Sex Determination Using a Discriminant Analysis of Maxillary Sinuses and Three-Dimensional Technology

Jeong-Hyun Lee[1,†], Hee-Jeung Jee[2], Eun-Seo Park[1], Seok-Ho Kim[1], and Sung-Suk Bae[3]

[1]Department of Oral Anatomy, Dental College, Dankook University, Cheonan 31116, [2]Department of Bio Health Convergency Open Sharing System, Dental College, Dankook University, Cheonan 31116, [3]Department of Dental Hygiene, Hanseo University, Seosan 31962, Korea

Background: Sexual dimorphism is important for sex determination in the field of forensics. However, sexual dimorphism is commonly assessed using cone beam computed tomography (CBCT) rather than three-dimensional (3D) modeling software; therefore, studies using a more accurate measurement approach are necessary. This study assessed the sexual dimorphism of the MS using a 3D modeling program to obtain information that could contribute to the fields of surgery and forensics.
Methods: The CBCT data of 60 patients (age, 20~29 y; 30 males and 30 females) admitted to the Department of Orthodontics at the Dankook University School of Dentistry were provided in Digital Imaging and Communications in Medicine (DICOM) format. The left MS and right MS were modeled based on the DICOM files using the Mimics (version 22; Materialise, Leuven, Belgium) 3D program and converted to stereolithography (STL) files used to measure the width, length, and height of the MS, infraorbital foramen (IOF), right MS, and left MS. The average of three repeated measurements was calculated, and a reliability test was performed to ensure data reliability (Cronbach's α=0.618). A canonical discriminant analysis was performed using a standard approach (left: Box's M=0.096; right: Box's M=0.115).
Results: Males had greater values for all parameters (MS width, MS length, MS height, IOF, right MS, left MS) than females. The discriminant analysis identified six independent variables (MS width, MS height, MS length, IOF, right MS, left MS) that could identify sex. The left MS and right MS correctly identified the sex of 81.7% and 71.7% of the patients, respectively, with the left MS having higher accuracy.
Conclusion: This study confirmed that, for Korean individuals, the left MS has a better ability to identify sex than the right MS. These results may contribute to sex identification in the fields of surgery and forensics.

Key Words: Anatomy, Maxillary sinus, Sexual dimorphism, Stereolithography, Three dimensional

Introduction

1. Background

The maxillary sinus (MS) is the largest of the paranasal sinuses, and its wall consists of the facial, infratemporal, orbital, and nasal surfaces[1]. Additional care is required when treating the MS because it is close to the teeth[2]. Clinical research related to the MS has increased[2-5]. It has been found that the MS grows until the alveolar bone is pneumatized[3], with completion occurring at approximately age 18 years[4]. The shape of the facial bone varies across races[5]; therefore, the MS has various shapes and sizes[6]. As a result, forensic studies to identify the sex of individuals by examining the MS have been performed[6-17].

In the field of forensics, the identification of sex based on the skeletal remains is important[7,18]. Sexual dimorphism is used to identify sex, with the hip and cranial bones being the current targets of sexual dimorphism assessments[8,9]. However, the assessment of sexual dimorphism may be difficult because of burial conditions and the pre-

sence of fractures[10]. Therefore, researchers have been investigating methods to identify sex based on the sexual dimorphism of the MS[6-17]. Previous studies reported that, unlike the cranium and other skeletal structures that experience severe damage as a result of an explosion or vehicle crash, the MS remains intact during such events[11]. However, most of these studies have involved subjects in Western countries[6-8,10-17,19], and studies involving three-dimensional (3D) modeling technology are lacking. One study reported that MS measurements using two-dimensional cone beam computed tomography (CBCT) may not be accurate[20]. Therefore, research using 3D modeling technology is necessary.

2. Objectives

This study aimed to identify sex by examining the sexual dimorphism of the MS of Korean individuals using a 3D modeling program and to obtain information that could contribute to the fields of forensics and surgery.

