

Anatomical characteristics and significance of the metopism and Wormian bones in dry adult-Chinese skulls

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Background: This study aimed to investigate the incidence, topographical distribution, morphology, and interrelationship of the metopism and Wormian bones (WBs) in dry adult-Chinese skulls.

Materials and methods: In this study, 285 dried adult-Chinese skull specimens from the Department of Anatomy at the Southern Medical University were examined. The incidence of different types of metopism and WBs were recorded. The length of the metopic suture was measured using a flexible ruler. Additionally, the lengths and widths of the WBs were measured using a vernier calliper.

Results: The incidence of metopism and WBs in Chinese adults were estimated at 10.18% (29/285) and 63.86% (182/285), respectively. The metopism always accompanied WBs (26/29, 89.66%), but the WBs did not necessarily accompany metopism (26/182, 14.29%). The locations of the WBs in the order of decreasing incidence were the lambdoid suture (78.57%, 143/182), pterion (34.62%, 63/182), asterion (12.09%, 22/182), lambda (8.24%, 15/182), sagittal suture (4.95%, 9/182), and Inca bone (3.85%, 7/182). These locations differed in topographical distribution and morphological patterns.

Conclusions: Chinese adults differ in incidence of metopism and WBs from adults of other races, indicating racial differences. The characteristics of WBs vary depending on the cranial site of occurrence. The metopism always accompanies WBs, but the WBs do not necessarily accompany metopism. (Folia Morphol 2023; 82, 1: 166–175)

Key words: Chinese, skull, metopic suture, metopism, Wormian bones, anatomical characteristics

INTRODUCTION

The skull is the most complex skeletal structure in the human body. The skull of a young adult consists of 28 separate flat and irregular bones, most of which are connected by “cranial sutures” [39]. The metopic

suture (MS) is an important cranial suture connecting the bregma to the nasion in the cranial vault. It presumably helps the fetus pass smoothly through the birth canal and assists in brain development, along with the coronal, sagittal, and lambdoid sutures [7, 16].

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Closure of the MS typically occurs in infancy or early childhood, but the exact timing is controversial. Most researchers believe that this process is completed by the age of 7 years [40–42]. Incomplete closure of the MS leads to a persistent metopic suture (also known as the metopism or median frontal suture) in adults [3, 26, 44]. Metopism is usually considered a normal anatomical variant, but several researchers believe it is associated with clinically significant findings [41, 44].

Wormian bones (WBs, also known as the isolated sutural bones or supernumerary bones) are irregularly shaped bones formed from additional ossification centres and almost always located in or near the cranial sutures and fontanelles [9, 27]. The isolated bone at the lambda is often referred to as Goethe's ossicle, or the Inca bone due to its prevalence in the skulls of the Incas (South American Indians) [39]. These WBs are present as one or more pterion ossicles or epipteric bones in the pterion and as os Kerckring in bregma [8]. As with metopism, WBs have pathological and diagnostic implications, and their incidence varies among different populations [27]. WBs distinguished normal variation or pathology from its number, arrangement pattern, and size as important factors [17, 22].

Although metopism and WBs have been reported in various ethnic populations, few related large-scale studies on Chinese adults have been performed. Therefore, this study aimed to investigate the incidence, number, morphology, and topographical distribution of the metopism and WBs and the interrelationships among these characteristics in Chinese adults.

MATERIALS AND METHODS

Materials

For this study, 285 dried skull specimens of Chinese adults with unknown age and sex were obtained from the Department of Anatomy of the Southern Medical University in China (the exclusion criteria were damaged skulls, such as those with trauma or pathology affecting the measurement parameters, and skulls of children). All the specimens were from cadaver donations, and written informed consent had been obtained from the donors. To precisely identify the cranial sutures and assess their structural integrity, all the skull specimens were cleaned and dried.

Methods

Firstly, we assessed the incidence, number, and shape of the metopism and WBs in the specimens.

