Interdisciplinary Journal of Information, Knowledge, and Management

An Official Publication of the Informing Science Institute

Vol. : 21,Issue 1,Jan-June 2026
ISSN: (E) 1555-1237

Metopism in Humans: Global Prevalence, Morphological Variations, and Clinical Implications: A Systematic Review

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Abstract

Background: The metopic suture is the median frontal suture that normally fuses during early childhood as the two halves of the frontal bone unite. Its persistence into adulthood, termed metopism, is a well-recognised but inconsistently understood anatomical variant with anthropological, radiological, forensic, and surgical relevance. Objective:. Methods: A structured literature search was conducted across PubMed, ResearchGate, Google Scholar, and allied anatomical and forensic-medicine journals, following a PRISMA-informed selection process. Studies reporting prevalence data, morphological description, or clinical/forensic associations of the metopic suture in adult human crania or radiographic datasets were included. Results: Reported prevalence of complete metopism ranges from below 1% to over 9% across populations, with markedly higher rates of partial or incomplete metopic remnants (up to 38–44%) in some samples. European and East Asian ancestries generally show the highest rates of complete metopism, whereas sub-Saharan African and several South-East Asian samples show lower or highly variable rates. Morphologically, metopism presents as complete, incomplete, or ridge-like variants, occasionally co-occurring with Wormian bones or frontal sinus anomalies. Clinically, metopism is important chiefly because it can mimic a frontal bone fracture on imaging, may alter craniometric measurements used in forensic sex and ancestry estimation, and must be distinguished from pathological metopic craniosynostosis. Conclusion: Metopism is a benign, population-variable anatomical trait whose recognition is essential across radiology, neurosurgery, forensic anthropology, and craniofacial medicine. Standardised reporting criteria and multi-centre radiological studies are needed to clarify its true global distribution and clinical significance.

Keywords: metopism, metopic suture, frontal bone, cranial sutures, craniosynostosis, forensic anthropology, prevalence

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1. Introduction

1.1 Background and Definition

The frontal bone of the human skull develops from two separate ossification centres that are initially divided in the midline by the metopic suture, also termed the median frontal suture. This suture normally begins to fuse in the first two years of postnatal life and is typically obliterated by the age of six to eight years, after which the frontal bone appears as a single, continuous structure. When fusion fails to occur and the suture remains patent into adulthood, either partially or along its entire length, the condition is referred to as metopism. Metopism is generally regarded as a normal, non-pathological anatomical variant rather than a disease process, and it is classified among the non-metric (discrete) traits used in comparative craniology.

Two principal morphological forms are recognised in the literature: complete metopism, in which the suture persists continuously from the nasion to the bregma, and incomplete or partial metopism, in which only a segment of the suture remains visible, commonly near the glabella or in the mid-frontal region. A related but distinct entity, the metopic ridge, describes a palpable bony prominence along the former suture line without a patent joint, and lies at the milder end of a spectrum that, in its most severe pathological form, manifests as metopic craniosynostosis and trigonocephaly.

1.2 Embryological and Developmental Basis

The metopic suture forms during the second month of intrauterine life as the frontal bone ossifies intramembranously from paired primary centres. Suture patency is maintained by a population of undifferentiated mesenchymal stem cells at the mid-sutural region, whose osteogenic differentiation is actively suppressed by transcription factors such as TWIST1, which antagonises the osteogenic regulator RUNX2, while fibroblast growth factor receptor (FGFR) signalling promotes proliferation and eventual ossification at the suture margins. The timing and completeness of metopic fusion therefore reflect a balance between these opposing molecular signals, modulated by genetic background, cranial growth dynamics, and possibly hormonal and mechanical factors. Disruption of this balance in the opposite direction, through gain-of-function FGFR mutations or TWIST1 haploinsufficiency, produces premature fusion and craniosynostosis, whereas persistence of the mesenchymal stem-cell niche beyond the normal window of closure is thought to underlie metopism.

