Cephalometric radiograph-based approach for sex determination using maxillary sinus index in Surabaya, Indonesia

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SUMMARY

Accurate sex determination is a critical aspect of individual identification in various fields, including anthropology, forensic science, and archaeology. Various parameters from the skull, mandible, pelvis, and long bones are commonly utilized for this purpose. Recently, the potential of the maxillary sinus as a sex-discriminatory parameter has been studied by Khaitan et al. through the analysis of lateral cephalometric radiography. This study aimed to evaluate the feasibility of implementing the sex determination formula devised by Khaitan et al. for the adult population of Surabaya, Indonesia. For this purpose, 130 digital cephalometric radiographs of outpatients in the DHDC Dental Office in Surabaya, Indonesia, were assessed. The maxillary sinus height and width were measured to derive the maxillary sinus index (MSI) and calculate the discriminant score (D) for sex identification. This study revealed that the maxillary sinus's average height in males was 37.111±5.13 mm, while in females, it was 34.538±4.36 mm. Males had an average maxillary sinus width of 44.152±4.11 mm, while in females it was of 38.849±3.33 mm. The MSI values for males (1.204±0.14) were higher than for females (1.135±0.10). The discriminant scores showed notable variations between males and females, with an 86% success rate for females and 27.8% for males. The present study provides evidence that the Khaitan formula can serve as a valuable complementary approach for sex determination in females. Sex determination based on the MSI is thought to be a population-dependent parameter in forensic sciences and requires careful interpretation in its application.

Key words: Forensic identification – Legal identity – Maxillary sinus index – Sex determination

INTRODUCTION

Sex estimation is a critical aspect of forensic sciences, anthropology, and archaeology, involving assessing a set of physical features and characteristics to identify a specific individual. Forensic medicine uses medical sciences to support criminal investigations, while forensic dentistry

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involves examining dental evidence and providing accurate dental findings (Marini et al., 2020). Among the various factors involved in human identification, sex determination is essential, with bones such as the pelvis and skull proving to be valuable sources of information in cases where the body is skeletonized or burnt (Steyn and İşcan, 1998; Kurniawan et al., 2023). A range of indices can be examined for sex determination, including skull circumference, mandibular bone, palate shape and height, mastoid process, tooth size, dental pulp, and sinuses (e.g., frontal and maxillary sinuses). The maxillary sinus, the most prominent paranasal sinus, starts developing during the 10th week of fetal life and is the first to develop after birth (Lorkiewicz-Muszyńska et al., 2015). Available reports and research indicate that the maxillary sinus remains mostly unaffected after severe injuries or burns. The maxillary sinuses are two cavities in the maxillary bone, with their apex extending to the zygomatic process and their floor reaching the alveolar bone (Sidhu et al., 2014).

A radiographic image of the sinus is a valuable tool for forensic anthropology, facilitating the identification of skeletal remains and sex determination. Several imaging modalities are available, including conventional techniques such as water's view and lateral cephalogram, as well as advanced technologies such as computed tomography (CT) and cone beam computed tomography (CBCT). Among these, the lateral cephalogram is highly regarded for its ability to provide detailed architectural and morphological information about the skull, enabling supplementary characteristics and multiple points of comparison to be identified. Moreover, this radiograph is cost-effective, easily accessible, and reliable for medical diagnoses, treatment planning, and forensic and anthropology studies (Devang Divakar et al., 2016; Abasi et al., 2019).

Khaitan et al. (2017) introduced a novel discriminant function formula for sex determination using the maxillary sinus index (MSI) based on lateral cephalometric radiographs. The study involved 50 healthy subjects (25 males and 25 females) aged 25-55 from the Indian population (Khaitan et al., 2017). However, there are limitations to the established method, as it is not always reliable, and other factors such as age and ethnicity must be taken into account (Tambawala et al., 2016). Therefore, further validation studies are required in different populations, such as the Indonesian population, with a high-risk disaster potential. This study aimed to assess the feasibility of the sex determination formula by Khaitan et al. for the adult population in Surabaya, Indonesia.

MATERIALS AND METHODS

One hundred and thirty (36 males and 94 females, aged 20-40) digital lateral cephalometric radiographs were retrospectively collected from the database of the DHDC Dental Office in Surabaya, Indonesia, between 2019 and 2022. This study involves good quality lateral cephalometric radiograph without abnormalities (such as congenital development and fractures) appearing on the radiograph. Ethical clearance approval of the present study was obtained from the Health Research Ethical Clearance Commission at the Faculty of Dental Medicine, Universitas Airlangga (number: 365/HRECC.FODM/VI/2022).

The lateral cephalometric data, including subject sex and age, were compiled in Microsoft Excel. Maxillary sinus height and width were measured using the SIDEXIS neXT Generation software, and the MSI was calculated based on the width-to-height ratio. The maxillary sinus height is defined as the distance between the highest and lowest points of the sinus, while the maxillary sinus width is the distance between the most anterior and posterior points (Fig. 1). The measurement of maxillary sinus height and width was conducted twice by a single observer, with a two-week time span between measurements to assess intra-observer reliability. Sex determination for each subject was predicted using the formula developed by Khaitan et al.: D=11.509 – (8.871*MSI). A subject was predicted as male if the D score was negative and predicted as female if the D score was positive.

