Review Article

Frontal Sinus as a Tool in Identification

Anuja Prem Kumar, Nagabhushana Doggalli, Karthikeya Patil[1]

From the Departments of Forensic Odontology and [1]Oral Medicine and Radiology, JSS Dental College and Hospital, JSS AHER, Mysuru, Karnataka, India

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Abstract

"Dead men do tell tales" – William R Maples
Identification of the dead is an integral part of obtaining justice, where crime is concerned and to provide closure to bereaving families. Various identification techniques have been developed to assist in identification of remains, especially using radiographs. This review aims at delving into the use of frontal sinus as an aid in the identification process, the pros and cons, and the future of this parameter in the field of identification.

Key Words: *Frontal sinus, personal identification, radiographs, sex determination*

Introduction

Identification of remains by comparison of ante and postmortem (AM, PM) radiographs both anatomically and radiologically, is one of the most commonly employed methods.[1] Schuller was the pioneer in establishing the importance of utilizing frontal sinus as a means of identification.[2] The anatomical position of the frontal sinus makes it easier to radiographically study the region both AM and PM. It has been proved time and again through various studies that the frontal sinus is a good aid in the process of identification. Identification is important in mass disasters, road traffic accidents, criminal investigations as well as accidents involving fire. The most common identification techniques are fingerprinting, dental comparison, and DNA profiling. Although when human soft tissue becomes putrid or burnt and DNA is severely damaged, then fingerprints or DNA analysis cannot be performed.[3] It is in these circumstances that anthropological methods are brought to the foray, of which comparative radiography is an important tool. Dentomaxillofacial radiography has become a common practice in dental clinics and hospitals and hence can be utilized in identification.[4] The skeleton survives both natural and unnatural abuse or violence and is almost always available for identification which is plausible due to the dimorphic characteristics of the human skeleton. The skull is the second-best region for identification after the pelvis. It is sexually dimorphic and aids in identification with an accuracy of up to 92%.[3] It has various structures that aid in identification such as the dentition, cranial suture patterns, vascular groove patterns, sella turcica area of sphenoid, frontal sinuses, mastoid pneumatic air cells, and sinuses.[2,5,6] It is said that the frontal sinus is unique to every individual, even between monozygotic twins.[4] Hence, it comes as a natural choice for identification where the skull is concerned.

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History

The application of radiology in forensic science was first introduced in 1896, 1 year following the discovery of X-rays by Roentgen who used them to demonstrate bullets lodged within the brain. Schuller was the first to report the use of radiographs for the purpose of identification in 1921.[7] Juan Rogelio *et al*. in their study state that identification by comparing frontal sinus radiographs was first suggested by Schuller in 1943.[8] In 1925, Culbert and Law performed the first case of identification using the frontal sinus. It was published in 1927.[6]

Frontal Sinus – Anatomy and Development

Frontal sinus is an air-filled cavity located within the frontal bone that consists of paired, irregularly shaped, loculated cavities, which communicate with the nasal cavity through the infundibulum.[9] Anatomically, it can be defined as pneumatic cavities covered by the mucosa, located between the internal and external cortical bones of the frontal bone. It consists of two chambers that are asymmetrical due to independent development of each sinus. It is separated by a bony septum.[9] It forms embryonically from an ethmoidal cell and is not visible at birth.[8] It begins to develop during the 4th or 5th week of intrauterine life and continues to grow after birth slowly until puberty, then rapidly until completing their growth,[6] by anterosuperior pneumatization of the frontal recesses into the bone. It reaches maximum size at 20 years of age.[7]

Why Frontal Sinus?

The anatomic location of the frontal sinus ensures that the region remains intact even when subjected to abuse or trauma.