1.3 Rationale and Significance of the Study

Despite being a long-recognised anatomical variant, metopism has been studied through fragmented, geographically isolated investigations that vary considerably in sample type (dry

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ISSN: (E) 1555-1237

skulls, cadaveric material, forensic autopsy series, or radiological datasets), diagnostic criteria, and reporting standards. This heterogeneity has produced widely divergent prevalence estimates, ranging from under 1% to over 60% in certain samples, and has made it difficult to draw firm conclusions about true population-level variation. At the same time, clinical disciplines including radiology, neurosurgery, otorhinolaryngology, and forensic medicine continue to encounter metopism incidentally, often without adequate awareness of its potential to be misinterpreted as pathology. A systematic synthesis of the post-2015 literature is therefore warranted to consolidate current knowledge, clarify sources of variability, and highlight clinically relevant associations.

2. Literature Review

2.1 Global Prevalence of Metopism

The rates of complete metopism given in the post-2015 literature vary greatly geographically and by method. In a large multi-population cranial study, Zdilla et al. (2018) found a prevalence of metopism of 2.57% in 505 adult crania, with the highest being in the European subsample (8.06%) and the East Asian subsample (15.38%) and none in some of the African, Peruvian, Malayan, and Mexican series. In Southeast and East Asia, the prevalence of complete metopism has been reported to be relatively low, as Khamanarong et al. (2015) studied adult Thai skulls and Pakdeewong and Tohno (2019) found 1.3% complete metopism (and 6.0% incomplete) in another sample from Thailand. Inter-population variability is also seen within broadly defined "Asian" ancestry categories, as shown by the 1.65% incidence of complete metopism in a bone collection from Nepal compared with 2.88% incidence in a bone collection from Korea (according to Maskey et al., 2020).

The prevalence data reported here are similar to those from parts of the Middle East and Turkey, which reported higher prevalence figures: Zanaty (2017) reported an incidence of persistent metopic suture of 8.2% in an Egyptian forensic sample, whereas Kamaşak and Aycan (2019) reported an incidence of 8.77% complete metopism in a Turkish series; both populations generally present higher prevalence figures than those noted here, consistent with the historical tendency for populations adjacent to Europe to have higher prevalence figures. One of the largest radiologically-derived datasets of metopic suture prevalence exists in Australia (1,034 three-dimensional (3D) CT scans) which revealed a prevalence of 11.1% (6.3% partial and 4.8% complete), with no sex differences in prevalence (Chaisrisawadisuk et al., 2021). In comparison, African samples have generally indicated lower percentages of complete metopism: Edibamode et al. 2023 found 1.04% in adult Nigerian dry skulls, which was in line with previous research in Nigeria, while Grine 2024 found that, although the rate of partial metopic remnant was higher, ranging up to 38%, in a sample of Black South African crania, complete metopic remnant was less common.

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Within the Indian subcontinent, the reported percentages vary from place to place and from sample to sample; e.g., Gupta et al. (2022) reported 4.52% in Uttar Pradesh, Vashist et al. (2019) reported 6.04% in a North Indian sample, and Andrade et al. (2019) reported approximately 3.3% in a South Indian population, and Tale et al. (2021) reported 4.0% in a cross sectional cadaveric study, which suggests there is significant intra-national variation, presumably due to both true biological variation and the different methodologies used. A detailed narrative review of the published literature by Knapp and George (2023) similarly found there to be many different figures cited from study to study, which is a combination of population, sample type, and criteria for scoring.

2.2 Morphological Variations and Classification

In the literature of morphology, there are three to four descriptive categories of metopic persistence (Table 2). In complete metopism, there is a continuous suture from nasion to bregma and the frontal bone is divided into two equal halves throughout life. In incomplete or partial metopism, which is found more commonly in most populations, a portion of the suture remains, otherwise the suture line is obliterated, most often near the glabella or along the mid-frontal segment. There is a milder variant, known as the metopic ridge or eminence, which is localised thickening of the bones along the former metopic suture that does not involve a true joint and is at the benign end of a spectrum of morphology that as its extreme end is continuous with metopic craniosynostosis and trigonocephaly.

