Frontal sinus pattern analysis for human identification using non-contrast computed tomography images: A Sri Lankan experience

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Abstract
Objective: Morphometry of frontal sinuses has been studied extensively in many countries. However, these findings cannot be generalized due to genetic and environmental factors affecting the skeletal structure. The main aim of this study was to morphometrically analyze the frontal sinuses in patients who underwent non-contrast computed tomography (NCCT) skull imaging at Teaching Hospital Peradeniya and to assess its association with age and sex.

Methods: This retrospective study included 300 NCCT skull images obtained by a multi-slice computed tomography (MSCT) scanner at the Teaching Hospital Peradeniya. This age- and sex-matched sample was selected using consecutive sampling and consists of seven age groups (20–29, 30–39, 40–49, 50–59, 60–69, 70–79, and 80–89). Right and left frontal sinus values (length, height, width of each sinus, and total width) were measured using the RadiaAnt DICOM Viewer 2020.2.3 software, and age and sex were obtained from the CT images. The association among the variables was analyzed using the t-test and binary logistic regression model.

Results: In our study sample, 59% (n = 177) were male and the mean age was 57.94 years. The means of left side sinus values were larger than right sinus values, which was statistically significant. A statistically significant association was seen between frontal sinus parameters and sex; those of males were higher than that of females. No significant association between the sinus size and age was observed.

Conclusion: Morphometric analysis of frontal sinuses using NCCT images is useful for the sex differentiation of unknown bodies for medico-legal purposes. Furthermore, the mean sinus values specific to the current study population will also be helpful in ethnic differentiation.

Keywords
Computed tomography, forensic, frontal sinus, human identification, imaging

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Introduction
Person identification is an important aspect of forensic medicine, for which the use of various techniques has been discussed in the literature. Instances, such as the discovery of unidentified human skeletal remains, putrefied dead bodies where facial recognition is difficult, bodies with extensive injuries and burns causing disfigurement, etc., mandate special techniques for person identification. Furthermore, accurate identification will also assist in crime reconstruction and assist in missing person investigations. Therefore, the development of accurate, reliable, and objective tools and methods for person identification necessitates considerable attention.

Some proven methods employed by forensic scientists and legal authorities for person identification are fingerprinting, DNA analysis, and odontology.1–3 However, in instances where these methods cannot be used, an anthropometric assessment of frontal sinuses will be useful.4 Four reasons that validate the use of frontal sinuses for person identification

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have been discussed in the literature. First is the universally accepted individual variability, which was proven by Christensen using mathematical models. The second is structural stability maintained throughout the lifespan. The third is resilience with the ability to withstand significant trauma, burns, postmortem decomposition, etc. Lastly, it is one of the most imaged areas of the body for diagnostic purposes, thus increasing the availability of antemortem records that can be used for comparison.4

The frontal sinus is part of the paranasal sinuses located in the frontal bone. It is a paired, irregular-shaped, air-filled cavity, lined by mucosa. The left and right sinuses are frequently observed to be asymmetrical in size, mainly due to the irregular and asymmetrical placement of the septum separating the two sinuses.5 This is an important factor in determining the unique nature of the frontal sinuses, making them highly variable among individuals. This makes it extremely valuable to be used as a tool for person identification.5

Therefore, this study morphometrically analyzed the frontal sinuses, employing non-contrast computed tomography (NCCT) skull images of patients presenting to a tertiary care hospital in Sri Lanka, to identify the frontal sinus patterns specific to the study population that will be useful for person identification.

Materials and methods

This retrospective study was conducted using stored digital NCCT skull images taken by a multi-slice computed tomography scanner (Siemens SOMATOM Emotion 16, Germany) at the Teaching Hospital Peradeniya, Sri Lanka between June 2020 and September 2021. The slice number and slice thickness were 16 and 1 mm, respectively. All digital images of patients between 20 and 90 years of age were considered for the study. Criteria for the exclusion of images were as follows:

• absent and single sinus
• bony erosions due to chronic sinusitis
• craniofacial fractures and deformities
• poor quality due to motion artifacts
• rotation of more than 15°

Ethical clearance was exempted by the ethics review committee at the Faculty of Medicine, University of Peradeniya (protocol number: 2021/EC/41). Consent was not obtained as this requirement was waived by the local ethics committee.