Address for correspondence:
Dr. Nagabhushana Doggalli, E-mail: drbhushan@rediffmail.com

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The thick bone of the anterior wall of the frontal sinus and its curved convexity forms a barrier to resist fracture thereby providing great resiliency.[3,7] It has been found that a force of 800–1600-foot pounds (high-impact accidents, GSW (gunshot wounds) is required to fracture the anterior wall.[3,7] That is twice as much required to fracture the parasymphyseal area of the mandible and 50% more than that required to fracture the malar eminence of zygoma.[7] The frontal sinus presents a high degree of unicity, even among mono and dizygotic twins.[3-5,9] It has a relatively stable structure throughout adult life.[3,4,6-8] It has become common practice to take paranasal sinus radiographs for diagnostic purposes and hence can be easily available for comparative radiography.[3]

Radiographs

Dental identification by radiographs, forms the main crux of forensic odontology. Radiographs having become a routine procedure in dental clinics and hospitals, is one of the quickest means to obtain health records of the victim, suspect, or deceased, as the case may be. Dental identification by radiographs is broadly of two types: comparative and reconstructive. Reports state that 72% of positive identification in modern forensics has been obtained by comparison of AM and PM radiographs.[7] Hence, it is safe to say that comparative radiography is the most commonly employed method used in forensic identification. Waters projection of the skull is one of the most commonly used radiographs to study the sinuses. It has been noted that posteroanterior radiograph of skull by Caldwell technique helps better view frontal sinus than Waters projection, where slight foreshortening of the image is seen.[7] Lateral cephalograms and cone-beam computed tomography (CBCT) have also been used to study the frontal sinus.[2,9]

Identification Using Frontal Sinus

Frontal sinus presents with anatomic variations that are unique to every individual.[3-5] Several studies have been published to prove the same.

Chaudhary and Singh in their study obtained Water's radiograph of fifty healthy individuals aged 20–40 years and used Ribeiro Fde's measurement criteria to study the variations in frontal sinus. The frontal sinuses, right and left were measured with the help of:

- Reference baseline – 10 cm line standardized at superior border of the orbit
- Greatest height on each side – maximum distance between base and upper lines of the frontal sinus
- Greatest width on each side – maximum distance between medial and lateral lines of right and left sides of the frontal sinus.

Mean and standard deviation was calculated and it was concluded that the frontal sinus was bigger and wider in males than females and was unique to every individual, thus proving that the frontal sinus can be used as an aide in personal identification. Keeping in mind that bone resorption could occur with advancing age, the sample was restricted to 40 years of age. The advantage of this technique is that it is simple and does not require expertise.[3]

Various scholars have proposed classification of frontal sinus to help form a standardized format that can be followed when required. Schuller proposed a classification from radiographs taken in the forehead–nose position. It includes seven characteristics – septum and its deviation, upper border (scallop, arcades), partial septum, ethmoidal and supraorbital extensions, height from planum, and total breadth and position of sinus midline. Schuller, however, did not evaluate the accuracy of the method. In 1987, Yoshino *et al*. classified frontal sinus into seven discrete variables – area size (right and left), bilateral asymmetry, superiority of area size, outline of superior borders, partial septa, supraorbital cells, and orbital areas. Each characteristic was assigned a class number and the frontal sinus patterns were formulated into a code number, by arranging the class numbers as serial numbers.[4] Taniguchi *et al*.'s criteria to measure asymmetry of frontal sinus and classification of nasal septum has been used by several researchers to analyze frontal sinus and nasal septal patterns. According to this criterion, the greatest horizontal dimension from midline septum on either side of the frontal sinus was measured. The difference in the right and left side dimension was divided by the greatest dimension and multiplied by 100. If the percentage obtained was >20%, it was classified as asymmetrical. Classification of nasal septum according to the direction of deviation of the septum as – straight, simple deviation to right or left side, sigmoid type, reverse sigmoid type, and others.[5] It has been found that radiographs of the same person, taken after a duration of 6–8 months, as well as with a change in angulation (3°–5°), the frontal sinus could still be positively identified. It is important to keep in mind that one cannot always replicate an AM radiograph with the same angulation, in a PM radiograph. It has been observed that even after multiple fractures to the skull, the frontal sinus remained unchanged.[4] Posteroanterior cephalograms are useful in analyzing frontal sinus and nasal septal patterns, both of which have been used in identifying two forensic autopsy cases. They have showed no AM and PM changes and thus prove to be reliable indicators for identification.[5] Human remains have been identified using frontal sinus morphology as well as by comparison of frontal sinus patterns AM and PM.[7]

