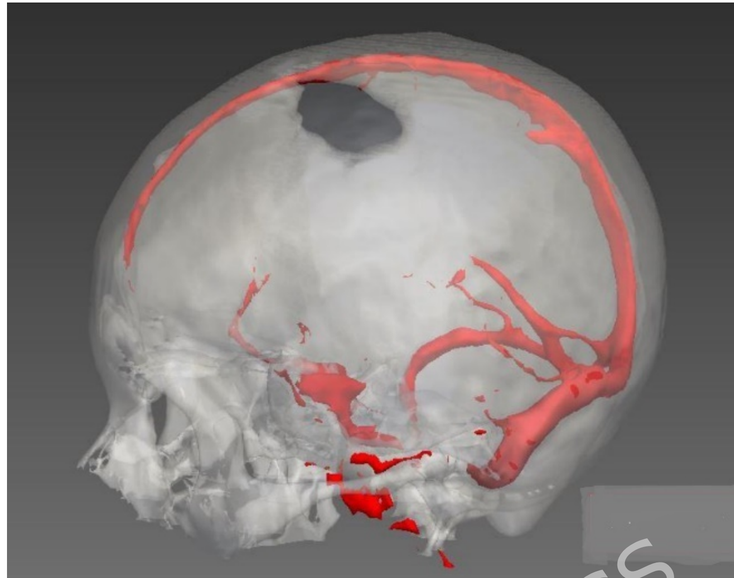

Figure 2: 3D Reconstruction of PACS Image using MITK Software with the bone and the venous sinus system superimposed for measurements

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Identification of the key point followed the method described by Teranishi et al.(12). Tangential lines were drawn along the superior margin of the transverse sinus (Line A) and the lateral margin of the sigmoid sinus (Line B). The intersection of these tangential lines generated a bisector (Line C), which extended medially to intersect the boundary of the venous sinus, thereby defining the anatomical "key point." The subsequent figure illustrates the stepwise identification and translation of the key point using the aforementioned software.

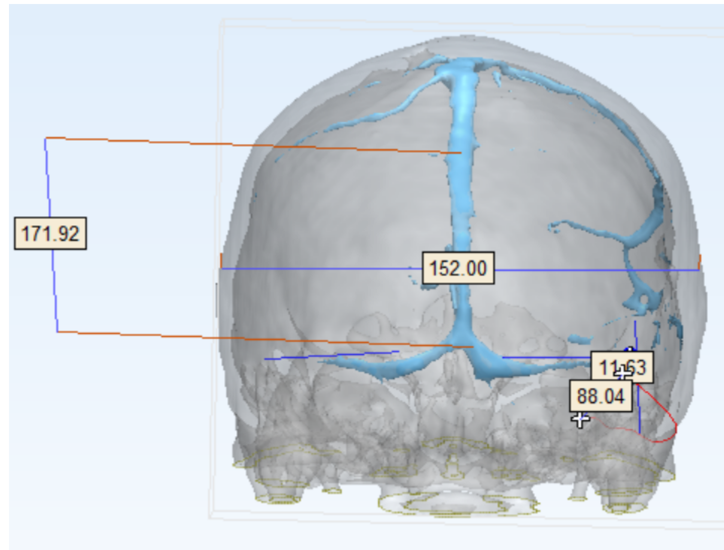

Figure 3: Figure depicting venous and bony anatomy craniometric measurements using 3 Matic Software from the designated anatomical points described.

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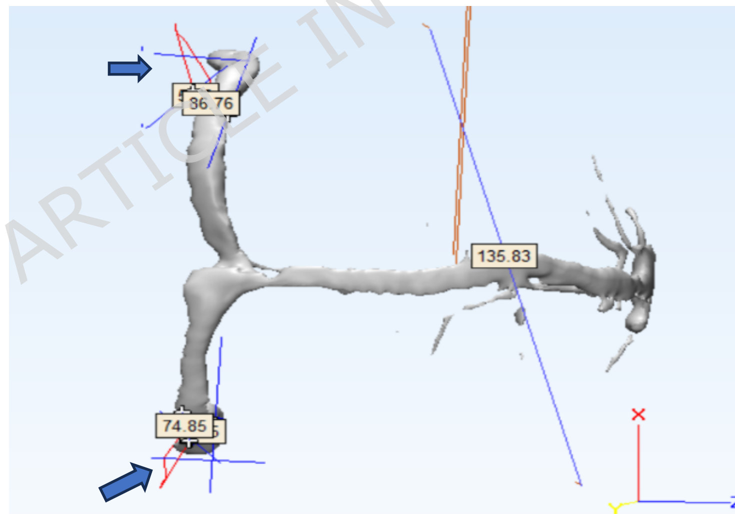
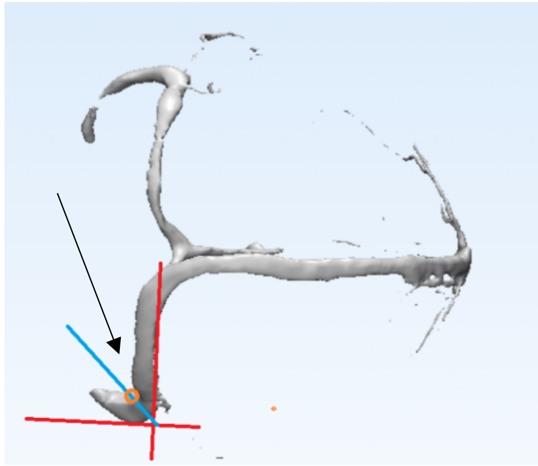


Figure 4: Localizing the transverse sigmoid sinus junction (TSSJ) and the "key point". The key point is shown with arrows.