Using data from available similar research in the literature,6 300 NCCT images were included in this retrospective study between June 2020 and September 2021. The study sample was categorized into seven main age categories: 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, and 80–89 years. Demographic data including age and sex were obtained from the CT images. The CT images were analyzed using the RadiaAnt DICOM Viewer 2020.2.3 software. Axial, coronal, and sagittal planes with a bone window of the CT images were used to obtain sinus measurements (Figure 1). Any visible pneumatization of the frontal bone divided into two cavities by a bony septum was considered the frontal sinus. The measurements obtained were as follows:

1. Right sinus height—maximum vertical distance between superior and inferior borders
2. Right sinus width—maximum horizontal distance between medial and lateral borders
3. Right sinus length—maximum horizontal distance between anterior and posterior borders
4. Left sinus height—maximum vertical distance between superior and inferior borders
5. Left sinus width—maximum horizontal distance between medial and lateral borders
6. Left sinus length—maximum horizontal distance between anterior and posterior borders
7. Total sinus width—maximum horizontal distance between the lateral borders of the two sinuses

All the measurements were obtained in millimeters, with a precision of 0.01 mm.

For each sinus measurement, two views were used and the mean value was taken.

• Axial and sagittal views for length measurements
• Coronal and sagittal views for height measurements
• Axial and coronal views for width measurements

All the measurements were obtained by a person with adequate technical experience, under the supervision and cross-checked by a board-certified Consultant Radiologist with more than 10 years of work experience.

Statistical analysis

The data were entered into an excel sheet and were analyzed using JASP version 0.14.1.0.7 Initially, descriptive statistical methods were used to describe the collected data. The mean length, height, and width measurements of the frontal sinuses were analyzed using analysis of variance (ANOVA) to assess its association with age.8 The association of the measurements with sex was analyzed using the t-tests.9 Furthermore, to find out the variables (sinus measurements) which were independently associated with the sex of the person, a binary logistic regression model was used.10

Results

The study sample of 300 was categorized into seven age groups (Table 1). It was further sub-categorized as male and female. The sample distribution in relation to age and sex is demonstrated in Table 1.
The mean age of the study population was 57.94 years. In the total study population, a male predominance was observed with 177 males and 123 females. The mean ages in the male and female groups were 57.29 and 58.87 years, respectively.

The mean measurements of the sinuses were obtained (from two views for each measurement) (Table 2). The left sinus measurements were observed to be larger than the right (Figure 2). This difference was statistically significant.

A statistically significant variation of all the sinus measurements with sex was observed (Table 3). All the mean sinus measurements were statistically higher than females which was statistically significant.

MRSL, mean right sinus length; MLSL, mean left sinus length; MRSH, mean right sinus height; MLSH, mean left sinus height; MRSW, mean right sinus width; MLSW, mean left sinus width; MTSW, mean total sinus width; SD, standard deviation.

WELCH test demonstrated homogeneity of the study population by age enabling the use of ANOVA statistical test to assess the association between sinus measurements and the age (Table 4). However, none of the sinus measurements demonstrated a statistically significant association with the age of the patients.

To find out the sinus measurements which were independently associated with the sex of the person, binary logistic regression model was used. Results of the final logistic regression results identified, mean left sinus length \( p < 0.001 \) and mean left sinus width \( p = 0.021 \) measurements were highly associated with the sex of the person.
Table 2. Summary of the frontal sinus measurements.

| Measurement of frontal sinus | Mean ± SD (mm) | Minimum (mm) | Maximum (mm) | p* |
|------------------------------|----------------|--------------|--------------|----|
| **Length**                   |                |              |              |    |
| Right                        | 11.553 (4.122) | 3.320        | 57.700       | 0.025 |
| Left                         | 12.030 (3.202) | 3.715        | 24.050       |    |
| **Height**                   |                |              |              |    |
| Right                        | 22.710 (8.608) | 5.085        | 46.250       | <0.001 |
| Left                         | 24.286 (9.131) | 2.960        | 60.850       |    |
| **Width**                    |                |              |              |    |
| Right                        | 25.295 (8.007) | 4.410        | 44.250       | <0.001 |
| Left                         | 27.775 (8.517) | 4.625        | 53.700       |    |
| **Total width**              | 52.593 (13.110)| 17.950       | 87.000       |    |

*p Value calculated using paired t-test.

