Datau et al.
Egyptian Journal of Forensic Sciences (2024) 14:36
https://doi.org/10.1186/s41935-024-00410-4

Egyptian Journal of Forensic Sciences

ORIGINAL ARTICLE Open Access

Linear measurements of the mandible on panoramic radiograph for sex estimation in populations in Yogyakarta, Indonesia

Selcaria Istna Datau[1], Sekar Khansa Aisha[1], Nurulita Fida Aulia[1], Rurie Ratna Shantiningsih[2,3], Munakhir Mudjosemedi[2], Ryna Dwi Yanuaryska[2,3] and Rini Widyaningrum[2,3*]

Abstract

Background Identification is one of the main aspects of forensics. Sex estimation is an essential part of identification because it can simplify the whole process. Mandible is the largest, strongest, and sexually dimorphic bone and is part of the orofacial structure, which has the second highest level of dimorphism after the pelvic bone. Sex estimation using the mandible can be performed by conducting various linear measurements on a panoramic radiograph, including right minimum ramus width (RMiRW), left minimum ramus width (LMiRW), right projective height of ramus (RPHR), left projective height of ramus (LPHR), right maximum ramus width (RMxRW), left maximum ramus width (LMxRW), right coronoid height (RCH), left coronoid height (LCH), symphysis height (SH), right mandibular corpus height (RMCH), and left mandibular corpus height (LMCH). This study aimed to analyze how linear measurements in panoramic radiographs differ between men and women and to estimate sex by utilizing these parameters.

Results In this study, 195 panoramic radiographs from 95 men and 100 women aged 20–40 years obtained from our dental hospital were used as a training data. Meanwhile, 61 panoramic radiographs from 29 men and 32 women outside the training data with same characteristics were used as the testing data. The linear measurements of the mandible using panoramic radiographs were taken with EzDent-i Vatech software. Independent *t*-test showed significant difference ($p < 0.05$) in some linear measurements of the mandible between adult men and women. These significantly different linear measurements were then subjected to discriminant function analysis to produce sex estimation equations. The equation accuracy percentage ranged between 63.6 and 94.4% for the training sample and 59.5% and 85% for the testing sample.

Conclusion The linear measurements of the mandible using diagnostically acceptable panoramic radiographs taken from a patient with standardized head positioning can serve as an alternative method for sex estimation. The accuracy of discriminant analysis for sex estimation varies depending on the parameter used in the estimation.

Keywords Sex estimation, Panoramic radiograph, Mandible, Linear measurement

*Correspondence:
Rini Widyaningrum
rinihapsara@ugm.ac.id
[1] Dental Study Program, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
[2] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
[3] Professor Soedomo Dental Hospital, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

Background

Forensic odontology, a branch of dentistry, deals with the appropriate handling of dental evidence and findings for identification or legal issues (Krishan et al. 2015). The main aspect of forensics is identification, which assists investigators in determining an individual's identity, such as sex, age, and specific population. Sex is one of the keys in identification. Given that men and women are the only two biological sexes in the world, the identification becomes easier when the sex is known because other possibilities can be eliminated; however, rare sex-related genetic disorders must be considered (Mello-Gentil and Souza-Mello 2022).

Sexually dimorphic bones are required in sex identification procedures. The mandible has been proven to be applicable in sex estimation procedures with high accuracy levels, just below the level of pelvic (Brogdon 2011). The mandible is a dense bone and resistant to impact; thus, it remains intact and usable for the identification of incomplete remains. Moreover, the mandible also provides sexually dimorphic characteristics due to differences in its growth duration, developmental phase, and muscle activity, which significantly differ between men and women (Toneva et al. 2021). The mandible in men has a larger size and tends to have a rougher shape compared with those in women (Brogdon 2011). The postpubertal period is chosen for measuring mandibular parameters for sex estimation, specifically from the age of 20 years when active mandibular growth has been achieved and thus sexual dimorphism can be observed due to hormone influences and mandibular growth stabilization until the age of 40 years before the aging process begins (Aurizanti et al. 2017).