Metopism can be partial (incomplete) or complete. The partial type extends upward from the nasion or downward from the bregma; the complete type connects the bregma to the nasion [44]. Following a previously described method, only the small bones surrounded by the suture were recorded as WBs [27]. Then, the length of the metopic suture was measured (accuracy ± 0.1 mm) using a soft ruler (Martin measure instrument). The lengths and widths of the WBs were measured using a digital vernier calliper (accuracy ± 0.01 mm) (Wuxi Kaibaoding Tool Co., Ltd., China).

The above measurements were independently performed by 2 researchers, each researcher taking 3 measurements (6 measurements in total) per parameter to calculate the mean \pm standard deviation (SD). The researchers who performed the measurements had > 2 years of experience in measurements and were uniformly trained to reduce systematic errors. Digital image acquisition (D610 type camera, Nikon) and processing (Photoshop 2020; Adobe Illustrator 2020, Adobe) were performed after the measurements were completed.

All the methods in this study followed the guidelines of the Helsinki Declaration. Ethical approval for this study was obtained from the Chinese Ethics Committee of Registering Clinical Trials (Reference number: ChiECRCT20210191).

Statistical analysis

The IBM SPSS Statistics 26.0 software for Windows was used to perform statistical analyses. The measurements were expressed as mean \pm SD ($\bar{x} \pm s$). The normality of the data was assessed using the Kolmogorov-Smirnov test. The paired samples t-test or Wilcoxon signed-rank test was used to determine whether the length and width of the bone were consistent. Statistical significance was determined by $p < 0.05$ for all the analyses.

Inter- and intra-observer reliability was determined by calculating the intra-class correlation coefficient (ICC) with a confidence interval (CI) of 95%. $ICC \leq 0.4$, $0.41 \leq ICC \leq 0.60$, $0.61 \leq ICC \leq 0.80$, and $0.81 \leq ICC < 1$ were considered to indicate poor, moderate, good, and very good agreement among the measurements, respectively. The ICC value of 1 indicates perfect reliability [43]. The ICCs of all the measurements were > 0.90 , indicating very good inter- and intra-observer agreement.

Consent to participate

All the methods in the study were carried out following the Helsinki guidelines and declaration.

Table 1. Incidence of metopism in different ethnic groups (in descending order of incidence)

No.	Author(s)	Year	Population	Specimen number (n)	Incidence (%)
1	Zdilla et al. [44]	2018	East Asian	13	15.38%
			European	62	8.06%
			Bengali	35	2.86%
			Egyptian	91	2.20%
2	Present study	2021	Chinese	285	10.18%
3	Brothwell [11]	1981	Iron Age Romano-British	NA	9.91%
			London (17 th C.)	NA	9.09%
			Lachish	NA	8.81%
			German	NA	8.37%
			Anglo-Saxon	NA	8.30%
			Chinese	NA	8.17%
			Ancient Egyptian	NA	3.87%
			Peruvian	NA	2.56%
			Melanesian	NA	2.02%
			N. American Indian	NA	1.45%
			Polynesian	NA	1.33%
			African Negro	NA	1.23%
			Australian	NA	0.63%
			Eskimo	NA	0.28%
4	Bilgin et al. [10]	2013	NA	631	9.7%
5	Çalışkan et al. [13]	2018	Turkish	185	8.1%
6	Cirpan et al. [14]	2016	Turkish	160	7.5%
7	Aksu et al. [4]	2014	West Anatolian	160	7.5%
8	Guerram et al. [20]	2014	European	143	4.41%
9	Ajmani et al. [3]	1983	Nigerian	206	3.4%
10	Agarwal et al. [1]	1979	Indian	1276	2.66%
11	Baaten et al. [5]	2003	Lebanese	NA	1.75%
12	Murlimanju et al. [26]	2011	Indian	81	1.2%

NA — not available

Ethical approval for this study was obtained from the Chinese Ethics Committee of Registering Clinical Trials (Reference number: ChiECRCT20210191).