The resulting data were tabulated in Microsoft Excel and analyzed using SPSS version 23.0 software. Descriptive analyses of maxillary sinus width, height, and MSI were performed, and the

significance of the difference between males and females was analyzed using an independent *t*-test. The correct sex prediction based on the D score was calculated in percentages for males and females.

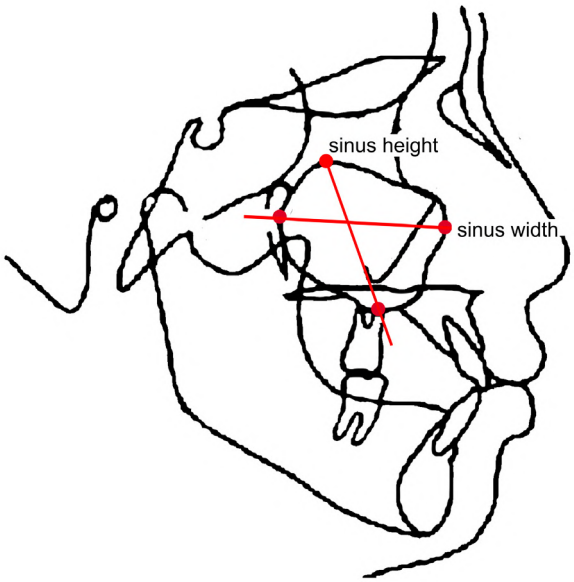

Fig. 1- Illustration of the maxillary sinus height and width on a lateral cephalometric radiograph.

RESULTS

This retrospective study analyzed 130 lateral cephalometric radiographs of patients aged from 20 to 40. The measurements of each parameter were found to have good reliability, with a Cronbach's Alpha value of 0.994 (>0.06). The study found that the parameters measured were significantly greater in males than in females. Table 1 presents the descriptive analysis and independent t-test results for maxillary sinus height, width, and MSI.

Maxillary Sinus Height

The maximum maxillary sinus height for males was 48.86 mm, while the minimum was 29.42 mm, with a mean of 37.112 ± 5.135 mm. On the other hand, the maximum sinus height for females was 49.27 mm, and the minimum was 23.91 mm, with a mean of 34.539 ± 4.362 mm. Our findings indicate that males have a significantly greater maxillary sinus height than females *($p < 0.05$)*.

Maxillary Sinus Width

The maxillary sinus width in males ranged from 37.06 mm to 52.67 mm, with a mean value of 44.153±4.114 mm. In females, the maximum maxillary sinus width was 46.83 mm, and the minimum width was 31.63 mm, with a mean of 38.849±3.335 mm. The independent *t*-test revealed a statistically significant difference in maxillary sinus width between males and females, with *$p<0.05$*.

Maxillary Sinus Index (MSI)

The MSI is calculated using the width-to-height ratio. The highest MSI value observed in males was 1.45, while the lowest was 0.91. Females had the highest MSI value of 1.49, and the lowest was 0.84. This study found a statistically significant difference in MSI values between males and females, with *$p<0.05$*. Furthermore, this study conducted the Pearson correlation test to analyze the correlation between the maxillary sinus index and sex determination. The results revealed a significant correlation between MSI and sex, with a coefficient of -0.256.

Table 1. Descriptive analysis and independent t-test of the maxillary sinus height, width, and MSI.

Parameters	Male			Female			Mean difference	*p-value*
	Mean	SD	SE	Mean	SD	SE		
Sinus height	37.112	5.135	0.856	34.539	4.362	0.452	2.573	0.005*
Sinus width	44.153	4.114	0.686	38.849	3.335	0.346	5.304	<0.001*
MSI	1.204	0.142	0.024	1.135	0.108	0.011	0.069	0.003*

MSI: Maxillary sinus index; SD: standards deviation; SE: standards error
*Indicates a significant difference between males and females; measurement unit for sinus height and width: mm

Discriminant Value for Sex Determination

In this study, the discriminant function formula developed by Khaitan et al. was utilized to predict the sex of the cephalometric radiographs based on the MSI value as follows: D= 11.509 – (8.871*MSI). Results showed that the Khaitan et al. formula accurately predicted the sex of 99 of 130 subjects (76.15%). Notably, the formula performed better in females, with a correct prediction rate of 94.68%, compared to males at 27.78% (Table 2).

Table 2. The performance of the sex determination formula by Khaitan for the Indonesian adult population.

Sex	N	Correct		Incorrect	
		N	%	N	%
Male	36	10	27.78%	26	72.22%
Female	94	89	94.68%	5	5.32%
Overall	130	99	76.15%	31	23.85%

DISCUSSION

Sex identification is crucial in establishing an individual identity for the living and the deceased. Previous studies have reported a 100% accuracy rate of sexual dimorphism in the complete skeleton. When utilizing a combination of the pelvis and cranium, the accuracy rate was 98%, followed by a combination of the pelvis and long bones (95%) (Teke et al., 2007; Tambawala et al., 2016). The pelvis and cranium are considered the most reliable anatomical sites for determining sex due to their accessibility and distinct sexual dimorphism. However, the reliability of sex determination from the skull appears to be lower before puberty. Several methodologies have been studied for sex determination, including DNA, morphological, and morphometric analyses (Sidhu et al., 2014; Prakoeswa et al., 2022).