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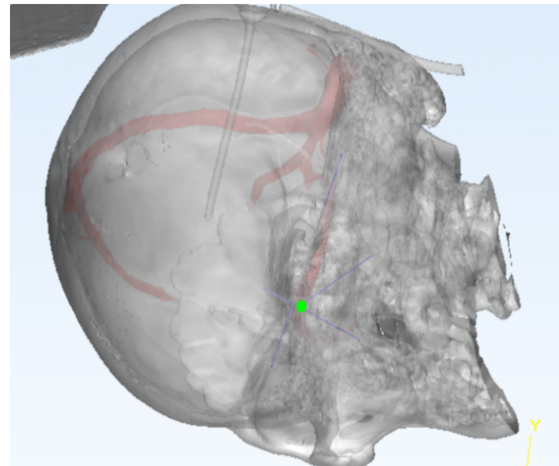

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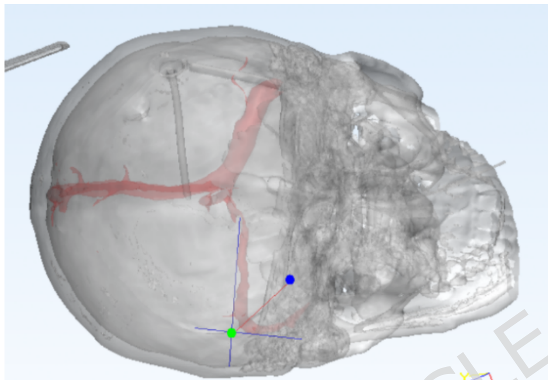

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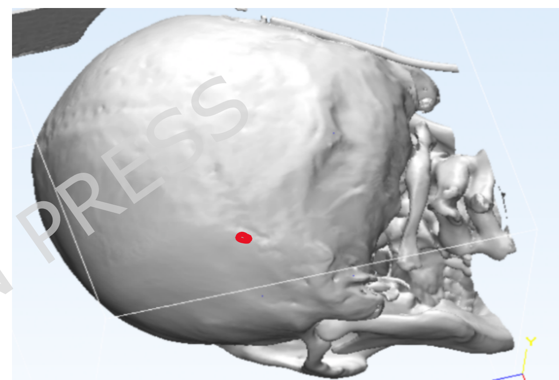

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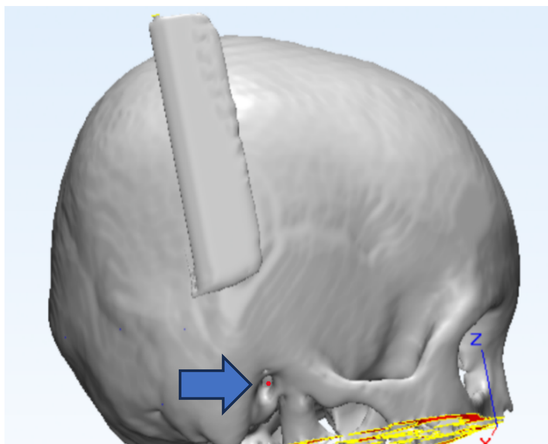

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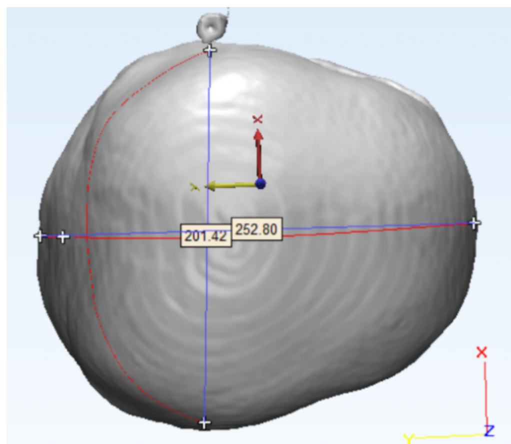

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Figure 5a, b, c, d, e: Figure 5a, locating the "key point" which is highlighted with a yellow circle (arrow pointing) using the method described, ensuring both the transverse and sigmoid sinuses are perpendicular to the line of sight before drawing the lines. Figure 5b, the transparency/opacity of the image is adjusted to visualize both the segmented vessels and the skull. Figure 5c, the 3D image view is adjusted until the "key point is well visualised as in Figure 5a, maintaining the perpendicular line of sight. Figure 5d, the skull transparency is made opaque to facilitate identification of surface landmarks (asterion, red dot) for measurement to the said "key point', and transparency adjusted again so both points are visualized simultaneously for the measurements. Figure 5e, the central part of the Internal auditory canal (marked by the blue arrow). Figure 5f depicts the cranial index measurement by measuring the maximum anterior-posterior and transverse diameter of the skull.

Measurement Landmarks and Indices

Craniometric analyses were performed using standardized anatomical landmarks and indices. The following reference points were identified:

1. **Asterion** – Defined as the convergence of the lambdoid, parieto-mastoid, and occipitomastoid sutures (19). In the 3D reconstructed images, this confluence of sutures was identified **(Figure 5d**).
2. **Internal Auditory Canal (IAC)** – A narrow, oval-shaped canal located within the petrous portion of the temporal bone (20). **Figure 5e** shows the point on the 3D model, which is the center of the canal, which is used for measurement.
3. **Cranial Index** – Derived by dividing the maximum anteroposterior diameter of the skull by the maximum transverse (biparietal) diameter and multiplying the result by 100 (21). This measurement

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is performed while the 3D image is perpendicular to the line of sight to the skull cranium. **(Figure 5f).**

The primary anatomical parameters assessed included:

- Distance from the asterion to the key point
- Distance from the key point to the IAC
- Vertical distance between the key point and the IAC

The length measurements were taken according to the contour of the skull to provide accurate measurements and representation. The convergent point of the parietomastoid, occipitomastoid, and lamboid sutures was the point for asterion, whereas for the IAC, the point taken was the center of the IAC. Both points were measured with respect to the key point, which was previously described. All measurements were obtained bilaterally. Skull orientation was standardized using the Frankfurt Horizontal Plane (FHP). To reduce inter-observer variability, examiners underwent calibration procedures, and all measurements were independently verified.

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RESULTS

Statistical analysis was performed using IBM SPSS Statistics version 26.0. Normality of continuous variables was assessed through

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visual inspection of histograms, and these variables were summarized as mean ± standard deviation (SD). Categorical variables were presented as frequencies and percentages. Depending on the distributional characteristics, either parametric or non-parametric tests were applied.