There are various parameters that are used in the analysis of frontal sinus. The most commonly used include – maximum height, maximum width, frontal sinus index (FSI) which is a ratio of the maximum height and width, Ribeiro Fde's measurement criteria, bilateral and unilateral aplasia, frontal sinus area, upper border (number of scallops, arcade), partial septa, supraorbital cells, and number of sinus cavities.[1,3-5,7,9] Schuller's and Yoshino *et al*.'s classifications include a number of other parameters thus, increasing the number of parameters extensively. Research has proved that combined probabilities of metric traits and discrete traits of frontal sinus are filled with potential errors and are not useful in identification. Superimposing two frontal sinus patterns over each other gives greater accuracy in identification than the use of metric variables. Superimposition is 100% reliable and accurate and can be performed with ease, even by observers having minimal experience with X-rays. It is important to note that unlike in metric measurements, subtle changes in angulation

and exposure of X-rays does not affect the outcome, thus making superimposition pattern matching, the simplest, most effective method with lowest levels of error for identification using frontal sinus.[6] In order to create a standardized method for comparing frontal sinus patterns, Christensen formulated the elliptical Fourier analysis (EFA). This method yielded an EFA-generated outline of each frontal sinus which was represented as a sum of trigonometric functions. The study revealed that there is a significant difference between the outlines of individual frontal sinuses.[1,6] However, Christensen herself states that the use of EFA to evaluate the outlines of frontal sinuses is complicated and time-consuming.[6]

Juan Rogelio *et al*. in their study attempted to improve to frontal sinus identification rates by formulating a segmentation algorithm, thereby minimizing human intervention in the process. Ninety anteroposterior radiographs of 29 individuals aged >20 years was taken. Here, frontal sinus recognition was divided into three steps – segmentation, features extraction and matching, and results evaluation. The first step segmentation extracts inner and outer border points of frontal sinus. It can be done manually using image editing software (Serif Photoplus) or semi-automatically using differential image foresting transform (DIFT) algorithm proposed by Falcao and Bergo. The second step extract features that can describe and uniquely identify a frontal sinus shape. Shape context, a descriptor of shapes proposed by Belongie *et al*. is used. In the third step, the similarity between two frontal sinuses is computed using the descriptors of shape context for every pixel belonging to each shape. Frontal sinus shapes of all individuals were compared and scores of genuine and imposter frontal sinus matchings were obtained. A receiver operating characteristic curve was generated and equal error rate obtained for frontal sinus segmentation. It was concluded that DIFT and shape context provided good results in the identification using frontal sinus. This method, however, is complicated and requires resources (software) and a sound knowledge of the algorithm used to better comprehend its working.

Frontal Sinus-Sex Determination

FSI is the parameter that is most commonly used for sex determination. Measurements of frontal sinus in lateral cephalometry are incorrect due to magnification and hence ratios were considered more reliable than single measurements. Thus, FSI, that is, the ratio of maximum height to maximum width of frontal sinus came into existence.[2] Mid-sagittal CBCT scans of the frontal sinus have also been used for sex determination. This study, however, states that FSI is not a reliable tool for sex determination as 92% females were correctly identified but only half of males were correctly identified. Furthermore, the addition of variables such as age, height, and width did not increase the ability to predict the gender.[9] To overcome variations in radiographic techniques such as angle, distance, and orientation of skull, lateral cephalograms have been used. In developing countries like India, CT is expensive and is not available to the common man and hence is not used extensively in forensic radiology. A study with sinus index had shown have a significantly higher ratio in females than males and correct sex was identified in 67.59% of the cases. Discriminant function analysis was performed and a discriminant equation obtained where a D value greater than zero indicated female while that lesser than zero indicated male.[2] Thus, this study shows that the frontal sinus can only be used as an adjunct in sex determination.