Materials and Methods

1. Ethics statement

A waiver of informed consent was requested before the CBCT data were retrospectively analyzed. This study was conducted with the approval of the Institutional Review Board of Dankook University Dental Hospital (approval no. DKUDH; IRB no. 2020-01-007).
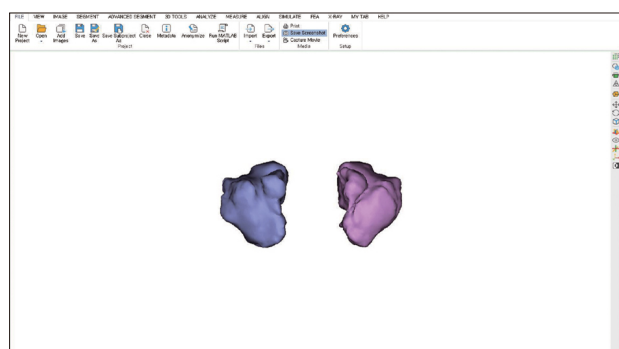
2. Study design

1) Cone beam computed tomography data

CBCT was performed by a single researcher. To reduce individual differences in the MS size of the subjects, a Frankfort horizontal plane was set perpendicular to the floor. Then, cranial CBCT (Alphard 3030; Asahi, Kyoto, Japan) was performed after aligning the CBCT equipment with the sagittal midline of the face. The imaging conditions were as follows: gantry angle, 0°; 120 kV; and AutomA. CBCT scanning was performed using the following parameters: slice increment, 0.39 mm; slice thickness, 0.39 mm; slice pitch, 3; scanning time, 4 seconds; and matrix size, 512×512 pixels. All CBCT data were provided in Digital Imaging and Communications in Medicine (DICOM) format.

2) Three-dimensional image production

The left MS and right MS were modeled in three different views, coronal, sagittal, and frontal, based on the DICOM files using the Mimics (version 22; Materialise, Leuven, Belgium) 3D program (Fig. 1). To extract a 3D model of the MS, the Hounsfield units (HU) were set to −1,024 HU (minimum) and −302 HU (maximum) for masking. Then, the left MS and right MS were separated using the Region Grow function, and the right and left masks were created. These data were converted to stereolithography (STL) files using the Calculate Part function. MS measurements were obtained from the STL files using the Distance function.

Fig. 1. Use of Mimics software (version 22; Materialise, Leuven, Belgium).

Table 1. Measurement Parameters of Maxillary Sinus

Parameter	Definition
Maxillary sinus width	Maxillary sinus width on coronal view
Maxillary sinus length	Maxillary sinus width on sagittal view
Maxillary sinus height	Maxillary sinus height above coronal view
Infraorbital foramen	Distance between infraorbital foramen
Right-left maxillary sinus	Right and left maxillary sinus distance

3) Measurements

All measurements were performed using the highest point of the Frankfort horizontal line. The average of three repeated measurements was used during the analysis (Table 1, Fig. 2, 3). Data reliability was ensured by performing a reliability test. A Cronbach's α value of 0.618 was observed, indicating satisfactory data reliability.

3. Sample size

The CBCT data of 60 subjects (age, 20～29 y; 30 males and 30 females) admitted to the Department of Orthodontics at Dankook University School of Dentistry without common or bilateral stones of the MS were collected. The

Fig. 2. Measurement parameters of the maxillary sinus. (1) Maxillary sinus width in the coronal view. (2) Maxillary sinus height in the coronal view. (3) Maxillary sinus length in the sagittal view.

Fig. 3. Measurement parameters of the skull in the anterior view. (1) Distance between the infraorbital foramen. (2) Distance be−tween the right and left maxillary sinuses.

target sample size was determined using G-power 3.1 (G*Power; Heinrich Heine Universität Düsseldorf, Düsseldorf, Germany) with the following settings: two tails; effect size 'd', 0.8; α error of probability, 0.05; and power (1-β error of probability), 0.8[21]. The target sample size was determined to be 50 subjects, with 26 subjects in each of the two groups. Ten additional subjects (resulting in two groups with 30 in each group) were included to improve the test accuracy.