Figure 2. Variation between right and left frontal sinus measurements.

Table 3. Variation of frontal sinus measurements with sex.

| Measurement | Male (n = 177) Mean ± SD | Female (n = 123) Mean ± SD | p* |
|-------------|---------------------------|---------------------------|----|
| MRSL        | 12.4 (3.2)                | 10.3 (5.0)                | <0.001 |
| MLSL        | 13.0 (3.2)                | 10.6 (2.6)                | <0.001 |
| MRSH        | 24.2 (8.0)                | 20.6 (9.1)                | <0.001 |
| MLSH        | 25.9 (8.7)                | 22.0 (9.2)                | <0.001 |
| MRSW        | 26.8 (7.6)                | 23.1 (8.1)                | <0.001 |
| MLSW        | 28.7 (8.4)                | 26.5 (8.6)                | 0.033 |
| MTSW        | 55.1 (12.7)               | 49.0 (12.9)               | <0.001 |

*p Value calculated using Student’s t-test.

Discussion

The development of the frontal sinus begins in the fetus around fourth to fifth week of gestation and continues up to early adult life. It reaches the maximum size by the second decade and remains constant thereafter.11,12

According to the literature, the variability of frontal sinuses is observed even among monozygotic twins.13,14 This uniqueness of the frontal sinus has been akin to that of fingerprints.15 Contributed by genetic and environmental factors, frontal sinus is recognized to be highly variable among different individuals.16 A descriptive study conducted among an Indian population demonstrated the uniqueness and asymmetry of the frontal sinuses.17 These findings further reinforce the validity of employing frontal sinus patterns for person identification.
In the literature, specific frontal sinus patterns in relation to age, sex, etc. have been studied in specific ethnic groups. However, due to environmental, racial, and genetic factors affecting skeletal development, the same tools cannot be applied universally. Although extensively studied in the literature, due to limited resources, lack of expertise and cost, this technique is not widely used or researched in developing countries like Sri Lanka.

With the development and increased availability of digital radiographic techniques, employment of frontal sinus pattern analysis for person identification has gained significant recognition. NCCT is considered the method of choice for imaging paranasal sinuses. It offers the added advantage of being able to manipulate images three-dimensionally. In the current study population, none of the frontal sinus measurements had a statistically significant association with the sex of the individual. All the measurements (length, height, and width) were found to be larger in the males compared to females. Furthermore, final logistic regression analysis demonstrated a high association of MLSL and MLSW values with sex. Therefore, these parameters have the potential to be used to develop a predictor model for accurate sex determination.

According to this study, morphometric analysis of frontal sinuses demonstrated a significant association with the sex of the individual. The mean adult sinus width, height, and depth were obtained as 27.9, 52.8, and 21.6 cm, respectively. All the mean sinus measurements in this study are higher compared to the present study population. However, in another study conducted in a Turkish population the mean measurements were observed to be similar to those of this study. This study observed left side sinus measurements to be greater than the right, which was also confirmed by the Turkish study. However, a study done in France did not observe a statistically significant difference between the right and left frontal sinus measurements.

In the current study population, none of the frontal sinuses demonstrated a significant association with the age. This further confirms that after the second decade, when the development of frontal sinuses completes, the sinus size remains static throughout life. A study conducted in Greece also concluded that frontal sinus is not a good predictor of age. Another study conducted in a German population observed that the frontal sinus development is completed by 18 years in males and 15–16 years in females, remaining static thereafter. This static nature was further confirmed by a study comparing skull radiographs performed 6–8 months apart. A study conducted in France using NCCT images also did not observe a statistically significant correlation with the age of the individual.

According to this study, morphometric analysis of frontal sinuses demonstrated a significant association with the sex of the individual. All the measurements (length, height, and width) were found to be larger in the males compared to females. Furthermore, final logistic regression analysis demonstrated a high association of MLSL and MLSW values with sex. Therefore, these parameters have the potential to be used to develop a predictor model for accurate sex determination.