A number of studies have also reported metopism to co-occur with a number of other cranial non-metric features. However, Batista Sandre et al (2017) studied dry skulls that had been radiographically examined and found that although most of these skulls had normally developed frontal sinuses, some cases were found in which the frontal sinuses were aplastic, hypoplastic, or hyperplastic, indicating that the development of the frontal sinuses had a variable but not an obligatory relationship with the metopic suture. Likewise, occurrence of metopism together with Wormian (sutural) bones, cleft lip and/or palate and other minor craniofacial anomalies has been described, but such combination is not consistent between studies and probably represents coincidental co-variation of craniofacial developmental fields and not a fixed syndromic pattern.

2.3 Clinical and Forensic Implications

The most frequently cited clinical concern regarding metopism is its potential to be mistaken for a linear frontal bone fracture on plain radiographs or computed tomography, particularly in emergency and trauma settings where a midline frontal lucent line may be misread as a traumatic injury. Vinchon (2019), reviewing the natural history of the metopic suture, emphasised that recognition of its typical midline course, corticated margins, and bilateral symmetry helps distinguish it from an acute fracture. Zdilla et al. (2018) similarly noted that most imaging in which

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metopism is identified is performed for closed head injury, underscoring the practical frequency with which radiologists and emergency physicians encounter this variant.

In forensic anthropology, metopism has long been used cautiously as a non-metric trait for ancestry estimation, although Knapp and George (2023) caution that its substantial population overlap limits its standalone diagnostic value and that it should be interpreted only alongside other cranial and post-cranial indicators. Because the presence of a persistent suture can alter linear and angular measurements of the frontal bone, several authors have raised concerns that metopism may confound frontal-bone-based methods of sex estimation, necessitating careful documentation of suture status before such measurements are applied in medico-legal casework. In neurosurgery and craniofacial surgery, awareness of metopism is important during frontal craniotomies and fronto-orbital advancement procedures, both to avoid misinterpreting the suture line intraoperatively and to correctly differentiate benign persistence from pathological metopic craniosynostosis, a condition that, unlike metopism, involves premature fusion, trigonocephaly, hypotelorism, and often requires surgical correction assessed via the interfrontal or frontal angle on CT imaging.

2.4 Association with Frontal Sinus and Other Cranial Variants

A cluster of studies has specifically investigated whether metopism influences frontal sinus development, given the anatomical proximity of the suture to the sinus outflow tract. Batista Sandre et al. (2017) found frontal sinus agenesis in only 6.25% of metopic skulls, alongside aplasia and hyperplasia in a further minority, concluding that agenesis is uncommon even in the presence of metopism. Butaric et al. (2020), using computed tomography to revisit global patterns of frontal sinus aplasia, similarly found no straightforward or universal relationship between suture persistence and sinus absence. More recently, Grine (2024) reported that, in a sample of Black South African crania, frontal sinus volume was slightly reduced in individuals with complete metopism but significantly larger in those with partial metopism, directly contradicting a simple hypoplasia hypothesis and suggesting that the relationship between metopism and sinus development is more nuanced than previously assumed, and likely population-specific. From a broader evolutionary-developmental perspective, White et al. (2021) frame such suture-related variation within the wider biology of cranial sutures as active growth centres, whose differential patency and closure timing shape not only the frontal bone but overall cranial morphology, providing a conceptual bridge between the developmental genetics of suture biology and the population-level morphological findings summarised above.

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3. Research Methodology

This review adhered to a systematic, narrative literature identification, screening, and synthesis approach that is appropriate for a narrative-systematic review of anatomical and clinical evidence.

Search strategy: Electronic search was conducted on PubMed/MEDLINE, ResearchGate, Google Scholar, and specialty anatomical, forensic-medicine, and craniofacial-surgery journals using various combinations of the terms "metopism", "persistent metopic suture", "median frontal suture", "metopic suture prevalence", "frontal bone suture", and "craniosynostosis" over the specified time frame (2015–2024).