4. Statistical methods

Measurements were analyzed using SPSS (version 23.0; IBM Corporation, Armonk, NY, USA). A canonical discriminant analysis using a standard approach was performed to assess the ability of the MS to identify sex. The Box's M of the covariance matrix of each group was determined. Box's M values of 0.096 and 0.115 were found for the left MS and right MS, respectively. Both of these values were greater than the significance level of 0.05, thus indicating the equality of variance and covariance matrices. For all analyses, a post hoc confidence interval of 95% and significance level of 0.05 were used.
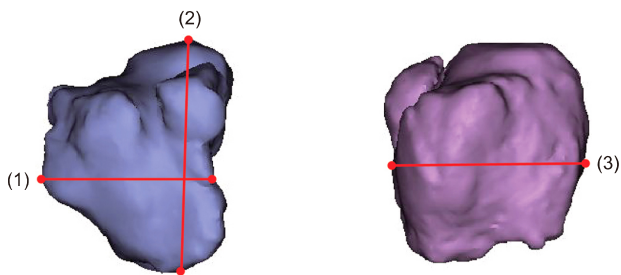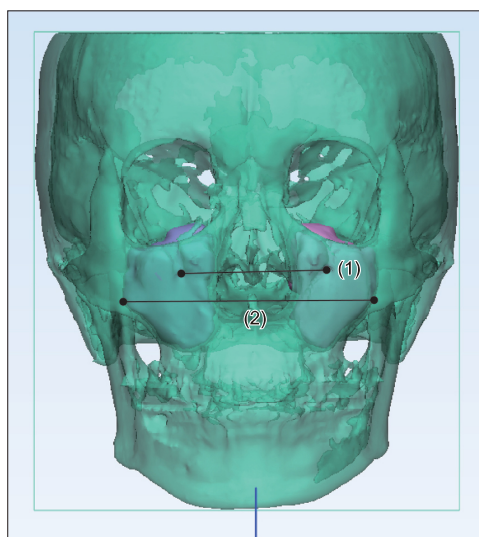
Results

1. Maxillary sinus size result

Table 2 and Fig. 4 show the MS dimensions of each sex. For males, the width, length, and height of the left MS were 29.32 mm, 41.54 mm, and 48.89 mm, respectively. For females, the width, length, and height of the left MS

Table 2. Comparison of Maxillary Sinus Sizes by Sex

	Parameter	Male (n=30)	Female (n=30)
Left	Maxillary sinus width	29.32±1.81	27.99±1.24
	Maxillary sinus length	41.54±3.16	39.10±1.92
	Maxillary sinus height	48.89±3.62	46.32±1.72
Right	Maxillary sinus width	29.09±4.49	27.46±3.44
	Maxillary sinus length	41.53±4.07	37.92±3.01
	Maxillary sinus height	47.50±3.11	45.85±1.88
Infraorbital foramen		53.38±4.32	50.37±4.21
Right maxillary sinus-left maxillary sinus		92.30±8.16	86.81±6.59

Values are presented as mean±standard deviation.

were 27.99 mm, 39.10 mm, and 46.32 mm, respectively. For males, the width, length, and height of the left MS were 29.09 mm, 41.53 mm, and 47.50 mm, respectively. For females, the width, length, and height of the right MS were 27.46 mm, 37.92 mm, and 45.85 mm, respectively. Males had greater left and right MS dimensions than females. The IOF was 53.38 mm for males and 50.37 mm for females. The distance between the right MS and left MS was 92.30 for males; however, it was 86.81 for females. Males had longer IOFs and distances between the right MS and left MS than females.

2. Discriminant function

The discriminant analysis identified six independent variables (MS width, MS height, MS length, IOF, right MS−left MS) that could identify sex. The left MS and right MS had Wilks λ values of 0.666 and 0.714, respectively, indicating that the right MS is a better determinant of sex (p < 0.05) (Table 3).