RESULTS

The incidence and characteristics of the metopism

Among all the specimens, 29 metopism cases were detected, corresponding to 10.18% (29/285) incidence, which differs from the incidence in other ethnic populations (Table 1) [1, 3–5, 10, 11, 13, 14, 20, 26, 44]. Of them, 27 and 2 cases were the complete and partial types (downward from the bregma), respectively. The mean length of the complete type was 12.13 ± 0.62 cm (range: 11.25–13.34 cm), and the partial type was 9.3 cm long on average (8.72 and 9.88 cm) (Fig. 1).

The incidence of WBs

Among the specimens, 182 had WBs, corresponding to 63.86% (182/285) incidence, which differs from the incidence in other ethnic populations (Table 2) [8, 11, 14, 15, 18, 23, 27, 32]. The locations of the WBs in the order of decreasing prevalence were as follows: the lambdoid suture (78.57%, 143/182), pterion (34.62%, 63/182), asterion (12.09%, 22/182), lambda (8.24%, 15/182), sagittal suture (4.95%, 9/182), and Inca bone (3.85%, 7/182).

The characteristics of the WBs in lambdoid, sagittal, and coronal sutures

The WBs in the lambdoid sutures showed unilateral distribution in 51 (35.66%) cases and bilateral

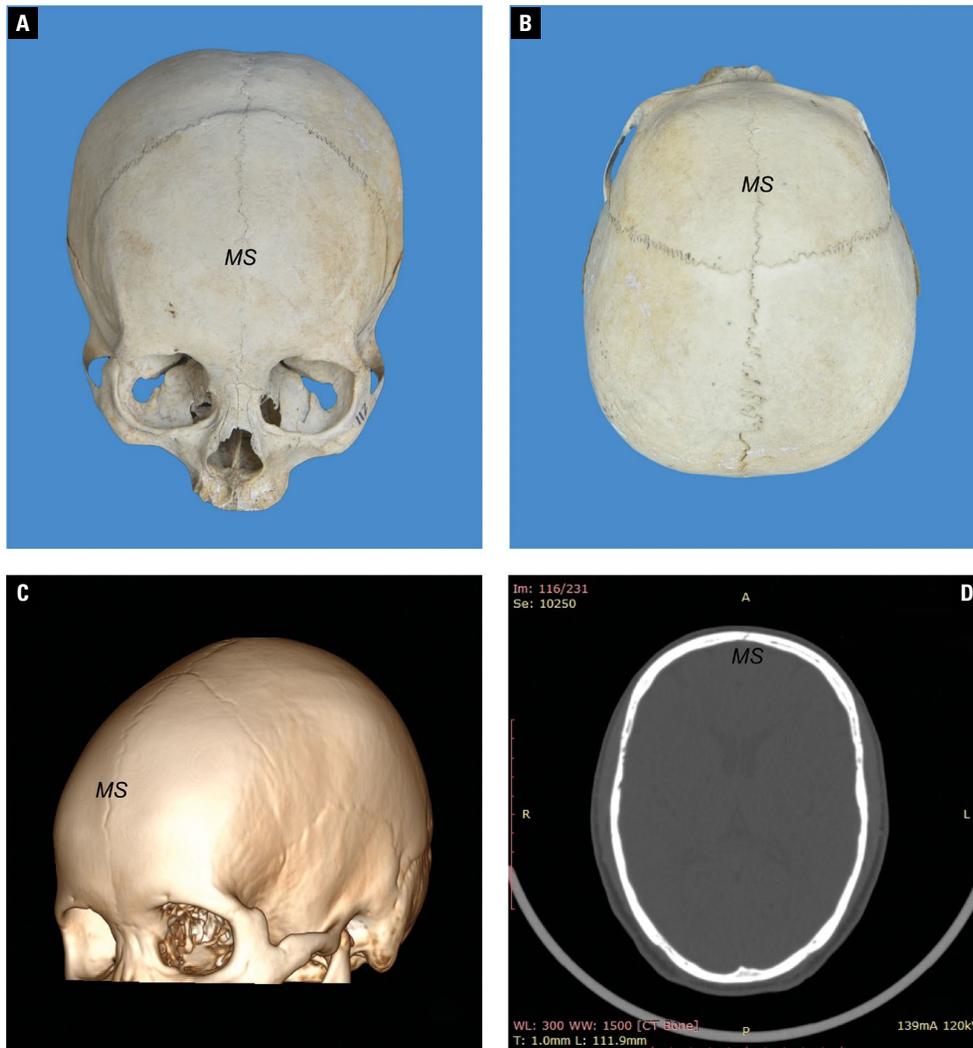


Figure 1. The anterior, superior, lateral, and cross-sectional views of the metopic suture (MS) (or metopism); **A.** Anterior view; **B.** Superior view; **C.** Three-dimensional visualisation of metopism via computer tomography (CT) (RadiAnt DICOM Viewer for windows); **D.** Metopism in a cranial CT cross-section.

in 92 (64.34%) cases. Of the lambdoid-suture WB cases, 29 had only 1 WB, 105 cases had 2–10 WBs, and 9 cases had > 10 WBs. There was no statistically significant difference in the number of WBs at the lateral level (right: 2.05 ± 2.24 ; left: 2.22 ± 2.17 ; $p > 0.05$). The majority of the WBs were parallel-fingered (with tentacles) (48.17%), elliptical (without tentacles) (24.08%), or single-fingered (with tentacles) (17.8%); the remaining minority was polygonal, round, triangular, or in another shape. The mean length and width of these bones were 1.37 ± 0.54 cm (range: 0.27–3.11 cm) and 0.79 ± 0.63 cm (range: 0.15–6.23 cm), respectively; the mean length was significantly greater than the mean width ($p < 0.001$).

We also detected 9 cases of WBs in the sagittal suture, which were located in the pars obelica and