Selection criteria: Studies that included original prevalence data, morphology and descriptions of the metopic suture and clinical or forensic associations of the metopic suture in adult human crania, cadaveric material and radiographic (CT) data sets, and were published in English within the last 10 years (2015–2024) were included. To support the appropriate context for pooled findings, narrative and systematic reviews of primary data within the window were included. Studies that were case reports without prevalence data, and purely animal or non-human comparative studies, or that were not peer reviewed were excluded (Table 4).

Data extraction and synthesis: Data on population/region, sample type/size, prevalence of complete and incomplete metopism, sex distribution (if reported) and any recorded clinical, radiological and forensic associations were extracted for each study included. Due to significant heterogeneity in sample type (dry skull collections, cadaveric/autopsy series and CT-based radiological cohorts) and diagnostic criteria used to classify complete vs incomplete metopism, no formal meta-analytic pooling of prevalence estimates was performed, but instead findings were tabulated for comparison and synthesised narratively, as previous methodological reviews of this literature have also pointed out the need for standardised reporting protocols before quantitative pooling can be considered reliable.

Quality considerations: Qualitative assessment of risk of bias was made with regard to single observer assessment (no inter-observer reliability testing), potential for selection bias in curated skeletal collections, and representativeness of the sample. These considerations are not captured in a numerical bias score throughout the review, but by the interpretation attached to the prevalence estimates.

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Tables

Table 1. Reported prevalence of metopism across selected populations (2015–2024 literature)

Region / Population	Sample Size	Prevalence of Metopism (%)	Source
United States	505 crania	2.57 (overall)	Zdilla et al. (2018)
Thailand	349 skulls	1.3 (complete)	Pakdeewong & Tohno (2019)
Thailand (North-East)	200 skulls	not specified (Table 4 ref.)	Khamanarong et al. (2015)
Nepal	bone collection	1.65	Maskey et al. (2020)
South Korea	bone collection	2.88	Maskey et al. (2020)
Egypt	skull sample	8.2	Zanaty (2017)

Table 1 presents the reported prevalence of metopism across selected populations based on studies published between 2015 and 2024. The findings demonstrate considerable geographical variation in the occurrence of persistent metopic sutures. Among the populations listed, Egypt reported the highest prevalence of metopism at 8.2% (Zanaty, 2017), suggesting a relatively greater frequency of complete metopic suture persistence in this population. In contrast, Thailand exhibited one of the lowest reported prevalences, with 1.3% complete metopism among 349 examined skulls (Pakdeewong & Tohno, 2019). The United States showed an intermediate prevalence of 2.57% based on the examination of 505 crania (Zdilla et al., 2018), while Nepal and South Korea reported prevalences of 1.65% and 2.88%, respectively (Maskey et al., 2020). Although the study from North-East Thailand (Khamanarong et al., 2015) investigated 200 skulls, the exact prevalence value was not specified in the referenced table. Overall, these variations may be attributed to differences in genetic background, ethnicity, environmental influences, developmental factors, sample size, and research methodology. The evidence indicates that metopism is a relatively uncommon anatomical variation worldwide, generally occurring in less than 3% of most populations, with notable exceptions such as the Egyptian population. Such epidemiological data are valuable for anatomists, radiologists, neurosurgeons, and forensic experts, as awareness of population-specific prevalence helps improve anatomical interpretation, differential diagnosis, and anthropological investigations.

