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CONTENT

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Predicting sex from panoramic radiographs using mandibular morphometric analysis in Surabaya, Indonesia*

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Abstract

Identity verification is a crucial component of forensic sciences, as it necessitates accurately determining an individual's sex, age, and ancestry. The mandible is a commonly studied facial bone for sex determination due to its durability and preservation. This study aims to evaluate various parameters in the mandible for sex determination through morphometric analysis of panoramic radiographs. Fifty-seven panoramic radiographs of patients (22 males and 35 females, 18 – 40 years old) were examined in this study. Ten specific parameters were determined as follows: Bi-condylar Breadth (BCD), Bi-Coronoid Breadth (BCR), Bi-Mental Foramen Breadth (BMF), Bi-Mandibular Notch Breadth (BMN), Bi-Gonial Breadth (BGN), Minimum Ramus Breadth (MRB), Symphysis Height (SYM), Ramus Height (RAH), Mandibular Body Length (MBL), and Mandibular Notch Length (MNL). The morphometric analysis of these parameters was evaluated using Adobe Photoshop®CS6 software. The discriminant function analysis showed a significant difference between males and females in two variables: SYM and RAH, with Wilks' lambda values of 0.857 and 0.924, respectively, and $p<0.05$. The mean value of symphysis height was 29.10 ± 4.42 mm in males and 25.97 ± 3.36 mm in females, with $p<0.004$. Similarly, the mean value of ramus height was 54.64 ± 10.79 mm in males and 49.89 ± 7.13 mm in females, with $p<0.038$. The formula $Z = -4.887 + (0.31*SYM) + (0.046*RAH)$ can be used to determine sex using these variables. These findings may have important implications for forensic investigations and provide a non-invasive method for sex determination.

Keywords: identification; legal identity; morphometric analysis; sex determination

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Introduction

The identification process begins with sex recognition, followed by age and stature estimation associated with sex. Sex determination in forensic sciences and anthropology can be accomplished through morphological and morphometric analysis of hard tissues (1–6). The morphological analysis examines differences in bone shapes and characteristics, while the morphometric analysis measures distances within bone components. Morphometric analysis is often preferred for sex determination studies due to its objectivity, accuracy, reproducibility, and lower intra- and inter-observer errors (7–9).

Most human bones are sexually dimorphic, with the pelvic bone being the most reliable sex predictor, followed by the skull and humerus (10). However, without adequate pelvic bones, the skull and mandible become essential variables for sex confirmation. In a study conducted by Williams and Rogers, it was found that distinct morphological characteristics of the skull and mandible could accurately predict sex with high precision, achieving an accuracy rate of 96% (11). Among the facial bones, the mandible exhibits the most significant degree of structural dimorphism after the pelvic and skull bones, making it a valuable tool in sex determination from skeletal remains. The mandible's unique features, such as its size, shape, and angle, provide reliable indicators of sex, and its durability and resistance make it a well-preserved bone (12,13).

Mandibular parameters, such as gonion angles, ramus length, coronoid, condylar, and mental foramen, have been extensively studied for sex determination (8,14–17). Various discriminant functions based on mandibular morphometric analysis have been proposed for different populations. However, the accuracy of these functions as sex estimators tends to decrease when applied to samples that differ from the reference population. Therefore, it is crucial to develop a population-specific formula for sex determination. In this study, we investigated several mandibular parameters to develop a specific formula for sex determination using panoramic radiographs in Surabaya, Indonesia population.

Methods

Data acquisition

This retrospective study involved 57 outpatients at the Dental Hospital Universitas Airlangga, Surabaya, consisting of 22 males and 35 females aged 18-40. The sample size of this study was calculated using the formula by Lameshow et al. (1991), which yielded a minimum sample size of 52.23 panoramic radiographs (18). Inclusion criteria required good quality digital panoramic radiographs with available information, such as sex, date of birth, and date of radiographic examination, with no abnormalities observed. The observer was blinded to other patient data in the medical records and only examined the radiographs. The researcher had sole access to the collected data.