pars lambdica of the suture. They were quadrilateral (44.44%), oval (33.33%), or finger-shaped (22.23%). The mean length and width of these WBs were 1.70 ± 0.30 cm (range: 1.35–1.91 cm) and 1.46 ± 0.79 cm (range: 0.6–2.15 cm), respectively; there was no statistical significance between the mean length and width. No WB was detected in the coronal suture (Fig. 2).

The characteristics of the WBs at the pterion and asterion

Of the cases with WBs around the pterion, 37 (58.73%) and 26 (41.27%) had unilaterally and bilaterally distributed WBs relative to the pterion, respectively. Of the bilateral cases, 20 were symmetrical in number and position. Most of the pterion WBs were

Table 2. Incidence of Wormian bones in different ethnic groups (In descending order of incidence)

No.	Author(s)	Year	Population	Specimen number (n)	Incidence (%)
1	Basnet et al. [8]	2019	Nepalese	70	88.57%
2	Natsis et al. [27]	2019	Greek	166	74.7%
3	Present study	2021	Chinese	285	63.86%
4	Cirpan et al. [15]	2015	West Anatolian	150	59.3%
5	Cirpan et al. [14]	2016	Turkish	160	59.3%
6	Ghosh et al. [18]	2017	Eastern part of India	120	45%
7	Khan et al. [23]	2011	Malaysian	25	24%
8	Ratnaningrum [32]	2020	Indonesian	69	15.9%
9	Brothwell [11]	1981	Chinese	NA	80.32%
			German	NA	75%
			Australian	NA	72.58%
			Iron Age Romano-British	NA	71.03%
			Melanesian	NA	64.15%
			Lachish	NA	63.41%
			Anglo-Saxon	NA	55.56%
			Ancient Egyptian	NA	55.56%
			Peruvian	NA	51.85%
			African Negro	NA	45.05%
			London (17 th C.)	NA	36.02%
			Polynesian	NA	29.92%
			N. American Indian	NA	28.18%
			Eskimo	NA	25%

NA — not available

epipteric (71.74%) (i.e. located at the intersection of the frontal, parietal, sphenoid, and temporal bones). However, some pterion WBs were around the squamosoparietal suture (13.04%), between the sphenotemporal and squamosoparietal (6.52%) or coronal and sphenoparietal (4.35%) sutures, or around the sphenofrontal (4.35%) or sphenotemporal (2.17%) suture. The pterion WBs were mostly quadrilateral (including rectangular, square, and rhombic; 69.7%), followed by triangular (21.2%), polygonal (6.06%), and circular (3.04%). The mean length and width of the pterion WBs were 1.87 ± 0.93 cm (range: 0.63–5.04 cm) and 1.07 ± 0.42 cm (range: 0.48–2.3 cm); their mean length was significantly greater than their mean width ($p < 0.001$).

