BJMS
Borneo Journal of Medical Sciences

REVIEW ARTICLE

# Frontal Sinus Anatomy for Human Identification in Forensic Anthropology: A Review

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Received: 30 September 2025

Accepted: 15 December 2025

Published: 13 July 2026

DOI: https://doi.org/10.51200/bjms.v20iSuppl.8004

## ABSTRACT

The frontal sinus has become a valuable tool in forensic anthropology, offering a unique and resilient marker for human identification. Located within the frontal bone, these paired cavities possess distinct morphological characteristics that remain stable throughout life. Its intracranial location contributes to the preservation of the frontal sinus, making it particularly useful in cases where other skeletal structures are compromised. Despite its documented forensic utility, research on the frontal sinus remains concentrated on specific populations. Since forensic anthropology is inherently population-specific, this variation highlights the importance of developing reference data tailored to underrepresented populations. This review synthesizes current knowledge on the anatomical basis, forensic significance, and applications of the frontal sinus, while emphasizing future directions and the potential of emerging technologies in advancing its role in human identification.

**Keywords:** *Anatomy, Human identification, Forensic anthropology, Frontal sinus*



## INTRODUCTION

The frontal sinus has emerged as a valuable tool for human identification in forensic anthropology (Choi et al., 2018; Zheng et al., 2023). These paired pneumatic cavities, located within the frontal bone, possess anatomical characteristics that are well preserved and remain distinct across individuals. Hence, making them particularly useful when other primary skeletal structures, such as the skull

or pelvis, are unavailable or compromised (Zaidun et al., 2024; Zulkiflee et al., 2022). Anatomically, the frontal sinus begins to develop in fetal life and continues to expand until early adulthood, after which its morphology remains relatively stable throughout life (Pereira et al., 2021). The morphology of the frontal sinus varies considerably among individuals, with no two sinuses being identical, even in monozygotic twins (Shamlou & Talman, 2022). The frontal sinus is also considered a resilient structure (Zulkiflee et al., 2024). Its intracranial location contributes to its preservation, even in mass disaster incidents. These characteristics underpin its application in forensic anthropology, where reliable personal identification often depends on features that are both unique and durable.

The forensic utility of the frontal sinus has been documented for decades, however, research has remained concentrated on specific populations, such as those in India and South Korea (Kim et al., 2013; Lee & Park, 2022; Nethan et al., 2018; Sheikh et al., 2018). Since forensic anthropology is inherently population-specific, inter-population variation in sinus morphology highlights the importance of establishing population-specific reference data (Zulkiflee et al., 2023). This review provides an overview of the role of the frontal sinus in human identification, tracing its anatomical basis, forensic significance, and practical applications, while also considering future directions.

## GROSS ANATOMY OF FRONTAL SINUS

Paranasal sinuses are air-filled spaces within the bones of the human skull (Čechová et al., 2019). They consist of the sphenoid, ethmoid, frontal, and maxillary sinuses. Among these sinuses, the frontal sinus is of particular interest in the forensic field due to its resilience and the unique characteristic for each individual (Garhia et al., 2019). The frontal sinus is a pneumatic cavity that is located within the frontal bone of the skull (Crosta, 2016). The general shape of the frontal sinus is triangular, with the base being inferior and its apex superior. The frontal sinus often appears as two irregular cavities extending upward and laterally into the squama frontalis (Čechová et al., 2019). Because the right and left lobes develop independently and are separated by a thin bony septum, the left and right frontal sinus might show asymmetry in their dimensions.

There are three boundaries that surround the frontal sinus, including the anterior (forehead), posterior (inner table of frontal bone), and inferior (orbital plate), forming three bony walls of the frontal sinus for a better preservation state. The anterior wall of the frontal sinus forms part of the brow, glabella, and forehead, and it is generally the thickest of the borders. The thickness can vary considerably, ranging between 2 and 12 millimetres (Arnold & Tatum, 2019). The posterior aspect of the frontal sinus wall is in contact with the frontal lobes of the brain. The posterior wall is formed by the inner table of the vertical part of the frontal bone and is therefore slightly convex forward (Christensen, 2003; Stefano Fusetti). It is usually much thinner, around 0.1-4 millimetres (Arnold & Tatum, 2019). Meanwhile, the inferior wall of the frontal sinus consists of the orbital plate, which is the superior and internal roof of the orbits, and this wall is the thinnest of the three frontal sinus walls (Christensen, 2003; Stefano Fusetti).

## DEVELOPMENT OF THE FRONTAL SINUS

The frontal sinus at birth is very small and indistinguishable from the ethmoid air cells. Initial formation begins during the third to fourth month of fetal life as outpouchings from the lateral nasal wall. In infancy, the development of the frontal sinus complex is still ethmoidal in the first year of birth and reaches pneumatisation by the second year. By the second or third year, the frontal sinuses become more prominent, with their apex

often extending above the nasion (Kanimozhi, 2018). The frontal sinus may not be detected radiographically until further pneumatization, which may take up to five or eight years of life (Crosta, 2016; Ertugrul Tatlisumak, 2017). The left and right lobes of the frontal sinus develop independently (Čechová et al., 2019). The major development of the frontal sinus occurs during puberty, with a slight height increment for several years later (Clemente, 2016; Gadekar et al., 2019). The spurt in development of the frontal sinus is completed earlier in girls (13 years old) than in boys (15 years old), and the growth is then complete by the age of 20 years (Christensen, 2003; Scheuer & Black, 2000). By age 21, almost all individuals display complete stabilization of all traits, suggesting minimal change in adult morphology.