The use of radiographs for identification has been widely accepted because it is a noninvasive, simple, and cost-effective method (Nagi et al. 2019; Zhang 2022). Panoramic radiography is an extraoral radiographic technique commonly employed because of its wide coverage of the oral and maxillofacial area, quick procedure, and low radiation exposure (Sairam et al. 2016). This approach provides a comprehensive 2D depiction of the oromaxillofacial region in a single image. It also offers morphological and morphometric information on bones during growth process and is accurate in measuring the vertical and horizontal dimensions of the mandible (Indira et al. 2012; Rad et al. 2020).Several previous studies have utilized multiple parameters in the mandible have been utilized to achieve a high level of accuracy in sex estimation (Prasetiowati et al. 2023). Nevertheless, the accuracy of these functions as sex predictors tends to decline when applied to samples that differ from the reference population. Hence, a sex estimation formula specific to the population must be created. This study analyzed various linear measurements of the mandible on panoramic radiographs that have been selected from a literature review and used them to construct a specialized sex estimation formula for the 20- to 40-year-old population in Yogyakarta, Indonesia, which has not been thoroughly explored.

Methods

Study design and ethical aspects

This analytical observational study had a cross-sectional design. Digital panoramic radiographs were collected retrospectively from the dental records in the Professor Soedomo Dental Hospital of Universitas Gadjah Mada, Yogyakarta, Indonesia. Ethical clearance was obtained from the Ethics Commission of the Faculty of Dentistry and Dental Hospital of Universitas Gadjah Mada (ref. no. 70/UN1/KEP/FKG-RSGM/EC/2023).

Sample characteristics

A total of 195 panoramic radiographs (95 men and 100 women) for training data and 61 samples (29 men and 32 women) for testing data were taken from patients aged 20–40 years who came to the university dental hospital from January 2021 to March 2024. These radiographs were taken based on the following inclusion criteria: (1) completely erupted teeth (excluding third molars); (2) the radiographic image covers the entire area that must be covered on a panoramic radiograph, namely the teeth, mandibular ramus and cervical vertebrae, nasal cavity and maxillary sinus, mandibular body, mandibular condyle, and hyoid bone; (3) minimal horizontal distortion and vertical distortion; (4) no artifacts, ghost images, or foreign objects (such as metal accessories, orthodontic appliances, glasses, and dentures) that could interfere with the anatomical image of the radiograph; (5) the hard palate and floor of the nasal cavity are clearly visible (not superimposed on the apices of the maxillary teeth); (6) the maxillary and mandibular anterior teeth are clearly visible; and (7) the radiograph has a right "R" and/or left "L" marker. The exclusion criteria were as follows: (1) radiographic images indicate errors in patient positioning during imaging, namely the patient's neck is too extended and produce a ghost image of cervical vertebrae on the anterior teeth, head position is not on the focal trough and caused the mesiodistal width of anterior teeth to decrease if it too far forward and the image of the anterior teeth to widen if it too far back, the Frankfort horizontal plane (FHP) is not parallel to the floor either due to the patient's head being too bent down and caused the occlusal plane to appear like the letter "V" or being too upturned and caused the occlusal plane to be inverted (reversed smile line), the patient's sagittal plane is not perpendicular to the floor or turns to one side and caused the part closer to the receptor to become narrow and the part away from it to widen, the patient's tongue is not on the palate and produced a radiolucent image covering the apex of maxillary anterior teeth, the patient moves during imaging and caused a deformity in the mandible, and the patient's mouth is open and caused a distortion of anterior teeth; (2) tooth loss in the mandible (partial/fully edentulous); (3) pathological or traumatic lesions in the mandible; and (4) radiographic features indicating temporomandibular joint disorders, including condyle hyperplasia (unilateral/bilateral), condyle hypoplasia (unilateral/bilateral), coronoid process hyperplasia, ankylosis, tumors, juvenile arthrosis, bifid condyle, osteoarthritis, and rheumatoid arthritis.

Variable measurements

Measurements were conducted using the EzDent-i Vatech software (Gyeonggi-do, South Korea). The measurement data included minimum ramus width (MiRW), projective height of ramus (PHR), maximum ramus width (MxRW), coronoid height (CH), symphysis height (SH), and mandibular corpus height (MCH).