The WBs at the asterion were mostly bilateral (66.64% vs. 33.36%, bilateral vs. unilateral, respectively). WBs were often found with the lambdoid suture (40.91%), squamosoparietal suture (27.27%), Inca bone (22.73%), or lambda bone (9.09%) (Fig. 3).

The characteristics of the Inca and lambda bones

We found that the lambda and Inca bones were distributed on the posterior side of the skulls. Among the cases with Inca bones, 4 had one bone mass, and 3 had two separated bones. Most of the Inca bones were triangular (4/7, 57.14%), but a significant fraction was polygonal (3/7, 42.86%). The mean length and width of these bones were 4.99 ± 0.57 cm (range: 4.5–5.8 cm) and 5.77 ± 4.46 cm (range: 2.7–12.4 cm), respectively; there was no statistical difference between the mean length and width ($p > 0.05$).

All the lambda bones were found in the posterior fontanelle and were single bones. They were triangular (42.86%, 3/7), circular (28.58%, 2/7), quadrilateral (14.28%, 1/7), or irregularly shaped (14.28%, 1/7). The mean length and width of these bones were 2.25 ± 1.31 cm (range: 0.56–4.08 cm) and 2.52 ± 1.62 cm (range: 0.4–5.02 cm), respectively; there was no statistical difference between the mean length and width ($p > 0.05$) (Fig. 4).