Gender-based differences in anatomical measurements were examined using independent samples t-tests and Mann–Whitney U tests. The independent t-test was used when assumptions of normality and homogeneity of variances were met, while the Mann–Whitney U test served as the non-parametric alternative for ordinal or non-normally distributed data. These tests were applied to the asterion–to–key point distance, key point–to–internal auditory canal (IAC) distance, vertical key point–to–IAC distance, and cranial indices. Although the t-test was prioritized for its statistical power when assumptions were satisfied, the Mann–Whitney U test was used when these assumptions were violated.

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Ethnic group comparisons were conducted using one-way ANOVA or the Kruskal–Wallis test, depending on adherence to normality and variance homogeneity assumptions. When overall group differences were significant, post hoc pairwise analyses were performed using the Mann–Whitney U test with adjusted p-values to identify specific between-group differences.

Paired samples t-tests and Wilcoxon signed-rank tests were used to evaluate right–left hemispheric differences, with the choice of test

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determined by the distribution of paired data. All statistical tests were two-sided, and statistical significance was defined as $p < 0.05$.

A total of 180 subjects were included in the analysis (Table 1), comprising 59 Kadazan (32.8%), 30 Malay (16.7%), 24 Chinese (13.3%), and 67 individuals from other ethnic groups (37.2%). Males represented 56.7% of the study population.

Table 1: Demographic characteristics of the participants (n= 180)

Characteristics		**Output**
Age in years, mean ± SD		45.38 ± 11.97
Gender, n (%)	Female	78 (43.3)
	Male	102 (56.7)
Race, n (%)	Malay	30 (16.7)
	Chinese	24 (13.3)
	Kadazan	59 (32.8)
	Others	67 (37.2)

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The asterion–to–key point distance on the left side ranged from 0.432 cm to 1.692 cm, whereas the right side ranged from 0.209 cm to 1.365 cm. A Wilcoxon signed-rank test revealed a statistically significant difference between left and right measurements ($Z = –3.833$, $p < 0.001$), with greater distances observed on the left side. In contrast, no significant right–left differences were identified for the key point–to–IAC

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distance (p = 0.372) or the vertical key point–to–IAC distance (p = 0.947) **(Table 2).**

Table 2: Differences in outcomes between left and right hemispheres

	Left	Right	P value
Asterion to key point, median (IQR)	0.76 (0.67, 0.85)	0.74 (0.65, 0.83)	<0.001[a]
Key point to IAC, median (IQR)	7.37 (6.68, 7.95)	7.15 (6.67, 7.88)	0.372[a]
Vertical distance from IAC to the key point, mean ± SD	22.10 ± 2.49	22.11 ± 2.45	0.947[b]

[a] Wilcoxon signed rank test; [b] Paired sample t-test

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Gender-Based Differences

Statistically significant differences were noted between males and females in all anatomical parameters assessed **(Table 3)**. Males had higher median values in:

(i) Asterion to key point [median (IQR): 0.79 (0.73, 0.84) vs 0.69 (0.63, 0.79); $p < 0.001$]

(ii) Key point to IAC [7.61 (7.07, 8.09) vs 6.77 (6.37, 7.42); $p < 0.001$]

(iii) Vertical IAC to key point [mean ± SD: 23.70 ± 1.34 vs 20.01 ± 1.08; $p < 0.001$]

(iv) Cranial index [80.74 ± 5.97 vs 77.28 ± 6.24; $p < 0.001$]

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Table 3: Differences in outcomes between genders

	Female	Male	P value
Asterion to key point, median (IQR)	0.69 (0.63, 0.79)	0.79 (0.73, 0.84)	<0.001[a]
Key point to IAC, median (IQR)	6.77 (6.37, 7.42)	7.61 (7.07, 8.09)	<0.001[a]
Vertical distance from IAC to key point, mean ± SD	20.01 ± 1.08	23.70 ± 1.34	<0.001[b]
Cranial index, mean ± SD	77.28 ± 6.24	80.74 ± 5.97	<0.001[b]

[a] Mann Whitney U test; [b] Independent sample t-test

These findings suggest a consistent pattern of larger cranial measurements in males compared to females.

Ethnic Group Comparisons

Analysis across ethnic groups revealed significant differences in **(Table 4**):

(i) Asterion to key point (*p* = 0.020)

(ii) Key point to IAC (*p* = 0.039)

(iii) Cranial index (*p* < 0.001)

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Table 4: Differences in outcomes between races

	Malay	Chinese	Kadazan	Others	P value
Asterion to key point, median (IQR)	0.79 (0.71, 0.85)	0.79 (0.71, 0.87)	0.77 (0.69, 0.83)	0.72 (0.63, 0.79)	0.020[a]
Key point to IAC, median (IQR)	7.54 (7.21, 7.87)	7.23 (6.92, 7.96)	7.39 (6.71, 8.05)	6.99 (6.36, 7.72)	0.039[a]
Vertical distance from IAC to key point, mean ± SD	22.88 ± 2.33	21.70 ± 1.83	22.01 ± 2.08	21.99 ± 2.35	0.184[b]

Cranial index, median (IQR)	84.55 (81.63, 86.23)	80.50 (78.50, 83.10)	80.20 (75.50, 85.40)	73.90 (71.60, 78.20)	<0.001[a]

[a] Kruskal Wallis test; [b] One Way ANOVA

No statistically significant difference was observed in the vertical distance from IAC to the key point across ethnicities.

Table 5: Post hoc pairwise comparison following the significance in Table 4

Group 1	Group 2	Outcome, p-value		
		Asterion to key point	**Key point to IAC**	**Cranial index**
Malay	Chinese	0.789	0.321	0.003
	Kadazan	0.564	0.450	0.010
	Others	0.033	0.010	**<0.001**
Chinese	Kadazan	0.296	0.825	0.794
	Others	**0.007**	0.063	**<0.001**
Kadazan	Others	0.039	0.058	**<0.001**

Statistical significance was denoted by p< 0.008 (0.05/6 pairs of comparison) after p-value correction to prevent Type I error inflation.