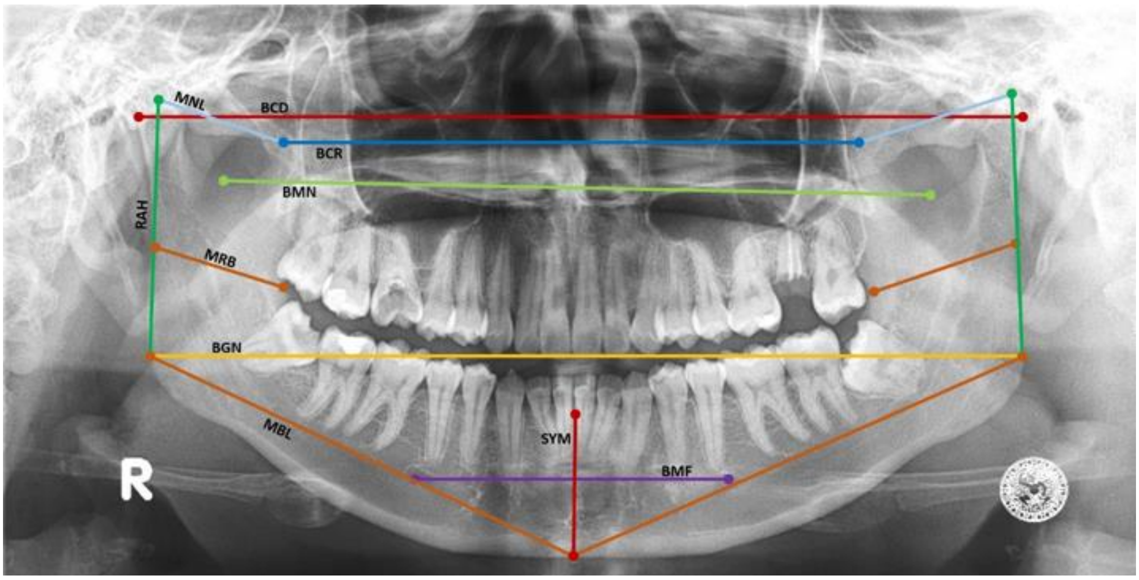

Figure 1 Ten mandibular parameters and the corresponding position on a digital panoramic radiograph for sex determination.

Ten mandibular parameters were determined on digital panoramic radiographs according to the method described by Bertsatos et al. (2019)(14). Figure 1 and Table 1 provide visual and numerical representations of these parameters. Each parameter was measured twice by the same observer using Adobe Photoshop®CS6 software, with a one-week interval between measurements, to ensure the reliability of the measurements. The resulting data were tabulated in Microsoft Excel 2019.

Table 1 Description of the measured variable for sex determination using a panoramic radiograph.

No	Parameters	Code	Definition
1	Bi-condylar Breadth	BCD	The linear distance between the right and left lateral condyle
2	Bi-Coronoid Breadth	BCR	Distance between the highest points of the mandibular coronoid processes
3	Bi-Mental Foramen Breadth	BMF	The distance between two mental foramen
4	Bi-Mandibular Notch Breadth	BMN	The distance between the right and left basis of the mandibular notch
5	Bi-Gonial Breadth	BGN	Direct distance between right and left gonial.
6	Minimum Ramus Breadth ●	MRB	The minimum distance between the anterior and posterior mandibular ramus
7	Symphysis Height	SYM	Direct Distance from Infradentale to Gnathion
8	Ramus Height ●	RAH	The distance between the superior processes condylar to the gonion
9	Mandibular Body Length ●	MBL	The distance between gonion and gnathion
10	Mandibular notch length ●	MNL	The distance between the superior processes condylar to the apex of coronoid processes

●= indicates a bilateral position of the parameter

Data analysis

The statistical analysis of this study was performed using IBM® SPSS® Statistics version 23.0 (IBM, Armonk, NY, USA). The reliability of the measurements was assessed using intraclass correlation (ICC) analysis. The discriminant function analysis was then conducted to investigate the variability of the parameters that differentiate between males and females.

Results

The present study examined 57 digital panoramic radiographs of outpatients (22 males and 35 females) aged between 18 and 40 in the university dental hospital. Ten mandibular parameters were measured, and mean values were determined, as summarized in Figure 2. The reliability of measurement is a critical aspect of anthropometric studies. Intraclass correlation (ICC) analysis showed that the measurement of each variable had excellent reliability with a correlation coefficient greater than 0.9 (19). Discriminant function analysis revealed a statistically significant difference between males and females in two variables: SYM and RAH, with Wilks' lambda values of 0.857 and 0.924, respectively, and p<0.05 (Table 2). The mean value of the symphysis height was 29.10+4.42 mm in males and 25.97+3.36 mm in females, with p=0.004. The mean value of ramus height was 54.64+10.79 mm in males and 49.89+7.13 mm in females, with p=0.038.