MiRW is the smallest anterior–posterior diameter of the ramus. PHR is the point between the highest part of the mandibular condyle and the lowest border of the bone. MxRW is the distance between the most anterior point on the mandibular ramus and a line connecting the most posterior point on the condyle and the angle of jaw (Sairam et al. 2016). CH is the measured distance between coronation and most protruding portion of the inferior border of the ramus. SH is the distance from infradentale between the central incisors to menton (Fekonja and Čretnik 2022; Rad et al. 2020). MCH is the distance from the alveolar process to the inferior border of the mandible, perpendicular to the base at the mental foramen (Sambhana et al. 2016).

Except SH, all the variable measurements were obtained on the right and left sides, with the assumption that all the radiographs were bilaterally symmetrical as described in Fig. 1. These measurements were collected and tabulated using special codes to ensure patient data confidentiality.

To ensure that the size of panoramic radiographs used in this study was the same, standardization of measurement was done by using the radiographs produced from the same X-ray unit. Radiographs selection was also done by strictly following the inclusion and exclusion criteria so that the radiographs used as samples are guaranteed not carried out distortion. In addition, radiograph measurements used the same software and computer unit by all measurers. The measurement tools in the software had been calibrated so that the measurement results are accurate.

Statistical analysis

The initial step was to assess interobserver reliability by measuring 10% of the sample (20 men and 20 women). Within 2 weeks after the initial measurements were taken, intraobserver reliability was tested by remeasuring 30% of the sample (40 men and 40 women). Kolmogorov–Smirnov normality test was conducted to determine the distribution of the data as a prerequisite for selecting inferential statistical methods.

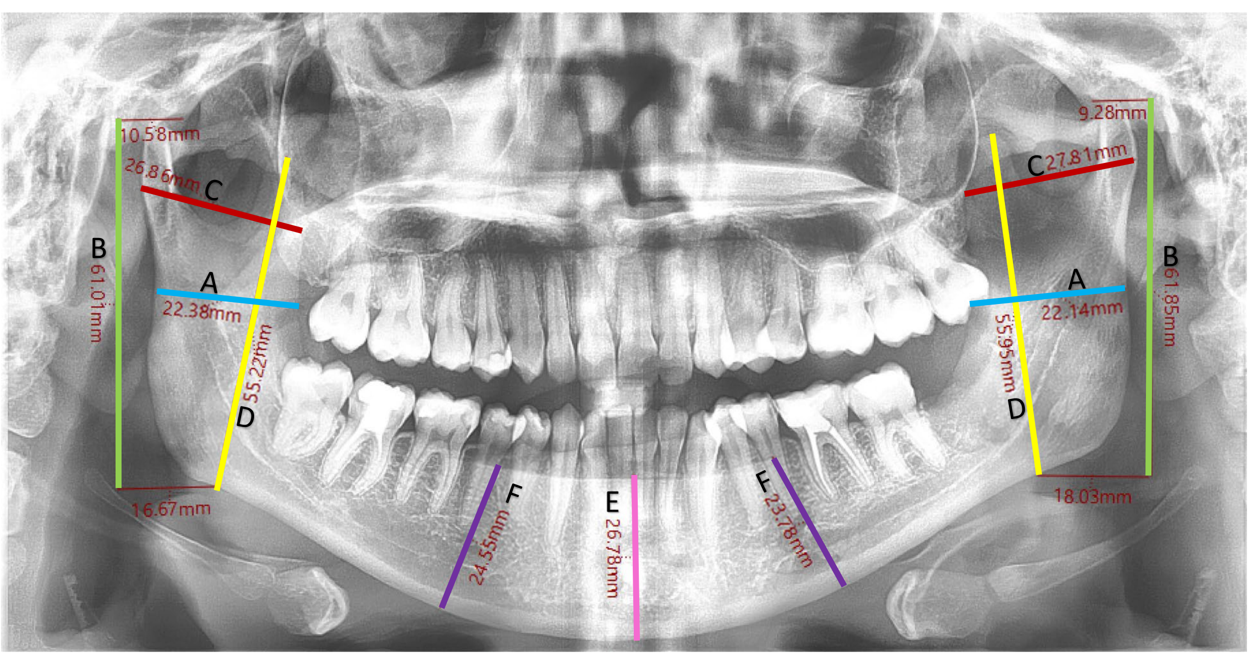

Fig. 1 Linear measurements on panoramic radiograph. A Minimum ramus width (MiRW), B projective height of ramus (PHR), C maximum ramus width (MxRW), D coronoid height (CH), E symphysis height (SH), and F mandibular corpus height (MCH)