Post hoc pairwise comparison **(Table 5)** demonstrated that:

(i) Chinese participants had significantly higher asterion-to-key point distances than the 'Others' group (*p* < 0.001)

(ii) Despite overall significance in the key point to IAC distance across races, no individual ethnic pair showed significance after p-value correction

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(iii) For cranial index, participants in the 'Others' category had significantly lower values than Malays (*p* < 0.001), Chinese (*p* < 0.001), and Kadazans (*p* < 0.001)

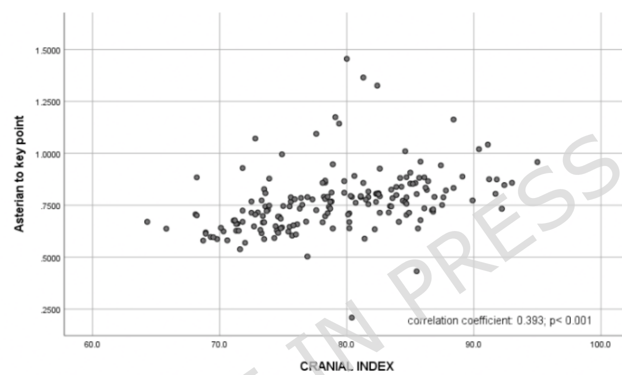

Figure 6a: Correlation between cranial index and asterion to key point. Significant, positive and weak correlation was observed between cranial index with Asterion to key point (coefficient: 0.393; p< 0.001)

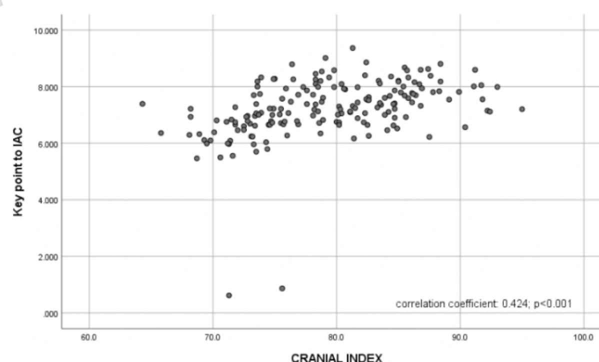

Figure 6b: Correlation between cranial index and key point to IAC. Significant, positive and moderate correlation was observed between cranial index with key point to IAC (coefficient: 0.424; p< 0.001

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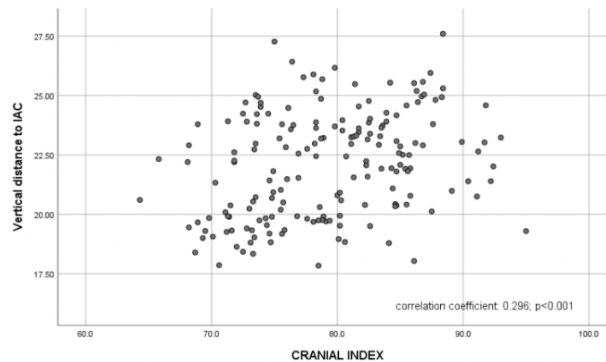

Figure 6: Correlation between cranial index and vertical distance to IAC. Significant, positive and weak correlation was observed between cranial index and vertical distance to IAC (coefficient: 0.296; $p < 0.001$).

In a cohort of 180 adults, hemispheric asymmetry of the transverse–sigmoid sinus junction was statistically detectable but anatomically minimal, with a left–right asterion–key point difference of only 0.2 mm. In contrast, sex-based morphometric variation was both statistically robust and clinically meaningful. Males demonstrated an 8.4 mm greater key point–to–internal auditory canal distance and a 3.69 mm greater vertical separation, with the latter showing a very large standardized effect (d = 2.987; 95% CI 3.34–4.04 mm). Given that posterior fossa drilling margins frequently operate within millimetric limits adjacent to the sigmoid sinus, a 3–4 mm positional shift may materially alter operative exposure and sinus injury risk. Ethnic differences in linear measurements were comparatively modest (≤5.5 mm; $\varepsilon^2 < 0.06$), whereas cranial index differences were substantial ($\varepsilon^2 = 0.280$), suggesting that global cranial morphology rather than categorical ethnicity may more strongly influence venous sinus positioning.

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DISCUSSION

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The diversity of human cranial morphology across global populations is well documented (22). In an extensive analysis of 148 ethnic groups, Matsumura and colleagues demonstrated substantial regional variation in neurocranial length–breadth proportions. Their findings revealed clear morphological contrasts, including the predominance of elongated cranial forms among African populations and more globular cranial configurations in Northeast Asian groups. Further underscoring the influence of ancestry on anatomical features, Jeong et al identified differences in naso-septal flap length and skull base dimensions amongst East Asian, Caucasian, and Middle Eastern populations (23). Similarly, a local study by Chan et al revealed inter-

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ethnic variations in medial orbital wall anatomy across Chinese, Malay, and Indian populations (24). Collectively, these studies reinforce the critical importance of considering both ethnic background and sex-related variations when assessing and interpreting skull morphology and measurements.

Researchers have reported the inconsistencies of external surface landmarks to date (25). These inconsistencies (26) have proven it difficult to localize the TSSJ precisely (27). Thus, there is a continuous need to perform morphometric and cadaver studies to learn more about these differences (28). Jurgaitis et al conducted a cadaveric study on anatomical landmarks for the TSSJ, underscoring the necessity of a thorough understanding of topographical anatomy to prevent iatrogenic damage during surgery, using the top of the mastoid notch as an external landmark (28). Historically, many other anatomical structures have been used to locate the junction between transverse and sigmoid sinuses, including the asterion, inion, superior nuchal line, and supra-meatal triangle (29). Despite numerous landmarks that are available, (30) some anatomical landmarks can be difficult to ascertain intraoperatively.