According to the structure matrix (Table 3), the SYM variable showed a higher sex discriminant value than the RAH, with a value of 0.588. A basic discriminant function formula can be determined based on two specific sex-determiner variables:

$$Z = A + B_1.X_1 + B_2.X_2 + \cdots + B_i.X_i$$

Z : Discriminant Score
A : Constant Value
B1, B2, ..., Bi : Discriminant Coefficient of the i-th Variable (1,2,3, ...)
X1, X2, ..., Xi : Results of the i-th Variable (1,2,3, ...)

As a result, the sex determination formula in this study using SYM and RAH variables can be determined as follows:

$$Z = -4{,}887 + (0{,}31)SYM + (0.046)RAH$$

Z : Discriminant Score
SYM : the measurement result of SYM variable
RAH : the measurement result of the RAH variable

The cutting score of Z is calculated based on the sample size and the centroid value of male and female subjects:

$$Z_C = \frac{N_M.C_M + N_F.C_F}{N_M + N_F} \rightarrow Z_C = \frac{(22x0.86)+(35x-0.54)}{22+35}$$

Z_C : Cutting Score
N_M : Male Sample Size
N_F : Female Sample Size
C_M : Centroids in Male Sample
C_F : Centroids in Female Sample

In this study, the cutting score for sex determination was calculated to be 0.0004. A subject is predicted to be male if the discriminant score (Z) is greater than 0.00 and female if the Z value is less than 0.00 (negative value) using this cutting score.

In this study, the discriminant function was tested on all study subjects. The results demonstrated that the formula could accurately predict the sex of 14 out of 22 male subjects (63.6%) and 33 out of 35 female subjects (94.3%).

Discussion

Sex determination is crucial in developing an individual's profile for forensic identification purposes. The mandible, the most prominent facial bone with a high degree of sexually

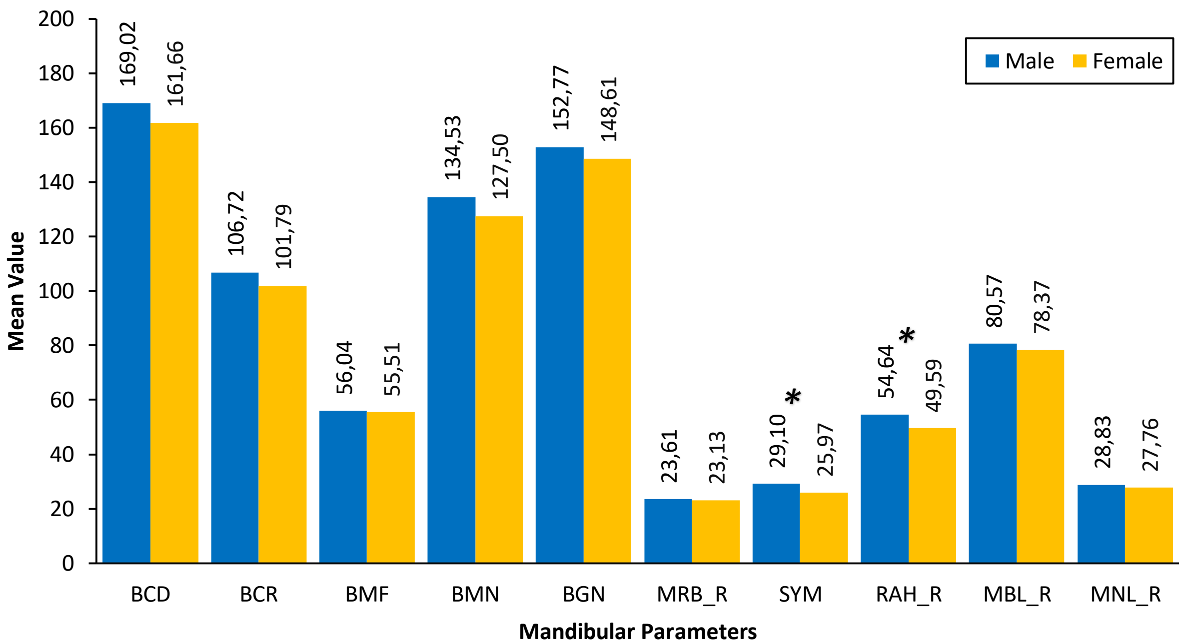

Figure 2 Comparison of the mean value of ten mandibular parameters between males and females. (*indicates significant difference between males and females, $p<0.05$).