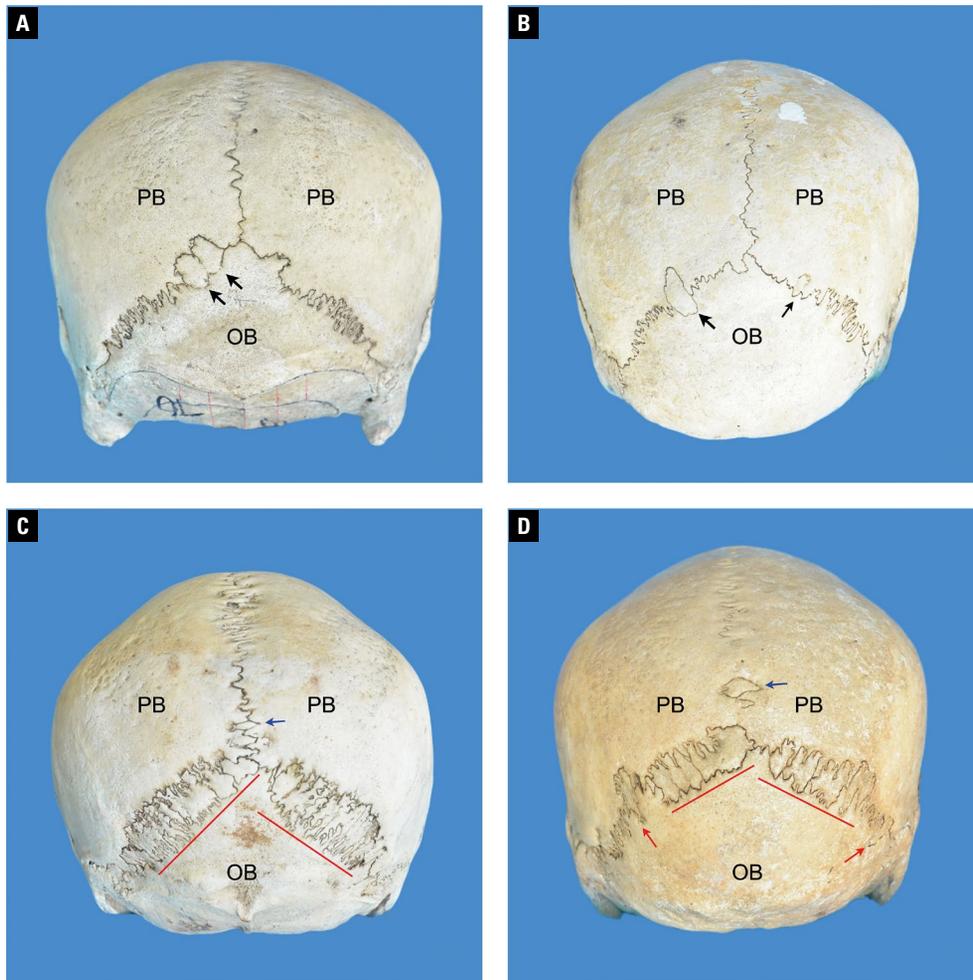


Figure 2. The Wormian bones (WBs) around the lambdoid and sagittal sutures; **A.** The two WBs are located on the same side of the lambdoid suture (black arrows); **B.** The two WBs are symmetrically located relative to the lambdoid suture and both oval-shaped (black arrows); **C, D.** The complex WBs bilaterally located relative to the lambdoid suture were in a parallel-fingered (red line) shape or single-fingered with tentacles (red arrows). WBs were also found around the sagittal suture (blue arrows); PB — parietal bone; OB — occipital bone.

The interrelationship between the metopism and WBs

Among the 29 cases of metopism, 26 concurrently had WBs (89.66%). These cases were only a sub-fraction (14.29%) of all the cases with WBs (182 cases).

DISCUSSION

In this study, we evaluated the number, shape, and size of the WBs in different cranial locations and summarized the anatomical characteristics of these bones. The WBs in the lambdoid suture were relatively small and numerous, with a wide range of variation in morphology; most of them were narrow finger-shaped or oval-shaped. The WBs at the pterion were more prominent in size and less in number compared with other location, they were mostly regular in shape and mainly epipteric bones. Unilaterally and bilaterally

distributed WBs were both observed at the lambdoid suture and pterion. However, the number of unilateral WBs at the lambdoid suture was lower than that of the bilateral ones. The bilateral WBs at the lambdoid suture was asymmetrical in number and location, whereas those at the pterion were mostly symmetrical. The WBs at the sagittal suture (lambda bone) were small in size, fixed in number and position, and mostly quadrilateral (small triangular) or oval (circular). The Inca bones were large, and primarily triangular. The WBs at the star point often concurred with WBs at other positions. The anatomical characteristics of WBs vary depending on the cranial site of occurrence.

The exact mechanism of WB formation remains unknown, and there are two major hypotheses. The first hypothesis suggests that formation of WBs is influenced by genetic factors [18]. The second hy-