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In cerebellopontine angle lesions, the retrosigmoid craniotomy and trans-labyrinthine approach is the method of choice to access this region. However, approaching this area can lead to minor and even major complications if advanced neuro-navigation is not available (31). To add to

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this complexity, the existence of racial variation in these landmarks (32), may pose a challenge to the neurosurgeon if they are not taken into consideration during the operative procedure. In Malaysia, and possibly other parts of the world, the neurosurgeon is confronted with patients of various racial backgrounds (32).

This study included 180 participants—43% female and 57% male. The racial composition was 32.8% Kadazan, 16.7% Malay, and 13.3% Chinese. Participant ages ranged from 22 to 80 years, with a mean age of 45 years. By the end of 2023, Sabah's total population reached 3.6 million, consisting of approximately 52% males and 48% females (9).

In the collected data, comparisons were made with measurements from both the left and right hemispheres, as well as differences in outcomes between genders and races. Variables measured included the asterion-to-key point length, the IAC-to-key point length, the vertical distance from the IAC to the key point, and the cranial index.

Indeed, there are various methods described for the localization of the transverse sigmoid junction (33) in literature. Amongst these methods, Li, Ribas, Tubbs Teranishi and Day were found to be more accurate estimates of the TSSJ, as these methods rely exclusively on local bony anatomy of the surgical field, allowing easier translation of the results to the clinical setting (33). However, this study was not designed to compare these methods, but rather, to establish the significance of differences in TSSJ within the local study cohort.

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Outcome Differences Between Left and Right

(a) Asterion to key point

The anatomical position of the asterion and its implications in neurosurgical procedures have been the subject of recent investigation (13). While that study reported no statistically significant differences based on side, sex, or asterion type, the findings of the present study demonstrate contrasting results. Similarly, another study published in the same year by a different institution reported mixed outcomes regarding the clinical relevance of the asterion and its relationship with surrounding surface landmarks (39). Such variability underscores the complexity of using the asterion as a consistent surgical landmark.

A significant difference was observed between the left and right asterion–to–key point distances ($p < 0.001$). The “key point” refers to the location on the outer cranial surface that directly overlies the junction of the posterior fossa dura, transverse sinus (TS), and sigmoid sinus (SS) (33). The asterion is formed by the confluence of the lambdoid, occipito-mastoid, and parieto-mastoid sutures and serves as an important surgical landmark in postero-lateral skull base approaches (19). Two morphological variants of the asterion have been described: Type I, characterized by the presence of a small or woven bone, and Type II, defined by its absence (34).

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Given the frequent reliance on this landmark during neurosurgical procedures and its close relationship to the venous sinuses, the distance between the asterion and the key point was evaluated. In the present study, the median asterion–to–key point distance was 7.6 ± 9 mm on the left and 7.4 ± 9 mm on the right. In comparison, a previous study reported a mean distance of 5.7 mm (range: –2.8 to 14.8 mm) between the asterion and the transverse–sigmoid junction(12). Additionally, Wirakiat et al found that in 65% of specimens, the venous sinuses were directly related to the asterion, followed by the infra-tentorial dura (25%) and supra-tentorial dura (10%)(19). These findings underscore the importance of precise burr hole placement in this region to minimize the risk of venous sinus injury and subsequent intraoperative blood loss.

(b) *Key Point to IAC*

The internal acoustic canal (IAC) represents another critical anatomical landmark within the posterior temporal bone(35). In contrast to the asymmetry observed in the asterion–to–key point measurements, no significant difference was found between the left and right key point–to–IAC distances ($p = 0.372$). Surface skull measurements demonstrated a mean distance of 7.37 ± 0.6 cm on the left and 7.15 ± 0.6 cm on the right.

(c) Vertical distance from IAC to Key point.

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The distance assessed in this parameter was measured along the outer skull surface, consistent with the methodology used for the previous measurements. Similarly, no significant difference was observed between the two hemispheres (p = 0.947). This additional measurement was included because the IAC, in particular, is readily identifiable on radiological imaging and following 3D reconstruction, thereby providing a reliable reference point for comparative analysis.

The external ear has been explored as an alternative surface landmark for identifying the sigmoid sinus during surgery, owing to its proximity and consistent visibility compared with bony landmarks that often require palpation. For instance, the crux of the helix has been evaluated as a potential landmark for locating the anterior border of the sigmoid sinus (36). More recently, the posterior portion of the auricle has been proposed as a reference point for identifying the transverse–sigmoid sinus junction (37).

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Outcome Differences Between Genders

In this study, all measured parameters including the asterion–to–key point distance, key point–to–IAC distance, vertical–to–IAC length, and cranial index, demonstrated significant sex-related differences ($p < 0.001$). Across all variables, males exhibited higher values than females. This finding aligns with established cranial dimorphism, wherein male

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skulls are generally larger (38) and differ in overall shape (39). Similar patterns have been documented in primates and humans, with growth trajectories influenced by geographic variation, environmental pressures, and genetic factors.

Previous studies have consistently shown that male and female crania differ in both size and morphology, and these distinctions can aid in sex estimation (40). Typically, male skulls display a more inclined forehead with pronounced glabellar and supra-ciliary prominences, whereas female crania exhibit a more vertical forehead and a more defined frontal eminence. Mapping of cranial sexual dimorphism by Bove et al further identified regions most predictive of sex, reinforcing the concept that male skulls tend to be larger and morphologically distinct (39).

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The cephalic index (CI), or the cranial index, is defined as the ratio of maximum cranial breadth to length, categorizes skulls into dolicho-cephalic, meso-cephalic, and brachy-cephalic types, with hyper- and ultrabrachy-cephalic sub-types (41). In the present study, females demonstrated a CI of 77.28 ± 6.24, compared with 80.74 ± 5.97 in males. These values indicate that the study cohort predominantly falls within the mesocephalic to brachycephalic range. Al-Fauri et al observed that brachycephalic individuals tend to have a smaller outer diameter of the transverse–sigmoid sinus junction (TSSJ), suggesting an association

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between skull morphology and venous sinus dimensions (42). Such cranial shape variations, as reflected in CI, may have direct implications for neurosurgical planning, as brachycephalic patients may present with comparatively reduced TSSJ dimensions (42).