Independent *t*-test was then performed to assess the intergroup differences in measurements and identify the significantly different variables between men and women, potentially serving as components in the discriminant function analysis equation. Given that the sample distribution prerequisites (normality) were satisfied, a discriminant function analysis equation was then established by utilizing the variables that significantly differed between men and women. The obtained equation was then tested for accuracy in estimating the sex of the same sample. The results were expressed in percentage. Afterward, the sex estimation equation was tested on a new sample, and the estimated sex was compared with the actual sex. The percentage of correct sex estimation results was then calculated.

Results

The reliability test was conducted using the intraclass correlation coefficient (ICC) two-way random effects model for consistency, and the results are listed in Table 1. Meanwhile, the results of the normality test are presented in Table 2.

According to Table 2, the normality test results indicate that all variables have a significance level (p > 0.05), suggesting that the data are normally distributed. Further analysis was then performed using parametric methods. The outcomes of the independent *t*-test to determine the differences in measurements between men and women are outlined in Table 3.

As shown in Table 3, the measurement results are significantly different ($p < 0.05$) between men and women. The mean ± SD of all linear measurements is greater in men than in women.

Based on the results in Table 3, discriminant function analysis equations were established by utilizing the variables that exhibited significant differences between men and women. The assumption was that the sample distribution prerequisites (normality test) are satisfied. Ten equations were developed as listed in Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13.

The 10 equations obtained from some combinations of variables were then tested for accuracy in estimating the sex of the training sample. The results were expressed in percentages as shown in Table 14.

The sex estimation equation produced by discriminant function analysis was then tested on a new sample, and the estimated sex was compared with the actual sex. The percentage of correct sex estimation results with testing sample is shown in Table 15.

Table 1 ICC score for intraobserver and interobserver tests

Linear measurement	*Intraobserver*	*Sig.*	*Interobserver*	*Sig.*
Minimum ramus width (MiRW)	0.990	0.000	0.989	0.000
Projective height of ramus (PHR)	0.996	0.000	0.994	0.000
Maximum ramus width (MxRW)	0.986	0.000	0.969	0.000
Coronoid height (CH)	0.996	0.000	0.988	0.000
Symphysis height (SH)	0.795	0.000	0.781	0.000
Mandibular corpus height (MCH)	0.909	0.000	0.907	0.000

Table 2 Normality test with Kolmogorov–Smirnov

Linear measurement	Sex	Statistic	df	Sig.
Right minimum ramus width (RMiRW)	Men	0.056	95	0.200*
	Women	0.049	100	0.200*
Left minimum ramus width (LMiRW)	Men	0.047	95	0.200*
	Women	0.086	100	0.064*
Right projective height of ramus (RPHR)	Men	0.054	95	0.200*
	Women	0.086	100	0.065*
Left projective height of ramus (LPHR)	Men	0.072	95	0.200*
	Women	0.074	100	0.197*
Right maximum ramus width (RMxRW)	Men	0.060	95	0.200*
	Women	0.066	100	0.200*
Left maximum ramus width (LMxRW)	Men	0.042	95	0.200*
	Women	0.076	100	0.169*
Right coronoid height (RCH)	Men	0.042	95	0.200*
	Women	0.063	100	0.200*
Left coronoid height (LCH)	Men	0.049	95	0.200*
	Women	0.055	100	0.200*
Symphysis height (SH)	Men	0.045	95	0.200*
	Women	0.071	100	0.200*
Right mandibular corpus height (RMCH)	Men	0.069	95	0.200*
	Women	0.049	100	0.200*
Left mandibular corpus height (LMCH)	Men	0.076	95	0.200*
	Women	0.063	100	0.200*

* p > 0.05 based on the normality test set in 95% confidence interval

Discussion

The methods for identifying bodies found in a disaster can be divided into comparative and reconstructive. The former requires the availability of complete antemortem data, which can be used for comparison with postmortem data. The latter focuses on deducing the identity of the body based on available postmortem data (Sassouni, 1963 sit. Sairam et al. 2016). The reconstructive method is useful for identifying fatalities in large-scale open disasters that occur over a large area, often in the absence of adequate antemortem data (Interpol 2018).