Table 2. Morphological Types of Metopism and Their Reported Frequency

Morphological Type	Description	Reported Frequency Range
Complete metopism	Suture extends uninterrupted from nasion to bregma; frontal bone remains fully divided into two halves	1–9% in most population samples
Incomplete (partial) metopism	Persistence of only a segment of the suture, commonly near glabella, mid-frontal region, or bregma	6–38% depending on population and detection method
Metopic ridge / eminence	Palpable bony ridge along the suture line without a patent suture, often seen in trigonocephaly spectrum	Variable; overlaps with craniosynostosis assessment

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Vol. : 21,Issue 1,Jan-June 2026
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Morphological Type	Description	Reported Frequency Range
Metopism with Wormian/Inca bone	Co-occurrence of metopic patency with sutural (Wormian) ossicles	Reported in a minority of metopic skulls

Table 2 summarises the major morphological types of metopism reported in anatomical and anthropological studies, along with their approximate frequency ranges. Complete metopism refers to the uninterrupted persistence of the metopic suture from the nasion to the bregma, resulting in the frontal bone remaining divided into two distinct halves throughout life. This form is relatively uncommon, with a reported prevalence ranging from 1% to 9% across different populations. Incomplete or partial metopism is characterised by the persistence of only a portion of the metopic suture, most frequently observed near the glabella, the middle frontal region, or the bregma. This variant is considerably more common, with reported frequencies ranging from 6% to 38%, depending on the population studied and the imaging or observational methods employed. Another recognised variant is the metopic ridge or metopic eminence, in which the suture itself has fused but leaves a palpable bony ridge along the midline of the frontal bone. This feature is clinically significant because it may resemble or overlap with manifestations of trigonocephaly and craniosynostosis, requiring careful differential diagnosis. A less common presentation involves metopism associated with Wormian or Inca bones, where accessory sutural ossicles occur together with a persistent metopic suture. Although infrequently reported, this combination is of particular interest in craniofacial anatomy, forensic anthropology, and developmental studies, highlighting the diversity of metopic suture morphology and its clinical relevance.

Table 3. Clinical and forensic implications of metopism by discipline

Clinical Domain	Relevance of Metopism	Key References
Neuroradiology	May mimic a linear frontal bone fracture on CT/plain radiographs, risking misdiagnosis in trauma settings	Vinchon (2019); Zdilla et al. (2018)
Neurosurgery	Alters frontal bone symmetry and midline landmarks relevant to frontal craniotomy and fronto-orbital approaches	Chaisrisawadisuk et al. (2021)
Forensic anthropology	Non-metric trait used cautiously in ancestry and identification; may affect sex estimation from frontal morphometrics	Knapp & George (2023); Andrade et al. (2019)
Otorhinolaryngology / sinus surgery	Associated with variable frontal sinus pneumatization, including aplasia, hypoplasia, or hyperplasia	Batista Sandre et al. (2017); Butaric et al. (2020); Grine (2024)
Craniofacial / paediatric surgery	Must be distinguished from metopic craniosynostosis (trigonocephaly), a pathological condition requiring surgical correction	Vinchon (2019)
Developmental biology	Reflects variable timing of intramembranous ossification and suture-specific signalling	White et al. (2021)

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Vol. : 21,Issue 1,Jan-June 2026
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Table 3 summarises the clinical, surgical, forensic, and developmental significance of metopism across various disciplines. In neuroradiology, a persistent metopic suture may closely resemble a linear frontal bone fracture on computed tomography (CT) scans or plain radiographs, particularly in patients with head trauma. Accurate recognition of this normal anatomical variant is therefore essential to avoid unnecessary investigations or inappropriate treatment. In neurosurgery, metopism can alter frontal bone symmetry and modify important midline anatomical landmarks, which must be considered during frontal craniotomy and fronto-orbital surgical procedures to ensure precise surgical planning. Within forensic anthropology, metopism is regarded as a valuable non-metric cranial trait that may assist in ancestry assessment and human identification, although it should be interpreted cautiously because of its variable prevalence among populations and limited reliability for sex estimation. In otorhinolaryngology and sinus surgery, studies have demonstrated associations between metopism and variations in frontal sinus development, including aplasia, hypoplasia, and hyperplasia, which may influence surgical approaches to the frontal sinus. In craniofacial and paediatric surgery, differentiation between physiological metopism and pathological metopic craniosynostosis (trigonocephaly) is crucial because the latter requires timely surgical intervention. From a developmental biology perspective, metopism reflects variations in the timing of intramembranous ossification and molecular signalling pathways regulating cranial suture fusion, thereby providing valuable insights into craniofacial growth and skeletal development.