A statistically significant but weak positive correlation was observed between CI index and asterion to key point distance (coefficient: 0.424; $p < 0.001$), and between CI and vertical distance to key point (coefficient: 0.296; $p < 0.001$). However, there was a statistically significant but moderate correlation between CI and key point to IAC (coefficient: 0.424; $p < 0.001$). These results indicate that there is a limited linear variation between the parameters measured and the CI. This weak-to-moderate correlation reflects the multifactorial nature of cranial and venous sinus anatomy, where multiple developmental and biomechanical factors influence surface landmarks**.**

Outcome Differences Between Races

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Anatomical variation of the asterion across individuals and populations has been well documented and is thought to arise from a combination of genetic and environmental factors that influence cranial shape and development (40). Specific genes involved in cranial morphogenesis, such as *MSX2*, have been implicated in these variations, suggesting a genetic basis for differences in suture formation and cranial junctional anatomy (41). In addition to genetic influences, the type of bone formation at the asterion plays a significant role in determining its

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anatomical characteristics. Two types of asterion, which have been described previously (28), were classified into two variants: Type I, characterized by the presence of a sutural (wormian) bone formed of woven bone, and Type II, defined by a simple junction without an intervening bone. The precise geometric center of the asterion may shift depending on the type present. Although population-based studies have not demonstrated statistically significant differences in mean distances between Type I and Type II asterions, greater individual variability has been observed in Type I cases. Furthermore, both types may coexist within the same individual. The prevalence of Type I asterion has been reported to be higher in Indian, Kenyan, Mexican, and Australian populations when compared with American and Turkish populations (42).

The internal auditory canal also exhibits variation in its osseous structure (43), which includes ethnic influences (44). In addition, the internal auditory canal might serve as a theory of gender dimorphism and eventually be used to determine the sex of an individual based on morphometric analysis of this structure, as claimed by Graw et al. in their study (45). The accessibility to this structure is influenced largely by the individual characteristics of the temporal bone and the variability of the surgical landmarks as a result of different skull base shapes among different races (46).

This study demonstrated significant differences in several parameters across the major racial groups included in the analysis. Given the diverse ethnic composition of the study cohort, participants were

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categorized into four groups: Kadazan, Malay, Chinese, and “Others,” the latter comprising the remaining ethnicities. Significant differences were identified for the asterion–to–key point distance ($p = 0.020$), the IAC–to–key point distance ($p = 0.039$), and the cranial index ($p < 0.001$), whereas the vertical IAC–to–key point distance did not differ significantly between groups ($p = 0.184$).

Group comparisons were performed using one-way ANOVA and the Kruskal–Wallis test. As both tests indicated significant differences, post hoc pairwise comparisons were conducted using the Mann–Whitney U test with p-value correction. This approach was essential for identifying specific inter-group differences, minimizing Type I error, and clarifying complex relationships in analyses involving multiple groups. Post hoc results revealed that the Chinese group exhibited a significantly greater asterion–to–key point distance compared with the “Others” group ($p < 0.001$). However, no significant pairwise differences remained for the key point–to–IAC measurements after p-value correction.

Regarding cranial morphology, individuals classified under the “Others” category exhibited significantly lower cranial index values compared with Malay ($p < 0.001$), Chinese ($p < 0.001$), and Kadazan participants ($p < 0.001$). The “Others” group included Bajau, Dusun, Suluk, Brunei, Kedayan, Murut, and Sungai ethnicities. Previous work by Mustapa et al supports these findings (47), reporting cephalic indices of 62.5 (male) and 61.7 (female) among the Rungus, and even lower values among the Bajau (50.9 in males, 49.4 in females). A lower cranial index,

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typically associated with dolichocephaly, indicates a long and narrow cranial shape. In such skull types, the asterion tends to be positioned more posteriorly due to the elongated cranial vault. Ethnic influences on cranial morphology and posterior fossa anatomy have been documented previously. For example, Dao Trong et al found that the vertical distance between the transverse and sigmoid sinuses differed by approximately 0.5 cm among Asians, African Americans, and Caucasians; a variation with practical implications for the retro-sigmoid approach to the cerebello-pontine angle (32).

Notably, individuals categorized under “Others” constituted approximately 37% of the study sample, representing a substantial portion of local patients. The consolidation of smaller ethnic subgroups into an “Others” category represents a methodological compromise driven by sample size constraints. Although statistically pragmatic, this grouping introduces heterogeneity within the category and may attenuate subgroup-specific anatomical distinctions. Accordingly, external generalizability to individual minority populations is limited. Future multicenter studies with larger, stratified sampling frameworks are warranted to validate and refine ethnicity-based morphometric patterns.

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In this cohort of 180 adults, hemispheric asymmetry of the transverse–sigmoid sinus junction was statistically detectable but anatomically minimal. In contrast, sex-based morphometric variation was substantial, with males demonstrating approximately 8.4 mm greater key

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point–to–internal auditory canal distance and nearly 4 mm greater vertical separation. These millimetric differences are clinically relevant in retro-sigmoid and posterior fossa approaches, where operative corridors frequently operate within narrow margins adjacent to the sigmoid sinus. Ethnic differences in linear measurements were modest; however, significant variation in cranial index and its correlation with sinus positioning suggest that global cranial morphology may be a more meaningful predictor than categorical ethnicity.

While the primary objective of this study focused on quantitative morphometric analysis, the reconstructed radiological datasets permitted visual assessment of general anatomical configurations of the transverse–sigmoid sinus junction. Variability in sinus dominance patterns and junctional morphology was noted; however, systematic qualitative classification was beyond the scope of the present investigation. The data demonstrated that the TSSJ was dominant over the right side, with left sides frequently noted to be aplastic or hypoplastic. Future studies incorporating structured variant classification systems may provide additional insight into the clinical and surgical relevance of these anatomical differences.

