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Radiomorphometric analysis of mandibular symphysis and ramus heights on panoramic radiographs for sex determination in Surabaya, Indonesia*

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Abstract

Sex determination is a fundamental aspect of biological profile reconstruction in forensic identification. Previous studies recommended the mandible as a valuable indicator for this matter. This study aimed to evaluate mandibular morphometric parameters on panoramic radiographs using an open-source software for sex determination in Surabaya, Indonesia. This study analyzed 57 digital panoramic radiographs (22 males, 35 females; age range 18–40 years) from the Dental Hospital, Universitas Airlangga. Ten mandibular metrics were evaluated with ImageJ software and analyzed using discriminant function analysis (DFA) to identify sexually dimorphic variables. Among these, Symphysis Height (Sym) and Right Ramus Height (RaH_R) were the most reliable indicators. The discriminant function model achieved an overall correct classification of 85.96% (86.4% for males and 85.7% for females). Future studies with larger and more diverse samples, 3D imaging modalities, and advanced analytical methods, such as machine learning, are needed to strengthen forensic applicability and improve accuracy in human identification.

Keywords: Indonesians; legal identity; mandibular ramus; mandibular symphysis; morphometric analysis; sex determination

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Introduction

Scientific analysis of bones and teeth is crucial in identifying an individual's age and sex. Morphological characteristics of the pelvis and skull have been regarded as the most reliable anatomical structures for this purpose. In situations where these structures are unavailable, various mandibular morphometric parameters have shown consistent sexual dimorphism across populations (1–3).

Morphological variations of the mandible related to sexual dimorphism have been extensively investigated through diverse analytical methods (4). In Greek populations, mandibular morphology has been evaluated through discriminant function analysis, whereas studies in Jordanian samples have focused on angular relationships among the coronoid, condylar, and gonion points using panoramic radiographs (4,5). Similarly, research on Mexican and Santa Maria Xigui populations has revealed regional differences in mandibular dimorphism, and investigations in Chinese populations have analyzed the vertical distance between the mandibular foramen and its lower border on panoramic radiographs (6,7). Collectively, these studies emphasize the mandible's strong potential as a reliable indicator of sex, although the specific anatomical regions demonstrating the greatest dimorphic variation differ across populations and analytical techniques.

Surabaya, the second-largest city in Indonesia, comprises a multi-ethnic population with diverse genetic backgrounds, lifestyles, and cultural influences. In recent years, several cases involving gender falsification and identity alteration have been reported in this region, highlighting the importance of developing reliable biological reference data to support forensic investigations. Establishing population-specific standards for the Surabaya population would enhance forensic identification accuracy in Indonesia. Accordingly, this study aimed to assess mandibular morphometric parameters on panoramic radiographs and to evaluate their discriminatory power for sex determination. Although panoramic radiographs are susceptible to dimensional distortions, they remain widely used, readily available, and cost-effective in clinical and forensic settings, making them a practical tool for morphometric assessment.

Materials and Methods

This retrospective cross-sectional study obtained institutional ethical approval from the Health Research Ethical Clearance Commission, Faculty of Dental Medicine, Universitas Airlangga (permit number: 394/HRECC.FODM/VIII/2020). A total of 57 panoramic radiographs (22 males and 35 females, aged 18–40 years) that met the inclusion criteria were selected from the archive of the University Dental Hospital. The relatively small sample size was due to the retrospective design and strict eligibility requirements (high-quality images, complete demographic data, absence of orthodontic appliances or abnormalities). All radiographs were obtained with the same unit (Instrumentarium Orthoceph OC 200) to reduce variability in image evaluation. Ten mandibular parameters (Table 1 and Figure 1), as introduced by Bertsatos et al. 2019, were measured using ImageJ version 1.54g (National Institutes of Health, USA) (8). The measurements were performed twice by a single observer to ensure consistency and minimize biases

The reliability of the measurements was assessed using the Intraclass Correlation Coefficient (ICC) analysis. Additionally, discriminant function analysis was employed to determine the most sexually dimorphic variables and to develop a population-specific model for sex estimation based on the study sample. All statistical analyses were conducted using IBM® SPSS® Statistics version 23.0 (IBM, Armonk, NY, USA).