Table 3 Results of independent *t*-test among all linear measurements

Linear measurement	Sex	Mean	SD	Sig. (2-tailed)
Right minimum ramus width (RMiRW)	Men	23.2599	2.16534	0.000*
	Women	21.7832	1.89383	
Left minimum ramus width (LMiRW)	Men	23.4252	2.16695	0.000*
	Women	21.9467	1.78940	
Right projective height of ramus (RPHR)	Men	65.0601	5.38885	0.000*
	Women	58.4835	3.75862	
Left projective height of ramus (LPHR)	Men	65.5961	4.89616	0.000*
	Women	58.2810	3.79362	
Right maximum ramus width (RMxRW)	Men	33.5764	2.67578	0.000*
	Women	32.1281	2.51848	
Left maximum ramus width (LMxRW)	Men	33.6522	2.79737	0.001*
	Women	32.3319	2.53833	
Right coronoid height (RCH)	Men	60.8754	4.19949	0.000*
	Women	54.2144	3.66056	
Left coronoid height (LCH)	Men	61.0692	4.27832	0.000*
	Women	54.3089	3.50867	
Symphysis height (SH)	Men	31.7020	1.85218	0.000*
	Women	27.9864	1.31624	
Right mandibular corpus height (RMCH)	Men	31.4854	2.03619	0.000*
	Women	28.2178	1.68003	
Left mandibular corpus height (LMCH)	Men	31.5406	2.10485	0.000*
	Women	28.1315	1.60031	

* $p < 0.05$ based on the independent *t*-test set in 95% confidence interval

Table 4 Discriminant function analysis by using 11 linear measurements

Linear measurement	Function coefficient	Discriminant function	Centroid
Right minimum ramus width (RMiRW)	−0.018	*Z* = −23.389–0.018 RMiRW + 0.055 LMiRW–0.035 RPHR + 0.077 LPHR + 0.072 RMxRW–0.074 LMxRW + 0.077 RCH + 0.023 LCH + 0.407 SH–0.015 RMCH + 0.086 LMCH	Men: 1.446 Women: −1.374
Left minimum ramus width (LMiRW)	0.055		
Right projective height of ramus (RPHR)	−0.035		
Left projective height of ramus (LPHR)	0.077		
Right maximum ramus width (RMxRW)	0.072		
Left maximum ramus width (LMxRW)	−0.074		
Right coronoid height (RCH)	0.077		
Left coronoid height (LCH)	0.023		
Symphysis height (SH)	0.407		
Right mandibular corpus height (RMCH)	−0.015		
Left mandibular corpus height (LMCH)	0.086		
(Constant)	−23.389		

Table 5 Discriminant function analysis by using linear measurements after stepwise method

Linear measurement	Function coefficient	Discriminant function	Centroid
Left projective height of ramus (LPHR)	0.058	*Z* = −22.733 + 0.058 LPHR + 0.098 RCH + 0.454 SH	Men: 1.417 Women: −1.346
Right coronoid height (RCH)	0.098		
Symphysis height (SH)	0.454		
(Constant)	−22.733		

Table 6 Discriminant function analysis by using linear measurements in the right mandibular side

Linear measurement	Function coefficient	Discriminant function	Centroid
Right minimum ramus width (RMiRW)	0.014	*Z* = −19.839 + 0.014 RMiRW + 0.042 RPHR − 0.008 RMxRW + 0.129 RCH + 0.327 RMCH	Men: 1.137 Women: −1.080
Right projective height of ramus (RPHR)	0.042		
Right maximum ramus width (RMxRW)	−0.008		
Right coronoid height (RCH)	0.129		
Right mandibular corpus height (RMCH)	0.327		
(Constant)	−19.839		

Table 7 Discriminant function analysis by using linear measurements in the left mandibular side

Linear measurement	Function coefficient	Discriminant unction	Centroid
Left minimum ramus width (LMiRW)	0.007	*Z* = −19.766 + 0.007 LMiRW + 0.080 LPHR − 0.032 LMxRW + 0.107 LCH + 0.321 LMCH	Men: 1.215 Women: −1.154
Left projective height of ramus (LPHR)	0.080		
Left maximum ramus width (LMxRW)	−0.032		
Left coronoid height (LCH)	0.107		
Left mandibular corpus height (LMCH)	0.321		
(Constant)	−19.766		