**Limitations**

Several limitations identified by the authors were as follows. This study was conducted in a cohort limited to a single tertiary care center in Sri Lanka; therefore, the results will not reflect the general population. Also, the sample size was not calculated. Future studies including several centers and larger sample size will be beneficial in formulating a more generalized conclusion as well as developing a predictor model. Furthermore, in this study, only height, width, and length parameters were used. In future research, sinus volume and shape may be studied in relation to age and sex.

### Table 4. Variation of frontal sinus measurements with age.

| Age group | MRSL Mean ± SD | MSL Mean ± SD | MRSH Mean ± SD | MLSH Mean ± SD | MRSW Mean ± SD | MLSW Mean ± SD | MTSW Mean ± SD | p* |
|-----------|----------------|---------------|----------------|----------------|----------------|----------------|----------------|----|
| 20–29 years | 11.4 (3.8) | 12.3 (3.8) | 23.5 (11.6) | 23.1 (10.5) | 25.5 (10.1) | 28.0 (8.9) | 53.2 (17.6) | 0.25 |
| 30–39 years | 12.0 (3.5) | 12.1 (2.7) | 23.7 (9.8) | 24.6 (10.9) | 26.9 (8.8) | 26.6 (7.9) | 53.5 (15.2) | 0.74 |
| 40–49 years | 13.3 (8.3) | 12.0 (2.9) | 23.5 (7.6) | 25.9 (9.7) | 25.8 (6.8) | 29.4 (8.5) | 54.3 (11.3) | 0.37 |
| 50–59 years | 10.7 (2.7) | 11.4 (3.2) | 22.3 (7.8) | 25.1 (9.1) | 25.4 (6.9) | 27.8 (9.3) | 52.7 (12.4) | 0.93 |
| 60–69 years | 11.6 (3.3) | 12.3 (3.9) | 20.9 (8.4) | 22.5 (8.3) | 24.5 (8.6) | 26.9 (9.5) | 51.0 (14.7) | 0.94 |
| 70–79 years | 11.7 (3.2) | 12.4 (2.9) | 22.0 (7.5) | 24.8 (8.6) | 25.1 (7.8) | 27.8 (7.9) | 52.0 (11.3) | 0.94 |
| 80–89 years | 10.9 (3.0) | 11.9 (2.4) | 24.8 (8.9) | 24.4 (8.4) | 24.8 (7.8) | 28.3 (7.2) | 52.9 (10.9) | 0.94 |

*p* Value calculated using ANOVA test.

ANOVA: analysis of variance; MRSL: mean right sinus length; MSL: mean left sinus length; MRSH: mean right sinus height; MLSH: mean left sinus height; MRSW: mean right sinus width; MLSW: mean left sinus width; MTSW: mean total sinus width; SD: standard deviation.
Conclusion

Morphometric analysis of frontal sinuses using NCCT images is useful for the sex differentiation of unknown bodies for medico-legal purposes. Furthermore, the mean sinus values specific to the current study population will also help in ethnic differentiation.

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Author contributions

Study conception and design—CW, AV, JU, SK
Data collection—CW, JU
Analysis and interpretation of results—CW, JU, AV
Draft manuscript preparation—CW, AV, SK, JU
Reviewed results and approved final manuscript—CW, AV, SK, JU

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The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

This retrospective study was exempted from ethical clearance by the ethics review committee at the Faculty of Medicine, University of Peradeniya (protocol number: 2021/EC/41). Consent was not obtained as this requirement was waived by the local ethics committee.

Ethical approval

Ethical approval for this study was waived by the ethics review committee at the Faculty of Medicine, University of Peradeniya (protocol number: 2021/EC/41) because this study does not involve human subjects and only uses digitally stored NCCT images.

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Note

Informed consent was not sought for this study because the need for informed consent was waived off by the review board due to the retrospective nature of the study.

Informed consent

Consent was not obtained as this requirement was waived by the local ethics committee.

Trial registration

Not applicable.