3. Discriminant analysis

The left MS correctly identified 22 of 30 males and 27 of 30 females. Furthermore, it correctly identified the sex of 49 of the 60 subjects, resulting in an accuracy rate of 81.7%. The right MS correctly identified 21 of 30 males and 22 of 30 females. Furthermore, it correctly identified the sex of 43 of the 60 subjects, resulting in an accuracy rate of 71.7%. Therefore, the left MS was a better determinant of sex than the right MS (Table 4).

Discussion

The MS comprises two air-filled compartments located on the left and right sides of the maxilla[6]. Additional care is required when treating the lower wall of the MS[12]. Forensic studies have analyzed the ability of the MS to identify the sex of individuals[6,8,9-12,15-21]. However, such studies mainly involved individuals in Western countries[6-8,10,11,12-17,19]; therefore, the same research should be
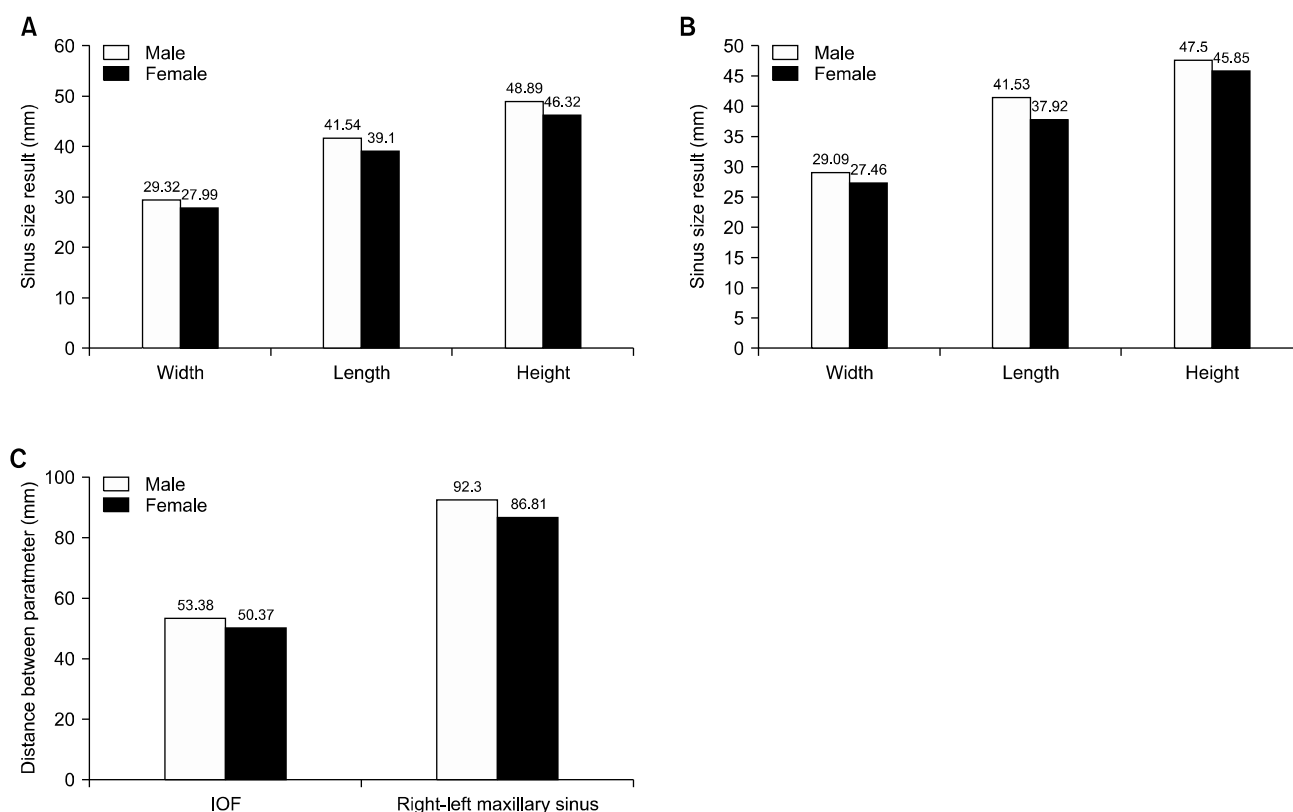

Fig. 4. Comparison of the maxillary sinus size according to sex. (A) Left maxillary sinus. (B) Right maxillary sinus. (C) Infraorbital foramen (IOF) and distance between the right and left maxillary sinuses.