Table 8 Discriminant function analysis by using MiRW

Linear measurement	Function coefficient	Discriminant function	Centroid
Right minimum ramus width (RMiRW)	0.230	*Z* = −11.876 + 0.230 RMiRW + 0. 296 LMiRW	Men: 0.398 Women: −0.378
Left minimum ramus width (LMiRW)	0.296		
(Constant)	−11.876		

Table 9 Discriminant function analysis by using PHR

Linear measurement	Function coefficient	Discriminant function	Centroid
Right projective height of ramus (RPHR)	−0.015	*Z* = −14.086 − 0.015 RPHR + 0.242 LPHR	Men: 0.860 Women: −0.817
Left projective height of ramus (LPHR)	0.242		
(Constant)	−14.086		

Table 10 Discriminant function analysis by using MxRW

Linear measurement	Function coefficient	Discriminant function	Centroid
Right maximum ramus width (RMxRW)	0.290	*Z* = −13.250 + 0.290 RMxRW + 0.113 LMxRW	Men: 0.292 Women: −0.277
Left maximum ramus width (LMxRW)	0.113		
(Constant)	−13.250		

Sex estimation is the first step in body identification because other estimates such as age, specific population, and stature rely on the sex estimation results (Mello-Gentil and Souza-Mello 2022). Sex can be identified using sexually dimorphic bones. The mandible is a sexually dimorphic bone whose sex estimation accuracy is second only to the pelvis (Brogdon 2011). Mandibular characteristics indicate sexual dimorphism that is related to growth duration, developmental phases, and muscle activity, which differ in men and women. The mandible

Table 11 Discriminant function analysis by using CH

Linear measurement	Function coefficient	Discriminant function	Centroid
Right coronoid height (RCH)	0.103	$Z = -15.068 + 0.103$ RCH $+ 0.159$ LCH	Men: 0.903 Women: −0.857
Left coronoid height (LCH)	0.159		
(Constant)	−15.068		

Table 12 Discriminant function analysis by using SH

Linear measurement	Function coefficient	Discriminant function	Centroid
Symphysis height (SH)	0.625	$Z = -18.625 + 0.625$ SH	Men: 1.191 Women: −1.131
(Constant)	−18.625		

is also often used in identifying the bodies of disaster victims because its strength and resistance to pressure allow it to survive in extreme conditions (Toneva et al. 2021).

The mandible can be used to estimate sex either through morphological methods to visually inspect mandibular characteristics or morphometric methods using quantitative linear measurements (Nagare et al. 2018; Verma et al. 2020). Sex estimation using morphological characteristics is subjective, and many anomalies can be misinterpreted by inexperienced examiners. Other reliable methods for estimating sex are morphometric measurements and statistical analysis, which have been widely used on human skeletal elements (Wankhede et al. 2015). The morphometric method is preferred over qualitative sex estimation because of its high level of objectivity, accuracy, and reproducibility. Errors in intraobserver and interobserver tests for the morphometric method are also low (Bertsatos et al. 2019). Dental radiograph can be used as a morphometric tool for sex estimation using linear measurements as shown in Fig. 1. Dental radiographs, especially panoramic radiographs, are a reliable method for identifying corpses. They can be used as a primary identifier because they provide photographic records of the teeth, jaw, and surrounding tissues, which are body parts that are highly resistant to decomposition and fragmentation during a disaster (Interpol 2018; Mello-Gentil and Souza-Mello 2022). Comparative methods for antemortem and postmortem dental radiographs can provide certainty of identity at the individual level (Kumar et al.