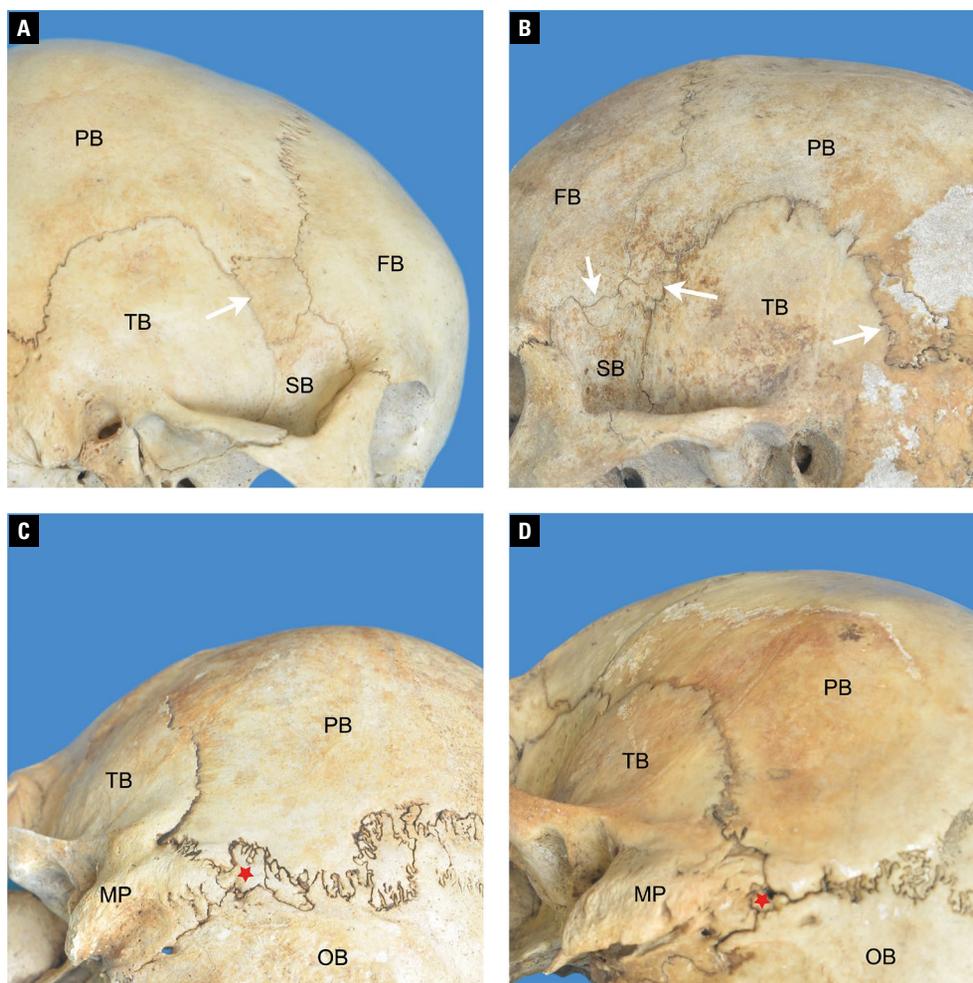


Figure 3. The Wormian bones (WBs) at the pterion and asterion; **A, B.** The WBs located at various locations near the pterion (white arrow); **C, D.** The WBs located at the asterion (red pentacle) appear together with the WBs around the lambdoid suture; FB — frontal bone; PB — parietal bone; TB — temporal bone; SB — sphenoid bone; OB — occipital bone; MP — mastoid process.

pothesis suggests that environmental factors (e.g. artificial cranial deformation) cause WBs to form. The higher occurrence of WBs in the occipital region than in the frontal region may be due to environmental factors [29, 34]. However, multiple scholars believe that genetic and environmental factors influence the locations and number of WBs formed, respectively.

As a normal variant, metopism does not have any medical or morphological implications. However, multiple researchers believe that it is usually associated with malformations in the frontal region (e.g. cranium bifidum, suprasellar teratoma, cleidocranial dysostosis, hypertelorism, and facial cleft) [41]. WBs are common in adults and are also often considered a normal anatomical variant. Kozerska et al. [24] have used microcomputed tomography to examine interseptal bones and found that these bones, like other cranial bones, have both dense and cancellous bone

tissues. However, occurrence of interseptal bones in children can be associated with numerous pathological conditions [27]. The presence of WBs in children is associated with developmental abnormalities in the central nervous system [31] (e.g. hydrocephalus [39], craniosynostosis [2], microcephaly, macrocephaly, cerebral palsy, epilepsy, and learning difficulties). Thus, the presence of WBs in children may serve as a marker for early diagnosis and treatment of paediatric central nervous system abnormalities. The presence of WBs can also be associated with certain types of congenital disorders (e.g. osteogenesis imperfecta [17, 36], Hajdu-Cheney syndrome [37], cleidocranial dysostosis [28], congenital hypothyroidism, rickets [25], limbic callosal syndrome [33] and Enlarged parietal foramina [30]).