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References

1. Shekar BC and Reddy CV. Role of dentist in person identification. Indian J Dent Res 2009; 20(3): 356.
2. Scheuer L. Application of osteology to forensic medicine. Clin Anat 2002; 15(4): 297–312.
3. Primorac D and Schanfield M (eds). Forensic DNA applications: an interdisciplinary perspective. Boca Raton, FL: CRC Press, 2014.
4. Chaudhary S and Singh U. Uniqueness of frontal sinus as tool for personal identification in forensic odontology. Ann Int Med Dent Res 2016; 2: 7–9.
5. Bell DJ and Gaillard F. Frontal sinuses [Internet]. Radiopaedia. https://radiopaedia.org/articles/frontal-sinus (accessed 14 May 2021).
6. Tatlisumak E, Ovali GY, Asirdizer M, et al. CT study on morphometry of frontal sinus. Clin Anat 2008; 21(4): 287–293.
7. Love J, Selker R, Marsman M, et al. JASP: Graphical statistical software for common statistical designs. J Stat Softw 2019; 88: 1–7.
8. Cuevas A, Febrero M and Fraiman R. An anova test for functional data. Comput Stat Data Anal 2004; 47(1): 111–122.
9. Semenick D. Tests and measurements: the T-test. J Strength Cond Res 1990; 12(1): 36–37.
10. King JE. Binary logistic regression. In: Osborne J (ed.) Best practices in quantitative methods. Thousand Oaks, CA: SAGE Publications, Inc., 2008, pp. 358–384.
11. Duque CS and Casiano RR. Surgical anatomy and embryology of the frontal sinus. In: Kountakis SE, Senior BA and Draf W (eds) The frontal sinus. Berlin: Springer, 2005, pp.21–31.
12. de Souza Jr LA, Marana AN and Weber SAT. Automatic frontal sinus recognition in computed tomography images for person identification. Forensic Sci Int 2018; 286:252–264.
13. Christensen AM. Assessing the variation in individual frontal sinus outlines. Am J Biol Anthropol 2005; 127(3): 291–295.
14. Tatlisumak E, Ovali GY, Aslan A, et al. Identification of unknown bodies by using CT images of frontal sinus. Forensic Sci Int 2007; 166(1): 42–48.
15. Christensen AM. Testing the reliability of frontal sinususes in positive identification. J Forensic Sci 2005; 50(1): 18–22.
16. Quatrehomme G, Fronzy P, Sapanet M, et al. Identification by frontal sinus pattern in forensic anthropology. Forensic Sci Int 1996; 83(2): 147–153.
17. Gadekar NB, Kotrashetti VS, Hosmani J, et al. Forensic application of frontal sinus measurement among the Indian population. J Oral Maxillofac Pathol 2019; 23(1): 147.
18. Yoshino M, Miyasaka S, Sato H, et al. Classification system of frontal sinus patterns by radiography. Its application to identification of unknown skeletal remains. Forensic Sci Int 1987; 34(4): 289–299.
19. Christensen AM and Hatch GM. Advances in the use of frontal sinuses for human identification. In: Latham KE, Bartelink EJ and Finnegan M (eds) *New perspectives in forensic human skeletal identification*. Cambridge, MA: Academic Press, 2018, pp. 227–240.

20. Yun IS, Kim YO, Lee SK, et al. Three-dimensional computed tomographic analysis of frontal sinus in Asians. *J Craniofac Surg* 2011; 22(2): 462–467.

21. Michel J, Paganelli A, Varoquaux A, et al. Determination of sex: Interest of frontal sinus 3D reconstructions. *J Forensic Sci* 2015; 60(2): 269–273.

22. Prado PA, Adams K, Fernandes LC, et al. Frontal sinus as an identity and sex indicator. *Morphologie* 2021; 105(351): 281–287.

23. Spaeth J, Krügelstein U and Schlöndorff G. The paranasal sinuses in CT-imaging: development from birth to age 25. *Int J Pediatr Otorhinolaryngol* 1997; 39(1): 25–40.

24. Patil N, Karjodkar FR, Sontakke S, et al. Uniqueness of radiographic patterns of the frontal sinus for personal identification. *Imaging Sci Dent* 2012; 42(4): 213–217.

25. Nateghian Z, Abedi I, Dashiti GH, et al. Frontal sinus pattern and evaluation of right and left frontal sinus volume according to gender, using multi detector CT scan. *J Forensic Sci Criminol* 2016; 4(4): 402.

26. Verma S, Mahima VG and Patil K. Radiomorphometric analysis of frontal sinus for sex determination. *J Forensic Dent Sci* 2014; 6(3): 177.