Paranasal sinuses are essential in establishing an individual's identity (Leao de Queiroz et al., 2016). Among these sinuses, the maxillary sinus is the largest and the first to develop at approximately ten weeks of gestation. Subsequently, it continues to pneumatize until the eruption of the third molars (around 20 years of age) and eventually reaches a distance of 5 mm inferior to the nasal floor. After the maximum growth period, the volume of the maxillary sinus decreases due to mineral loss in the bone matrix. The maxillary sinus dimension tends to stabilize after the second decade of human life (Sahlstrand-Johnson et al., 2011; Gupta et al., 2014). Therefore, only subjects aged 20 years and above were considered in this study to ensure accurate measurements.

The present study revealed a significant difference between males and females in the average height and width of the maxillary sinus, with $p<0.05$. This finding is consistent with previous studies by Teke et al. (2007) and Queiroz et al. (2016), which also reported a greater mean height of the maxillary sinus in males than in females (Teke et al., 2007; Leao de Queiroz et al., 2016). Mathew et al. (2020) found significantly higher maxillary sinus dimensions in males than females, except for intermaxillary distance (Mathew and Jacob, 2020). A study by Uthman et al. (2011) and Tambawala et al. (2016) reported that maxillary sinus height was the best-discriminating parameter for studying sexual dimorphism, with an overall accuracy of 71.6% (Uthman et al., 2011; Tambawala et al., 2016).

In a study by Sharma et al. (2014), the measurement of maxillary sinus volume and dimension was analyzed using CT scans. The study yielded noteworthy findings, particularly concerning sexual dimorphism. Specifically, significant differences in maxillary sinus length and volume were observed between male and female subjects. Of the parameters analyzed, maxillary sinus length proved to be the most effective discriminator, with an accuracy rate of 69.81% (Sharma et al., 2014). The present study's findings are consistent with previous research, which suggests that the differences in observed parameters are more pronounced in the anteroposterior dimension of the maxillary sinus, with $p<0.001$.

A study conducted on 33 CT images of the maxillary sinus in a Korean population classified the maxillary sinuses into six categories based on their lateral aspects and the shapes of their inferior walls. The study found that all measurements, including the anteroposterior length, height, width, and volume of the sinuses, were more significant in males than in females, consistent with our findings (Kim et al., 2002).

Fernandes (2004) elucidated the role of the maxillary sinus in ethnic classification through their investigation. Their findings revealed that European crania had significantly larger antral volumes than Zulu. Moreover, males exhibited larger volumes compared to females. In contrast, Zulu male sinuses were narrower than Zulu female sinuses. The study showed that population group was a significant factor, with European sinuses being wider than Zulu sinuses (Fernandes, 2004).

The variations observed in the results of maxillary air sinus dimensions across various studies can be attributed to various factors. These include differences in ethnicity and population group, affecting body stature, skeletal size, height, and physique. Genetic and environmental factors may also play a role, as can anatomical variations of the sinus. Additionally, alterations in osteoclastic and osteoblastic activity, as well as the pneumatization process of the sinus, may contribute to these variations. These factors highlight the need to carefully consider the various influences on maxillary air sinus dimensions in research and clinical practice (Abu El-Dahab and Dakhli, 2023).

While the dimensions of the maxillary sinus can help support sex determination, there are limitations to this method. The maxillary sinus exhibits anatomical variability between the sexes, but there is also an overlap in measurements between males and females. Additionally, factors such as tooth loss, age, and ethnicity can affect the dimension of the maxillary sinus, which may impact its usefulness in sex determination (Tambawala et al., 2016; Leao de Queiroz et al., 2016; Velasco-Torres et al., 2017; Mathew and Jacob, 2020). Other factors affecting the maxillary sinus dimensions include cephalometric parameters and certain medical conditions such as chronic rhinosinusitis (Akay et al., 2020; Pérez Sayáns et al., 2020; Abate et al., 2023).

This study's limitations include a small sample size due to the strict inclusion and exclusion criteria. This study highlights the importance of conducting similar analyses on a more extensive and diverse population. Additionally, measuring the maxillary sinus on lateral cephalograms has limitations related to the two-dimensional view of the sinus, which can result in inaccurate measurements (Abate et al., 2023). Nonetheless, some studies have demonstrated that maxillary sinus measurements on lateral cephalograms are reliable and can assess the relationships between different skeletal classes (Dhiman et al., 2015).

CONCLUSIONS

The findings of this study provide evidence that the Khaitan formula can be a valuable supplementary method for sex determination in females. It is important to note that sex determination based on the MSI is a parameter influenced by the population in forensic science studies and requires careful interpretation during application.

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