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The study of craniometrics has been a pivotal subject for many neurosurgeons in their early days, as it forms the basis for localization. Advances in neuroimaging have transformed preoperative and intraoperative surgical planning, and the development of neuro-navigation systems has enhanced the accurate recognition of vital

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intracranial structures (49). Through the implementation of neuro-navigation as well as cadaveric and population studies, the reliability and accuracy of these cranial landmarks have been questioned. The asterion, for instance, was considered not a reliable landmark for the transverse sigmoid sinus junction (49). In this modern era of medicine, where precision is key, the use of neuro-navigation is more accurate than traditional surface marking, with studies showing a discrepancy of up to 44% in an experienced surgeon (50). Unfortunately, developing countries that do not have the means to obtain these resources depend on traditional methods of localization, which can be difficult in deep-seated lesions.

Among the many techniques of localization of the transverse sigmoid sinus, the techniques of Li, Ribas, Tubbs, Teranishi, and Day were each found to be more accurate estimates, in comparison to those of Lang and Samii, Rhoton, and Avci (33). The Teranishi method, which was used in this case, usually identified the posterior fossa dura (88%), and rarely exposed the sigmoid sinus (5%), and was never found external to the margins of the venous sinuses (33). A study by Hall et al demonstrated one of the most extensive head-to-head comparisons of existing techniques for localization of the initial burr hole in a retro-sigmoid craniotomy; however, it did not specifically examine the impact of racial background (33). The use of the Teranishi method here was because it is simple, and was found to be more effective than the previous methods. Furthermore, the usage of the asterion as an external

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skull bony landmark for the prospective location of the transverse sigmoid sinus junction is because the asterion is a single point inside the operative field in the lateral suboccipital approach, and can be observed just before craniotomy (12).

The 3 major factors that are known to affect skull size and shape are race, gender, and age. According to Supawannwiwat et al, these three factors impacted their results; race, however, was not studied due to their predominantly Thai recruits (1). Their anatomical study also identified a more reliable bone landmark for the TSSJ at the intersection of the supramastoid crest and the squamosal suture, compared with the squamosal and parietomastoid suture. Similarly, a study on gender identification using manual measurements of foramen magnum dimensions noted a larger foramen magnum index in females than in males, with little racial influence, due to the sample predominantly comprising individuals of Indian ethnicity. However, the French sample cited in their study did not report significant differences in foramen magnum length, but their width did (51). With respect to the variation of head shape in various ethnic groups, the study by Golalipour, stated that hereditary factors primarily affected the shape of the head; however, the environment had a secondary effect on it (52). Using the skull-based categorization, anthropologists broadly identified three or four racial groups: Caucasoid, Negroid, and Mongloid (53). From an anthropological view, however, skeletons may show features "typical" of two or more racial groups (54). Thus, even in forensic anthropology, classifying

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human remains into specific races is a problem due to the lack of an account of the occurrence of racial hybridity (2). A recent study in Bangladesh revealed a clear ethnic difference in cranial parameters despite the 2 groups studied (Bengali and Manipuri adult males) belonging to the same race, that is, Mongolo-Dravidian, where Dravidian influence was more among Bengali and Mongolian influence was more among Manipuri. This could be attributed to different etiological factors like genetic, environmental, geographical, occupational, nutritional, and climate (55).

Although using the many techniques described above was considered relatively accurate, e.g., the Teranishi et al method, these methods possess several limitations in clinical practice, particularly regarding anatomical variability and reliance on surgical exposure (12). Key limitations of this method in determining the transverse-sigmoid sinus junction (TSSJ) include dependency on visible structures intraoperatively, anatomical variability, potential for insufficient exposure, and the majority of these studies were derived from cadaveric skulls, which do not account for soft tissue or individual variation. This has led to new methods of determining the keyhole position in the lateral suboccipital approach (56).

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From an embryological perspective, the asterion, like other sutures of the cranium, develops through intramembranous ossification and is maintained by the underlying dura mater. Genetic regulation of woven bone formation plays a key role in determining the final meeting point of

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these cranial bones. In addition, suture patency and closure are modulated by multiple biological pathways, including dural signaling mechanisms as well as osteoblastic and osteoclastic activity (43). The interplay of these developmental, genetic, and biomechanical factors likely contributes to the observed anatomical variability of the asterion**.**

Another factor that contributes to this variability is the asymmetry of the venous sinuses. In many populations, the right transverse sinus and its continuation, the sigmoid **s**inus**,** are larger and dominant compared to the left. This dominance reflects the disproportionate venous drainage load, where the superior sagittal sinus often preferentially drains into the dominant transverse sinus, while the straight sinus drains more into the less dominant side (57). Dominance asymmetry may arise from subtle differences in embryological growth and venous channel maturation. These affect the caliber of the dural venous channels, which major venous pathways become the primary outflow route, and how early venous plexuses regress or enlarge. Venous flow patterns during development, influenced by factors such as right–atrial pulsations, can promote a larger venous caliber on one side. The right venous system, responding to greater pulsatility, often develops a larger lumen than its counterpart (58). Another main explanation includes the flow pattern of the brain venous circulation. The right transverse sinus, which receives blood from superficial veins, is larger than the left transverse sinus, which receives blood from the deeper veins of the brain (59). These differences can also affect the location of

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the keyhole, and thus the practical placement of the burr hole during craniotomy. To a certain extent, geographical differences do exert some effect on the dominance of vessels. This was demonstrated by a study comparing Czech and Italian skulls, for which the former displayed an asymmetry of the confluence of sinus to the right in comparison to their counterpart (60). This was in accordance with previous studies, which stated that geographical distances, climate, and migration flow can influence cranial proportions (61,62).