During diagnosis or forensic identification, knowledge of metopism, WBs and craniosynostosis is es-

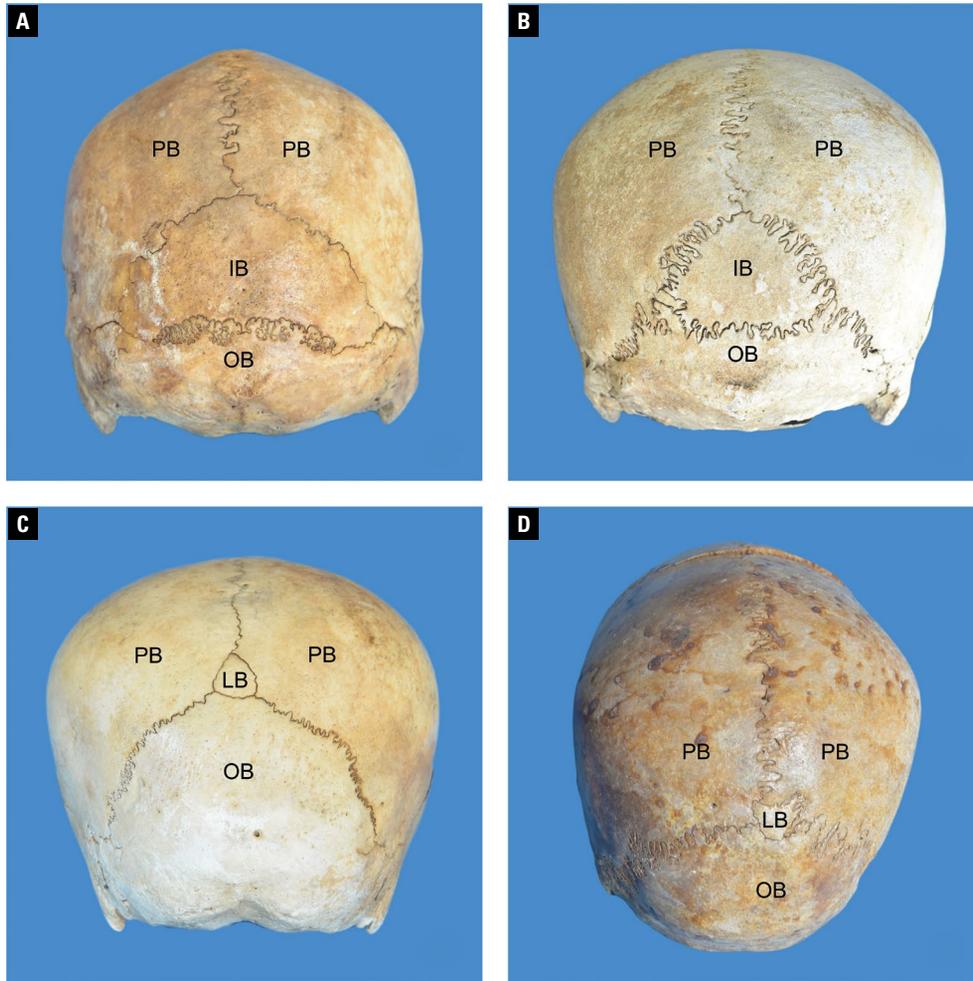


Figure 4. The Inca and lambda bones; **A, B.** Inca bones in the shape of large triangles; **C.** A lambda bone with a small triangular shape; **D.** An irregularly shaped lambda bone; PB — parietal bone; OB — occipital bone; IB — Inca bone; LB — lambda bone.

sential. Their presence may interfere with radiological assessment and forensic identification (easily confused with fractures or gunshot wounds) [6, 12, 19, 38]. Additionally, brain surgeons should always be cautious during a surgical operation because WBs may move and damage surrounding tissues, leading to complications [21, 35].

CONCLUSIONS

Chinese adults differ in incidence of metopism and WBs from adults of other races, indicating racial differences. The characteristics of WBs vary depending on the cranial site of occurrence. The metopism always accompanies WBs, but the WBs do not necessarily accompany metopism. These results may provide an anatomical basis for teaching, clinical practice, and forensic work.

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