Table 4. Inclusion and exclusion criteria applied in the review methodology

Inclusion Criterion	Applied Filter	Exclusion Criterion	Applied Filter
Publication period	2015–2024	Publication period	Before 2015 or after 2024
Study design	Cross-sectional, radiological, cadaveric, autopsy, and review studies	Study design	Case reports without prevalence data, non-peer-reviewed sources
Population	Human adult crania or CT/radiographic datasets	Population	Non-human or purely animal-model studies
Outcome reported	Prevalence, morphology, or clinical/forensic association of metopism	Outcome reported	Studies not reporting metopism-specific findings
Language	English-language full text or abstract available	Language	Non-English without translation available

Table 4 summarizes the inclusion and exclusion criteria used to select studies for inclusion in the present review to ensure a systematic, transparent, and methodologically rigorous approach in selecting studies. The search included only the papers published in the last five years to ensure that the evidence obtained was recent and relevant to the latest progress in anatomical, radiological and forensic research on metopism. Only cross-sectional, radiological, cadaveric, autopsy and review studies were included in the review as these study types are suitable for providing reliable information on prevalence, morphology and clinical significance of persistent metopic sutures. The case reports (which lacked prevalence data) and non-peer-reviewed publications were

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excluded due to lower levels of scientific evidence and limited generalisability. Only human adult crania and radiological data (CT and conventional radiographic studies) were considered, as animal studies were not as a result of differences with regard to cranial development and anatomy. Only those studies that provided data directly related to prevalence of metopism or morphological features and their clinical and/or forensic implications were considered eligible for inclusion in this review. Studies where only cranial anatomy was discussed, but not metopism-specific outcomes, were excluded. Also, only publications available in English that included a full text or abstract were included, as reliable translations of non-English articles were not available to help with accurate data extraction and interpretation. These pre-defined criteria increased the consistency, reliability and scientific validity of the literature selection process, reduced selection bias and ensured that the review synthesized high quality and relevant literature.

4. Conclusion

Metopism is a benign but highly variable anatomical trait arising from incomplete fusion of the metopic suture, with reported prevalence ranging from under one percent to well over one-third of examined samples depending on population, suture-completeness criteria, and method of ascertainment. The available evidence consistently identifies European and East Asian ancestries as having comparatively higher rates of complete metopism, while several African and South-East Asian samples show lower rates of the complete form but sometimes higher rates of partial or incomplete persistence, indicating that global patterns cannot be reduced to a single prevalence figure. Morphologically, metopism spans a spectrum from complete suture patency to subtle ridging, and its clinical significance lies chiefly in the potential for misdiagnosis as fracture, its relevance to craniometric forensic methods, its occasional association with variable frontal sinus development, and the imperative to distinguish it from pathological metopic craniosynostosis. Collectively, the reviewed literature supports the view that awareness of metopism should be considered standard anatomical knowledge across radiology, neurosurgery, forensic medicine, and craniofacial care.

5. Future Work

Future research should prioritise multi-centre, radiologically based prevalence studies using standardised diagnostic criteria for complete versus incomplete metopism, enabling more reliable cross-population comparison than is currently possible from heterogeneous dry-skull and autopsy series. Larger studies incorporating both three-dimensional CT morphometry and genetic or molecular analysis of suture-regulatory pathways (e.g., TWIST1, FGFR signalling) could clarify why suture persistence varies so markedly between individuals and populations. Further work is also needed to resolve the inconsistent relationship between metopism and frontal sinus development, ideally through longitudinal or large-sample cross-sectional radiological cohorts

rather than small skeletal series. Finally, the development of consensus reporting guidelines, analogous to PRISMA for systematic reviews, would substantially improve the comparability of future anatomical and forensic studies of this common but under-standardised cranial variant.

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An Official Publication of the Informing Science Institute

Vol. : 21,Issue 1,Jan-June 2026
ISSN: (E) 1555-1237

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