The transverse sinus and sigmoid sinus run in bony grooves on the internal surface of the skull (the transverse and sigmoid sulci). As sinus dominance affects the size and position of these bony grooves, external cranial landmarks (e.g., asterion, suprameatal triangle, mastoid process) may not reliably predict the TSSJ if they assume symmetrical sinus anatomy. Furthermore, dominance asymmetry can shift the junction point of TS and SS anteriorly or posteriorly relative to traditional surface markers used in neurosurgery (5). Dominant sinuses tended to be situated more anteriorly within the temporal bone and have closer spatial relationships with structures like the external auditory canal and facial nerve, resulting in positional shifts that are directly relevant to surgical approaches to the posterior cranial fossa. Similarly, this study also revealed that the left-sided measurements observed greater distance measurements compared to the right side, corroborating the statement. Attention to cranial base asymmetry is crucial for both investigative analysis and insight into developmental anatomy. In-depth anatomical

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understanding is therefore fundamental to safe and effective surgery in this highly complex region (63).

Ethnic-related morphometric variation of cranial structures is increasingly recognized in anatomical, anthropological, and radiological literature. It provides a plausible explanation for the differences in transverse–sigmoid sinus junction (TSSJ) measurements observed in this study. Previous craniometric research has demonstrated that cranial morphology varies substantially across populations, reflecting differences in genetic ancestry, evolutionary adaptation, and developmental influences. Morphometric analyses have shown measurable cranial overlap but persistent structural differences among Asian and other global populations, highlighting that cranial dimensions and skull base morphology are influenced by ancestral lineage and population history (64). Within Southeast Asia, population studies have demonstrated significant craniofacial diversity resulting from complex migration patterns and admixture events across the region. Morphometric skeletal analyses indicate that Southeast Asian populations occupy intermediate cranial morphologic positions relative to East Asian and Australo-Melanesian groups, suggesting considerable biological variability even within geographically related populations (65). These findings support the hypothesis that ethnic differences identified in the Sabah population may represent underlying population-specific cranial base morphology, which in turn could influence the spatial relationship between key

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neurosurgical landmarks such as the asterion, internal auditory canal, and TSSJ.

From a neurosurgical perspective, variation in venous sinus anatomy is widely documented. Studies analyzing cranial venous circulation have demonstrated that transverse sinus morphology commonly exhibits asymmetry and dominance patterns influenced by developmental and demographic factors (66). These anatomical variations are clinically relevant because the position of the venous sinuses directly affects surgical corridor planning, particularly during posterior fossa and skull base approaches. Similarly, surgical anatomy investigations emphasize that preservation of the transverse and sigmoid sinuses is critical during cranial procedures, as injury to these structures can result in significant morbidity. Landmark-based radiological studies further support population variability in sinus positioning. Investigations using asterion-based reference systems have demonstrated measurable differences in the relationship between skull surface landmarks and underlying venous sinus pathways, reinforcing the importance of individualized anatomical assessment during surgical planning. Additionally, morphometric analyses evaluating transverse sinus distance from external cranial landmarks have highlighted the relevance of demographic variables such as sex and dominance patterns in predicting venous sinus location (67). This study, at best, tried to achieve the standards of modern anatomical study as suggested using the AQUA checklist (68).

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Collectively, these findings suggest that the ethnic variations in TSSJ morphometry observed in the present Sabah cohort are biologically plausible and consistent with broader anthropological and neurosurgical evidence demonstrating population-specific cranial structural diversity. The results reinforce the need for region-specific anatomical datasets to improve surgical safety, particularly in multi-ethnic populations where reliance on generalized anatomical norms may increase the risk of sinus injury. Furthermore, the findings support the growing emphasis on personalized surgical planning using radiological morphometry rather than extrapolating anatomical data derived from other populations.

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Limitations

This study is subject to several limitations, including dependence on radiological imaging and static craniometric measurements. As this was a hospital-derived cohort, the findings may not fully represent the broader Sabah population, extrapolation to the broader Sabah population should be undertaken cautiously. In addition, multiple ethnic groups within the diverse population of Sabah were collectively categorized as "Others," which may obscure meaningful anatomical distinctions and warrants further subgroup analysis based on the cranial indices assessed. Future research would benefit from incorporating genetic, developmental, and environmental variables to better elucidate the factors underlying the observed anatomical variability. Longitudinal and multi-center studies may further clarify the evolution of these anatomical

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features and enhance understanding of transverse–sigmoid sinus junction (TSSJ) variation across broader populations. This study utilized radiological data derived from hospitalized patients undergoing clinically indicated imaging rather than a randomly selected community cohort. Consequently, the sample may be subject to selection bias and may not fully represent anatomical characteristics within the general population, thereby potentially limiting external validity. However, the use of clinically acquired imaging reflects real-world patient populations encountered in neurosurgical practice and provides anatomically reliable, high-resolution data obtained under standardized diagnostic protocols.

Furthermore, previous anatomical and radiological investigations have similarly relied on clinically indicated imaging datasets, which remain valuable for defining surgically relevant landmarks and population-specific anatomical variation. Therefore, while generalization to the broader population should be interpreted cautiously, the findings retain strong clinical applicability, particularly for preoperative planning and risk mitigation in patients requiring neurosurgical intervention. Finally, lower-resolution radiological imaging may not capture fine topographical relationships, and thus, the study may be improved by using higher-resolution equipment. Future investigations integrating higher-resolution imaging modalities and standardized methodological reporting may further strengthen the reliability, reproducibility, and clinical applicability of anatomical variation studies, as recommended in

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recent discussions on improving reporting standards in anatomical research (69).

CONCLUSION

This prospective radiological study demonstrated significant anatomical variation of the transverse–sigmoid sinus junction (TSSJ) in the adult Sabah cohort. The asterion–to–“key point” distance was greater on the left side, with males showing larger asterion–to–“key point, “key point” to internal auditory canal, and vertical “key point” measurements. Ethnic differences were observed, with Chinese participants demonstrating higher asterion–to–“key point” values, while minority ethnic groups exhibited lower cephalic indices. Statistically significant weak to moderate correlations were identified among key linear parameters. These findings highlight the importance of population-specific anatomical considerations during preoperative planning to reduce the risk of TSSJ-related complications. The present findings support a precision-based neurosurgical paradigm, in which individualized morphometric assessment supersedes demographic generalization in operative planning.

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