Results

Linear measurements of ten mandibular parameters were performed twice on panoramic radiographs. ICC analysis produced coefficients exceeding 0.8, indicating good measurement consistency across the two measurement sessions. The descriptive statistics (Table 2) showed that male subjects exhibited higher mean values in most parameters compared to females. Statistically significant dimorphism was found in bi-condylar breadth (BiCon), bi-coronoid breadth (BiCor), bi-mandibular notch breadth (BiMdN), symphysis height (Sym), and right and left ramus height (RaH) ($p < 0.05$).

Stepwise discriminant function analysis (DFA) identified Sym and RaH_R as the most influential variables for sex determination, with Wilks' lambda values of 0.746 and 0.701, respectively. As a result, only Sym and RaH_R were incorporated into the discriminant function model, highlighting their reliability in sex classification.

Statistical analysis revealed a strong correlation between two mandibular parameters (Sym and Rah_R) and sexual dimorphism, with a canonical correlation (CC) value of 0.645. This indicates that approximately 41.60% of the variance in

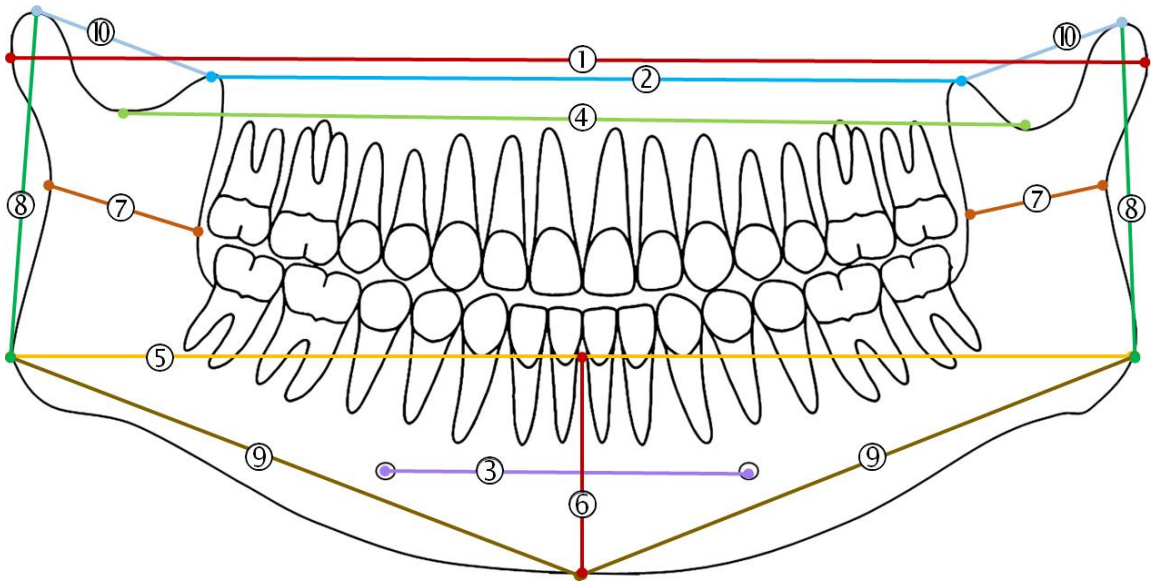

Figure 1. Illustration of the ten mandibular morphometric parameters analyzed in this study. Each numbered landmark corresponds to the parameters listed in Table 1.

sexual dimorphism can be explained by the discriminant function derived in this study. Furthermore, an analysis of the absolute values in the Structure Matrix (Table 3) showed that Sym contributed more substantially to the discriminant function than RaH_R, suggesting that symphysis height is a more reliable parameter for sex estimation in the studied population.