## ANATOMICAL VARIATIONS OF THE FRONTAL SINUS

The frontal sinus exhibits complex and diverse anatomical variations among individuals, forming the foundation of its forensic utility. One of the most notable variations is in the pattern of the frontal sinus (N. D. I. Zulkiflee et al., 2022). While the medial and orbital regions tend to be relatively consistent, the upper and lateral portions often show irregular and unpredictable patterns, a variation that some studies attribute to random development (Christensen, 2003). The degree of development of the frontal sinus also varies widely. Some individuals exhibit a complete absence of the sinus (aplasia), while others present with highly complex or enlarged structures extending into adjacent cranial bones (N. D. I. Zulkiflee et al., 2022). Bilateral absence, where both sinuses are missing, is relatively rare but has been documented in certain populations such as Malaysia and India (Verma et al., 2015; N. D. I. Zulkiflee et al., 2022). Unilateral absence, where one sinus is missing, is more frequently observed in certain populations (Gadekar et al., 2019; Verma et al., 2015). Asymmetry is another common feature, as the left and right sinuses develop independently. In many cases, one side is dominant, leading to differences in size or shape between the two lobes (N. D. I. Zulkiflee et al., 2022). Additionally, lobulation within the frontal sinus also varies, with some individuals presenting a simple, unlobulated cavity, while others display multiple lobes created by partial septa. Understanding these variations is essential for the application of the frontal sinus in forensic identification. Each of these anatomical features, such as presence or absence, asymmetry, and the number of lobes, contributes to the unique anatomical fingerprint of an individual's frontal sinuses.

## FRONTAL SINUS IN FORENSIC INVESTIGATIONS

Establishing an accurate identity of an unknown individual is crucial in forensic anthropology. Parts of the bony skeleton, such as the pelvis, skull, and long bones, have been used to establish a biological profile with an average classification accuracy of 88% (Usha Jambunath, 2016). However, estimating biological profiles can be challenging as those skeletal remains are often less durable (Daniel García-Martínez et al., 2017). Therefore, there is a need to estimate the biological profile from as many skeletal remains as possible, including the frontal sinus, to reinforce the multimodal approach.

The frontal sinus exhibits significant variability and uniqueness for each individual, even in identical twins (Christensen, 2003). The resilience of the frontal sinus makes it useful for profiling purposes. The frontal sinus is highly resistant to trauma and has a high probability of staying intact even if retrieved from any event of disaster or mass fatality (Patil et al., 2012). As it is an internal body structure, the arched feature of its anterior wall protects the frontal sinus from decomposition and damage (Garhia et al., 2019). In addition, the stability of the frontal sinus is further enhanced as it is located posterior to the thick outer wall of the frontal bone in the glabellar region (Javaid & Usmani, 2020). It has been found that a force of

800-1600 foot-pounds is required to fracture the anterior walls of the frontal sinus, proving its resilience (Patil et al., 2012).

Numerous studies have shown that the frontal sinus has the potential to be used for identifying the biological profile of human skeletal remains. Recently, Čechová et al. (2019) investigated sexual dimorphism among the Czech population using the frontal sinus and found a 64.07% success rate. A similar comparison was found in a study conducted on Iranian individuals, with 61.3% of correct sex determination (Akhlaghi et al., 2016). Both studies concluded that the frontal sinus appeared larger and had more scallops in males than in females. Another recent study from Boston using the frontal sinus by Shamlou et al. in 2022 demonstrated a significant dimension difference between males and females, confirming sex as a factor that had an influence on the dimensional differences. Shamlou et al. found that males tended to have a greater frontal sinus depth compared to females (Shamlou & Talman, 2022). Similarly, a frontal sinus study among South Koreans demonstrated a significantly larger frontal sinus volume in males than in females (Park et al., 2022). Another study conducted among the Colombian population demonstrated sexual dimorphism in the frontal sinus with 84.31% classification accuracy (Perlaza, 2014). In the Malaysian population, Zulkiflee et al. (2022) also observed significant sex-related differences in frontal sinus shape, achieving 80.6% accuracy in sex classification.

A study on age determination among the Korean population showed that the frontal sinus volume and dimension degenerate with age (Park et al., 2022). The degeneration was attributed to craniofacial bony expansion with ageing, resulting in a smaller frontal sinus area. Meanwhile, another preceding study used the frontal sinus to estimate population affinity among the New Mexican population, showing that White people possessed left frontal sinus dominance and a smaller frontal sinus dimension than Black people (Vance, 2021). Therefore, in cases where the identity of an individual is suspected, and primary skeletal remains yield an inconclusive result, another identification method using the human frontal sinus would be beneficial to use in conjunction with other available skeletons.

## CONCLUSION

The frontal sinus anatomical structure represents a valuable and reliable tool for human identification in forensic anthropology contexts, particularly when other skeletal structures are unavailable. Its structural stability provides forensic anthropologists with an important basis for identification. Although numerous studies have examined the application of the frontal sinus across different populations, research remains concentrated on certain groups. In Malaysia, for instance, only a single parameter of frontal sinus shape has been studied among the Malaysian population, highlighting the need for further research to strengthen and complement existing databases. Future studies should not only expand within underrepresented populations but also explore multiple parameters of the frontal sinus, leveraging current advancements in technology and artificial intelligence to enhance accuracy and applicability.

## CONFLICT OF INTEREST

The authors declare that they have no competing interests.

## ACKNOWLEDGEMENT

Not applicable.

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