Table 3. Sex Discriminant Function of Maxillary Sinus

Parameter	Coefficient (mm)
Left	DF=0.338 (width)+0.068 (length)+0.191 (height)+0.128 (IOF)−0.018 (right maxillary sinus−left maxillary sinus)−26.530
Right	DF=−0.050 (width)+0.145 (length)+0.141 (height)+0.117 (IOF)+0.040 (right maxillary sinus−leftmaxillary sinus)−20.545

DF: discriminant function, IOF: infraorbital foramen.

Table 4. Results of Sex Discriminant Analysis of the Maxillary Sinus

Parameter		Holdout samples	Correctly classified	Accuracy (%)	Total accuracy (%)
Left	Male	8	22	73.3	81.7
	Female	3	27	90.0	
Right	Male	8	21	70.0	71.7
	Female	9	22	73.3	

performed in other locations to obtain more information. This study assessed the sexual dimorphism of the MS of Korean individuals.

During this study, males had a larger MS than females, consistent with the observations of previous studies[13-17]. The greater MS size of males may be attributable to their greater skeletal frame. This difference in the size of the MS between males and females may be useful when attempting to identify sex during surgery or forensic procedures.

During this study, the left MS and right MS were used to correctly identify 73.3% and 70.0% of males and 90.0% and 73.3% of females, respectively. These results were similar to those obtained by Ekizoglu et al.[15] and Paknahad et al.[16], who used the MS to correctly identify 74% of males and 78% of females, respectively. Sidhu et al.[17] reported that the shape of the MS on cephalometric radiographs could identify sex with high accuracy and reliability. Similar results were observed in the present study. Therefore, our results may provide useful contributions to the fields of surgery and forensics in Korea.

The left MS and right MS identified sex with accuracy rates of 81.7% and 71.7%, respectively. Buikstra and Ubelaker[19] reported left dominance when comparing paired bones. Furthermore, Plato et al.[22] reported that the left hand of individuals with asymmetric hands tended to be larger than the right hand, possibly because of the greater physical activity of the right hand. The left MS and right MS are located near the cheekbones, which are paired bones; therefore, this may explain why the left MS was a better determinant of sex than the right MS. Consequently, it may be advisable to use the left MS rather than the right MS when attempting to identify sex and per-

forming MS measurements.

1. Suggestions

This study aimed to assess the sexual dimorphism of the MS. Identification accuracy rates of 81.7% and 71.7% were observed for the left MS and right MS, respectively, indicating that the left MS is a better determinant of sex than the right MS. Based on these results, the left MS may be used for sex identification during surgery or forensic procedures. Further studies with improved designs are necessary.

2. Limitations

This study had several limitations. First, the sample size was not large enough to identify sex with sufficient accuracy. However, we performed the discriminant analysis after ensuring clear differences in the MS according to sex. Second, although they were performed in the same locations, slight errors in the MS measurements obtained using the 3D models could have occurred. However, a reliability test was performed using average measurements to ensure data reliability (Cronbach's α=0.618), and we attempted to overcome the limitations of this study by using all of the measurements.

Notes

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Ethical approval

This study was conducted with the approval of the Institutional Review Board of Dankook University Dental Hospital (approval no. DKUDH; IRB no. 2020-01-007).

Author contributions

ORCID

Jeong-Hyun Lee, *https://orcid.org/0000-0001-8358-8679*
Hee-Jeung Jee, *https://orcid.org/0000-0001-7638-2621*
Eun-Seo Park, *https://orcid.org/0000-0001-7941-1344*
Seok-Ho Kim, *https://orcid.org/0000-0002-1517-6557*
Sung-Suk Bae, *https://orcid.org/0000-0003-4338-0915*

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