The derived equation for sex determination in this study using Sym and RaH_R variables can be determined as follows:

Z = -16.729 + (0.020)Sym + (0.011)RaH_R

Z: Discriminant Score
Sym: the measurement result of the Sym variable
RaH_R: the measurement result of the RaH_R variable
Individuals with Z > 0 were classified as male, those with Z < 0 as female

The discriminant score (Z) threshold is calculated based on the sample size and the centroid value of males and females, resulting in a cutting score of 0.0007 and rounded to 0.00 for practical interpretation. According to this threshold, individuals with a Z score greater than 0.00 were classified as male, whereas those with a negative score were classified as female. The discriminant function was subsequently cross-validated using all study samples (Table 4), achieving a correct classification rate of 86.4% for males (19 of 22 samples) and 85.7% for females (30 of 35 samples), resulting in an overall correct classification of 85.96%.

Discussion

Sex determination plays an important role in forensic identification, contributing to the reconstruction of an individual's biological profile. The mandible, as the largest and most robust facial bone, exhibits pronounced sexual dimorphism, making it a valuable skeletal element for sex estimation (1). This study aimed to evaluate various mandibular parameters through radiomorphometric analysis and identify those most effective for sex determination. Five parameters exhibited significant dimorphic variation: bi-condylar breadth (BiCon), bi-coronoid breadth (BiCor), bi-mandibular notch breadth (BiMdN), symphysis height (Sym), and right and left ramus height (RaH). Among these, symphysis height (Sym) and right ramus height (RaH_R) demonstrated the strongest discriminatory power in distinguishing between sexes. A study by Datau et al. (2024) on different populations in Indonesia found a significant difference in symphysis height, ramus height and width, coronoid height, and mandibular corpus height (9).

The current findings reinforced the significance of mandibular morphometric analysis for sex determination in forensic and anthropological contexts. The observed sexual dimorphism in mandibular measurements aligns with previous research, where males exhibited consistently

larger dimensions than females due to physiological and developmental differences. Notably, symphysis height (Sym) and right ramus height (RaH_R) emerged as the most sexually dimorphic parameters, underscoring their relevance in sex estimation. Tunis et al. (2020) further corroborated these observations, reporting that males typically possess a higher, thicker, and more lingually inclined symphysis than females (10–12). Similarly, Aki et al. (1994) found that males displayed a higher and deeper symphysis compared to females. However, despite the statistical significance of these findings, variations in absolute measurement values across studies suggest that mandibular morphology may differ based on population-specific factors such as genetic background, environmental influences, and dietary habits (10). Several previous studies have demonstrated the utility of mandibular measurements for sex determination across different populations. Bertsatos et al. (2019) analyzed Greek populations and reported similar findings regarding the significance of ramus height in sexual dimorphism (5). Likewise, Leversha et al. (2016) found a correlation in mandibular morphology with age and sex in Far North Queensland, particularly in ramus height and bigonial width (13). Additionally, Franklin et al. (2008) investigated Australian samples and identified symphysis height as a key determinant of sexual dimorphism. These studies highlight the influence of genetic and environmental factors on mandibular morphology, reinforcing the need for population-specific standards in forensic analysis.

Regarding the usefulness of the mandibular ramus for sex determination, Kharoshah et al. (2010) examined an Egyptian population and emphasized the importance of mandibular ramus measurements for sex determination (14). Ceballos et al. (2025) explored Chilean samples and reported that the maximum height of the mandibular ramus presented the greatest predictive power of 76.5% (15). Similarly, Gamba et al. (2016) conducted a study on a Brazilian population and found that mandibular metrics, including gonial angle and ramus height, significantly contributed to sex estimation (16). In a study by Dayal et al., mandibular ramus height was identified as the best parameter, with a 75.8% accuracy rate (17). Saini et al. studied the dry mandible 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 (18).