dimorphic characteristics, is commonly employed in such analyses (20). The present study aimed to develop a specific formula for sex determination by evaluating ten mandibular parameters. Among the observed parameters, the symphysis and ramus heights were discovered to have significant values for sexual dimorphism in Surabaya, Indonesia population. These findings align with earlier studies that identified symphysis and ramus heights as sex-discriminatory elements in the mandible. Specifically, males tend to have a higher symphysis height than females, while females have a slightly lower ramus height than males (21,22). Tunis et al. (2020) similarly discovered the existence of sexual dimorphism through the analysis of symphysis size and shape, highlighting that males have a higher, thicker, larger, and more lingually oriented symphysis than females (23). A study by Aki et al. (1994) found that males had a higher and deeper symphysis than females (24). Although the results were statistically significant, differences in the measurement values of the studies were

Table 1 Reliability test of the measurements using intraclass correlation coefficient (ICC) analysis

Mandibular Parameters	Intraclass correlation	Degree of reliability
BCD	0.960	excellent
BCR	0.958	excellent
BMF	0.999	excellent
BMN	0.944	excellent
BGN	0.987	excellent
MRB	0.996	excellent
SYM	0.857	good
RAH	0.924	excellent
MBL	0.988	excellent
MNL	0.982	excellent

observed, demonstrating variability between populations (20).
A study conducted by Indira et al. identified the mandibular ramus as the most sexually dimorphic bone regarding minimum ramus breadth, condylar height, and projective height of the ramus (25). Giles found mandibular ramus height, maximum ramus breadth, and minimum ramus breadth to be highly significant, with an 85% accuracy rate in American Whites and Negroes (26). Steyn and Iscan (1998) achieved an accuracy rate of 81.5% in South African Whites using five mandibular parameters, including bi-gonial breadth, total mandibular length, bicondylar breadth, minimum ramus breadth, and gonion-gnathion (27). In a study by Dayal et al., mandibular ramus height was identified as the best parameter, with a 75.8% accuracy rate (28). Saini et al. studied the dry mandibular in the North Indian population and concluded that the mandibular ramus was a strong sexually dimorphic bone. The researchers hypothesized that muscle and hormonal differences could be potential contributing factors to the significant distinction between males and females (7).
The variability in bone remodeling patterns can contribute to the difference in mandibular size between males and females. Several factors, including genetics, race, masticatory muscle activity, hormonal, and socio-environmental factors (e.g., nutrition, food, climate, and pathologies), can influence bone remodeling and formation patterns. Males typically have greater bone volume and size than females because their bone formation primarily occurs in the periosteum, while females' bone formation primarily occurs in the endosteum (29–32). Sexual dimorphism of the mandibular bone can be observed from an early stage of human life. However, the level of sexual dimorphism decreases during childhood (between 4 and 14 years old) and becomes more apparent during adulthood (33,34). In a study by Loth et al. involving non-metric mandibular analysis of a South African sub-adult population, the shape differences in the symphysis and anterior mandibular corpus were helpful for sex determination with an accuracy of more than 80% (35). Similarly, a study on the Iranian sub-adult population identified that symphysis height and bi-gonial breadth of the mandible could be utilized for sex determination in people aged 12 to 19 (36).
Mandibular ramus and symphysis height can be measured non-invasively and efficiently using various radiographic imaging techniques such as panoramic radiography, cephalometry, and cone-beam computed tomography (CBCT). Among these techniques, the digital panoramic radiograph is commonly used by clinicians for diagnosing oral and maxillofacial diseases and is advantageous due to its broad coverage with a low radiation dose and efficient image processing (37). However, panoramic radiographs are subject to drawbacks such as magnification and geometric distortion, which can be influenced by factors such as X-ray exposure angle, the distance between the X-ray source and the object, and the object's position in the X-ray focal point (20). Positioning errors can also affect image quality due to the relatively narrow image layer of panoramic radiographs, resulting in blurred, magnified, or reduced objects that may be distorted (38). Furthermore, the focal trough shape and location vary across equipment brands. White and Pharoah reported that horizontal magnification in the posterior region is lower than in the anterior region, suggesting that objects in the posterior region of the jaw have less horizontal geometric distortion than those in the anterior region. Vertical magnification is more determined by the distance between the X-ray source and the object, which remains relatively constant throughout the horizontal rotation of the X-ray exposure (39).
The discriminant function developed in this study can successfully determine the sex of up to 82.5% of subjects; however, 17.5% were misclassified. Several factors, including the determination of a detailed scale and the precision of landmark point placement on a digital panoramic radiograph, may influence the misclassification of sex determination using Adobe Photoshop®CS6 software. Furthermore, Adobe Photoshop® CS6 software is a bitmap-based graphic software that is sensitive to image contrast or dark-light differences, where color contrast can cause the deformation of objects in the image, affecting the image's authenticity and final measurement results (40–42). The contrast adjustment factor was not regulated in this study, which may have contributed to the misclassification of 17.5% in sex determination using Adobe Photoshop®CS6 software. Most of the determined landmarks in the panoramic radiograph pass through areas with varying dark and light conditions, both horizontally and vertically, which can widen the pixel value of the images and cause a slight bias in scaling before