In a one of its kind study, Cameriere *et al*. tried to identify if frontal sinus can help identify individuals belonging to family groups by means of false-positive identification and if kinship can affect erroneous identifications. Anteroposterior radiographs of 99 individuals belonging to 20 families in the age group 15–74 years were taken. Cameriere used Yoshino *et al*.'s classification of frontal sinus, but he replaced frontal sinus size and bilateral asymmetry with two continuous variables SOR_1 (ratio of left frontal sinus area and left orbit area) and SOR_2 (ratio of right frontal area and right orbit area). This study revealed that frontal sinus cannot be used to identify kinship of individuals.[1]

Discussion

Despite a strong evidence in literature stating that the variations in frontal sinus are as unique as fingerprints, its role in identification is not practically popular. The reason being several contradicting statements in various studies. While Chaudhary *et al*. state that the development of the frontal sinus is completed by 18–20 years of age,[3] in Cameriere *et al*.'s study, it is observed that the same is completed by 15 years of age.[1] Nikam *et al*. state that development is completed before 20 years of age.[7] Most studies claim that after reaching a maximum size by 20 years of age, the frontal sinus remains stable throughout life. Several others state that with advancing age frontal sinus shows changes such as bone resorption along the walls thus making them appear larger[3,6] and gradual pneumatization from atrophic changes.[4] It is also subject to structural and developmental changes like hyperpneumatization in athletes.[2] Pathological changes may also be visible as seen in cases of acromegaly, sinusitis, or sclerosed mastoid where bony tissue may be formed.[4] Trauma and surgery can also modify frontal sinus.[6] Thus, frontal sinus as a means of identification should be used with caution. Presence of unilateral or bilateral aplasia, history of orthodontic treatment, trauma, endocrine disturbances, facial asymmetries, and developmental anomalies are commonly excluded from most studies. However, these abnormalities become documented deviations from normal anatomy and may help in individualization.[6] Although frontal sinus is radiographically visible by 5–6 years of age,[5] its use in developing skulls in limited since the dimensions of frontal sinus tend to stabilize after maturity[2] and continues to develop until it reaches a maximum size by 20 years of age. Frontal sinus pattern matching by comparison of AM and PM radiographs is one of the most common techniques for frontal sinus identification. However, AM radiographs may not be available in all cases. In a developing nation like India where dental hygiene has not yet reached every household and ignorance is still at large, it is highly unlikely that health records will be available for every individual. Furthermore, several parameters are used to analyze frontal sinus with no set standard and no error rates. A standardized technique with known error rates is what will

stand up in a court of law. Despite evidence suggesting that superimposition pattern matching is the most reliable, simple, and accurate method for identification using frontal sinus, it is puzzling to note that a vast majority of the studies revolve around metric measurements of the frontal sinus.

Thus, superimposition pattern matching is the technique deployed when frontal sinus is used in the process of identification. FSI is calculated to ascertain the sex of an individual albeit, not 100% accurate. Frontal sinus cannot be used to identify developing skulls. Identification by frontal sinus is not common practice, due to lack of a standard technique, error rates, and a numerical classification system. However, the idiosyncratic nature of frontal sinus akin to that of fingerprints, results in it being the method of choice when other identification techniques cannot be employed.

Conclusion

Frontal sinus is a useful aid in identification when AM dental records are absent, mandible is missing postmortem, in cases of mass disasters or when skull is available and other means of identification are bleak. In spite of several studies propagating the use of frontal sinus for identification, it is still not a popular choice due to the lack of a standardized technique. In a study conducted by Ana-Gabriela *et al*., the frontal sinus was measured along the internal contour in millimeters. The height of the sinus was measured through the bony septum and not the sinus cavity as seen in most studies. These can be standardized to avoid the varying ranges of measurements that several researchers resort to, resulting in a lack of protocol. For forensic odontology to flourish, the government should help educational institutions and health sectors (clinics) to set up databases of patients' health records. This, in turn, will help the forensic odontologist to access information for comparative analysis, which is the heart of identification.

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Conflicts of interest

There are no conflicts of interest.

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