The correct classification rates obtained in this study (86.4% for males and 85.7% for females) are consistent with those reported in previous studies utilizing mandibular morphometric parameters for sex estimation. However, the canonical correlation value of 0.645 (explaining 41.6% of the variance) indicates that incorporating additional variables or employing alternative analytical approaches may improve classification accuracy. Misclassification occurred in 14.04% of cases, highlighting that mandibular morphometry should not be used as a sole identification tool but in combination with other biological indicators. Variations in mandibular morphology observed across different studies may be influenced by population-specific characteristics, environmental factors, and genetic determinants that collectively contribute to inter-population differences in sexual dimorphism (19).

The use of open-source software, such as ImageJ, in this study demonstrates the feasibility of employing accessible tools for forensic applications. This approach enhances reproducibility and allows for wider implementation across different research settings. Nevertheless, certain limitations must be acknowledged. The study sample was derived from a specific population, potentially limiting the generalizability of the findings to other ethnic or geographical groups. Furthermore, reliance on a two-dimensional imaging system introduces potential measurement distortions that may be mitigated by three-dimensional imaging modalities (20,21).

Previous studies using panoramic radiographs have shown that measurements along the vertical axis offer better sex discrimination than those along the horizontal axis (22,23). This contrasts with studies using dry mandibles, where horizontal measurements demonstrated superior discriminatory ability (24,25). These discrepancies may arise from differences in horizontal dimension distortions in panoramic radiographs, influenced by patient positioning relative to the X-ray source and the panoramic imaging technique, which captures the mandible by rotating around the patient's head.

Panoramic radiographs represent a practical and widely accessible tool for human identification, particularly in sex estimation. Numerous studies

Table 1. Mandibular morphometric parameters analyzed in this study, adapted from Bertsatos et al. (2019).

No	Parameters	Abbrv.	Definition
Unilateral parameters			
1	Bi-condylar Breadth	BiCon	The distance between the right and left lateral condyle (cdl-cdl)
2	Bi-Coronoid Breadth	BiCor	The distance between the right and left coronoid processes (co-co)
3	Bi-Mental Foramen Breadth	BiMen	The distance between right and left mental foramen (mf-mf)
4	Bi-Mandibular Notch Breadth	BiMdN	The distance between the right and left mandibular notch (mn-mn)
5	Bi-Gonion Breadth	BiGn	Direct distance between right and left gonion (go-go)
6	Symphysis Height	Sym	Direct distance from infradentale to gnathion (in-gn)
Bilateral parameters (Right and Left)			
7	Minimum Ramus Breadth	MinRaB	The minimum distance between the anterior and posterior mandibular ramus
8	Ramus Height	RaH	The distance between the superior processes condylar to the gonion (cs-go)
9	Mandibular Body Length	MdBL	The distance between gonion and gnathion (go-gn)
10	Mandibular notch length	MdNL	The distance between the coronion and condylion superior (co-cs)

Table 2. Descriptive Statistics and Sex-Based Differences in Mandibular Linear Measurements Using ImageJ Software.

Parameters		Male (n= 22)				Female (n= 35)				Sig.
		Mean	S.D	Min.	Max.	Mean	S.D	Min.	Max.	
Unilateral										
BiCon		2583.91	172.82	2184,08	2841,10	2457.57	133.81	2211,23	2682,13	0.003*
BiCor		1634.47	139.93	1380,00	1871.39	1558.11	109.12	1353.07	1778.01	0.025*
BiMen		823.80	139.05	459.15	1101.34	826.38	104.03	576.17	1102.08	0.936
BiMdN		2060.11	154.85	1758.69	2304.10	1942.52	117.56	1684.17	2160.02	0.002*
BiGn		2326.78	185.20	2017.15	2718.09	2259.82	149.93	1892.21	2571.65	0.140
Sym		443.53	46.64	360.13	567.04	395.25	28.81	341.95	452.97	0.000*
Bilateral										
MinRaB	R	376.82	49.87	311.48	550.19	367.32	46.90	248.97	448.32	0.470
	L	350.80	40.15	283.75	484.66	348.80	49.96	255.46	435.31	0.875
RaH	R	818.25	57.40	715.01	921.43	750.12	58.19	603.01	837.73	0.000*
	L	792.79	52.10	695.33	872.74	740.68	67.58	544.33	873.20	0.003*
MdBL	R	1255.97	102.44	1078.60	1431.92	1219.90	88.99	952.00	1384.54	0.166
	L	1204.01	122.40	1030.75	1435.33	1163.60	75.21	1001.44	1350.53	0.128
MdNL	R	446.85	37.80	367.10	515.18	428.29	47.35	340.47	526.04	0.126
	L	414.77	36.83	344.92	483.34	402.48	44.71	316.43	500.30	0.286