Table 2 Descriptive statistics and significance of differences between sexes using Adobe® Photoshop® CS6 software

Parameters	Male				Female				Sig.
	Mean	SD	Max.	Min.	Mean	SD	Max.	Min.	
BCD	169.02	17.52	195.10	136.38	161.66	17.95	198.69	128.08	0.134
BCR	106.72	12.97	125.97	81.95	101.79	10.75	126.80	80.81	0.126
BMF	56.04	9.70	74.85	38.94	55.51	7.93	76.72	42.36	0.822
BMN	134.53	14.81	159.41	109.23	127.50	14.02	156.38	103.65	0.077
BGN	152.77	18.74	182.32	120.89	148.61	17.85	195.70	117.17	0.405
MRB	23.61	3.44	31.74	18.14	23.13	3.92	31.47	15.35	0.644
SYM	29.10	4.42	40.88	22.58	25.97	3.36	33.73	19.89	0.004*
RAH	54.64	10.79	91.64	43.35	49.59	7.13	70.17	37.52	0.038*
MBL	80.57	10.62	96.60	61.53	78.37	9.23	105.00	61.60	0.413
MNL	28.83	3.56	36.19	22.09	27.76	4.20	36.83	20.70	0.324

Measurement unit in millimeters (mm) **Indicates a significant difference between male & female*

Table 3 Strength and Accuracy of Functions, Structure Matrix, Coefficient of Discriminant Functions, and Centroids

Canonical Correlation (CC)	Wilks' Lambda Sig.	Structure Matrix		Constant (A)	Coefficient (B)		Centroids (C)	
		SYM	RAH		SYM	RAH	Male	Female
0.570	0.033	0.588	0.414	-4.887	0.310	0.046	0.860	-0.540

Table 4 Classification results of the sex determiner formula

Prediction	Male			Female			Overall Accuracy	
	N	N prediction	%	N	N prediction	%	Total	%
Correct	22	14	63.6%	35	33	94.3%	47/57	82.5%
Incorrect		8	36.4%		2	5.7%	10/57	17.5%

measurement, ultimately affecting the accuracy of the results. Digital manipulation of radiographic images is often considered beneficial for improving reproducibility and diagnostic accuracy, as it enhances the visualization of anatomical structures. By using digital panoramic radiographs, filters may be readily applied to enhance the visualization of bone architecture (43,44). However, Tihanyi et al. found that in their study, the digital brightness and contrast adjustments did not improve the accuracy of linear measurements on radiographic images (45). While some authors suggest that digital manipulation can enhance the diagnostic value of radiographic interpretation, caution should be exercised when using digital filters or adjustments, as they may not constantly improve measurement accuracy.
This study was limited by a small sample size resulting from the impact of the COVID-19 pandemic. Additionally, since the study was conducted on a homogenous population, the accuracy of sex determination may be affected when applying the findings to a different population. However, despite this limitation, the study identified two critical variables for sex determination using digital panoramic radiographs: symphysis height and ramus height. These findings demonstrate the potential application of these variables for sex determination in more extensive studies and further research. This method can support identification in various settings, such as mass disasters, criminal investigations, and missing person cases.

Conclusions
This study demonstrates the utility of mandibular measurements on digital panoramic radiographs for sex determination and its comparability with similar studies. The symphysis and ramus height were found to be the most sexually-dimorphic mandibular parameters. A formula for determining sex using these variables has been proposed. However, the small sample size of this study indicates the need for future research with larger sample sizes to enhance the accuracy of sex determination through mandibular parameters.

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Ethical approval
The study was approved by the Health Research Ethical Clearance Commission at the Faculty of Dental Medicine, Universitas Airlangga (number: 394/HRECC.FODM/VIII/2020).

Declaration of Interest
None

Author Contributions
AK, AS, and AC contributed to the study design and data analysis. AK, TFN, AHN, and KW collected the data and wrote the draft of the paper. AK, BNR, and BFWRP searched the literature and reviewed the paper. AK, AY, and AM are the supervisor of this study. All authors have contributed and approved the final draft of the manuscript.

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