**indicates statistically significant difference; measurement unit in pixels*

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_R		Sym	RaH_R	Male (n: 22)	Female (n: 35)
0.645	0.000	0.773	0.690	−16.729	0.020	0.011	1.047	−0.658

Table 4. Classification results of the sex determiner formula. Cross-validated on all study samples.

Prediction	Male			Female			Overall Accuracy	
	N	N prediction	%	N	N prediction	%	Total	%
Correct	22	19	86.4%	35	30	85.7%	49/57	85.96%
Incorrect		3	13.6%		5	14.3%	8/57	14.03%

have demonstrated that mandibular features captured on panoramic radiographs exhibit sufficient sexual dimorphism for reliable sex determination. Nevertheless, these radiographs possess inherent limitations, including geometric distortion and magnification variability among individuals. Such distortions may result from factors such as X-ray beam angulation, the distance between the X-ray source and the object, and the subject's positioning within the focal trough. According to White and Pharoah (2014), horizontal magnification tends to vary between anterior and posterior regions—being slightly greater in the anterior area—whereas vertical magnification is largely influenced by the source-to-object distance, which remains relatively stable due to the rotational acquisition process of panoramic imaging (26).

Although this study offers valuable insights into mandibular morphometry for sex determination, several limitations should be acknowledged. First, the sample was restricted to individuals from Surabaya, Indonesia, and may not represent populations with differing genetic or environmental characteristics. Second, two-dimensional panoramic radiographs may introduce measurement distortions caused by magnification and geometric variation, potentially affecting the accuracy of the results. While ImageJ provided standardized and reproducible measurements, observer error remains possible. Automated landmarking and AI-based morphometric analysis may reduce such errors and improve reliability.

Furthermore, although the discriminant function model demonstrated satisfactory accuracy, its reliability requires validation using larger and more demographically diverse samples. Future research should incorporate 3D imaging techniques, machine learning approaches, and expanded datasets to improve the precision, reproducibility, and forensic applicability of mandibular morphometric analysis.

Conclusion

This study highlights the reliability of mandibular morphometric analysis using panoramic radiographs for sex determination in the Surabaya population. Symphysis height (Sym) and right ramus height (RaH_R) were identified as the most discriminatory parameters. While these findings are consistent with previous research, the limitations of 2D imaging, relatively small sample size, and population-specific variation underscore the need for further validation. Future studies should employ larger and more diverse samples, 3D imaging modalities, and advanced analytical methods such as machine learning to strengthen forensic applicability and improve accuracy in human identification.

Declaration of Interest

None

Author Contributions

AK: Conceptualization, methodology, formal analysis, writing original draft, review, supervision. TFN: methodology, data curation, investigation, writing original draft. AC: methodology, validation, investigation, visualization. BNR: data curation, writing original draft, review. MIM: investigation, data curation, visualization. NNWN: data curation, investigation. SS: data curation, investigation. RAR: visualization, writing original draft, review, supervision. AM: visualization, writing original, review, supervision.

Statement on the use of artificial intelligence in manuscript preparation

The authors declare that artificial intelligence (AI) tools were used solely to assist with language editing and improving the clarity and readability of the manuscript. The AI tools were not used to generate scientific content, analyze data, interpret results, or draw conclusions.

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