Table 13 Discriminant function analysis by using MCH

Linear measurement	Function coefficient	Discriminant function	Centroid
Right mandibular corpus height (RMCH)	0.233	$Z = -16.874 + 0.233$ RMCH $+ 0.334$ LMCH	Men: 0.973 Women: −0.924
Left mandibular corpus height (LMCH)	0.334		
(Constant)	−16.874		

Table 14 Percentage of accuracy for the discriminant functions with the training sample

Equation	Total men sample ($N = 95$) *N* (%)	Total women sample ($N = 100$) *N* (%)	Mean accuracy percentage (%)
$Z = -23.389$–0.018 RMiRW + 0.055 LMiRW–0.035 RPHR + 0.077 LPHR + 0.072 RMxRW–0.074 LMxRW + 0.077 RCH + 0.023 LCH + 0.407 SH–0.015 RMCH + 0.086 LMCH	85 (89.5%)	98 (98.0%)	93.8%
$Z = -22.733$ + 0.058 LPHR + 0.098 RCH + 0.454 SH	86 (90.5%)	98 (98.0%)	94.4%
$Z = -19.839$ + 0.014 RMiRW + 0.042 RPHR–0.008 RMxRW + 0.129 RCH + 0.327 RMCH	79 (83.2%)	94 (94.0%)	88.7%
$Z = -19.766$ + 0.007 LMiRW + 0.080 LPHR–0.032 LMxRW + 0.107 LCH + 0.321 LMCH	81 (85.3%)	94 (94.0%)	89.7%
$Z = -11.876$+ 0.230 RMiRW + 0. 296 LMiRW	59 (62.1%)	65 (65.0%)	63.6%
$Z = -14.086$– 0.015 RPHR + 0.242 LPHR	72 (75.8%)	84 (84.0%)	80.0%
$Z = -13.250$ + 0.290 RMxRW + 0.113 LMxRW	60 (63.2%)	67 (67.0%)	65.1%
$Z = -15.068$ + 0.103 RCH + 0.159 LCH	77 (81.1%)	84 (84.0%)	82.6%
$Z = -18.625$ + 0.625 SH	79 (83.2%)	94 (94.0%)	88.7%
$Z = -16.874$ + 0.233 RMCH + 0.334 LMCH	77 (81.1%)	86 (86.0%)	83.6%

Table 15 Percentage of accuracy for the discriminant functions with the testing sample

Linear measurements	Total men sample *N* = 29 *N* (%)	Total women sample *N* = 32 *N* (%)	Mean accuracy percentage (%)
Z = −23.389–0.018 RMiRW + 0.055 LMiRW–0.035 RPHR + 0.077 LPHR + 0.072 RMxRW–0.074 LMxRW + 0.077 RCH + 0.023 LCH + 0.407 SH–0.015 RMCH + 0.086 LMCH	20 (68.9%)	25 (78.1%)	73.5%
Z = −22.733 + 0.058 LPHR + 0.098 RCH + 0.454 SH	22 (75.8%)	26 (81.3%)	78.6%
Z = −19.839 + 0.014 RMiRW + 0.042 RPHR–0.008 RMxRW + 0.129 RCH + 0.327 RMCH	19 (65.5%)	28 (87.5%)	76.5%
Z = −19.766 + 0.007 LMiRW + 0.080 LPHR–0.032 LMxRW + 0.107 LCH + 0.321 LMCH	21 (72.4%)	28 (87.5%)	80.0%
Z = −11.876 + 0.230 RMiRW + 0. 296 LMiRW	23 (79.3%)	20 (62.5%)	70.9%
Z = −14.086–0.015 RPHR + 0.242 LPHR	23 (79.3%)	29 (90.6%)	85.0%
Z = −13.250 + 0.290 RMxRW + 0.113 LMxRW	20 (68.9%)	16 (50.0%)	59.5%
Z = −15.068 + 0.103 RCH + 0.159 LCH	16 (55.2%)	24 (75.0%)	65.1%
Z = −18.625 + 0.625 SH	21 (72.4%)	22 (68.8%)	70.6%
Z = −16.874 + 0.233 RMCH + 0.334 LMCH	20 (68.9%)	24 (75.0%)	72.0%

2015; Viner and Robson 2017). Dental radiographs are also one of the postmortem data that can be employed in reconstructive methods to identify bodies in an open mass disaster (Carabott et al. 2014).

The results of the reliability test are shown in Table 1. ICC values > 0.9 indicate very good reliability, and ICC values > 0.7 indicate good reliability. These findings reveal that the measurements are reliable and have a high level of reproducibility (Koo and Li 2016). The use of software in this research also influences the reliability. The same software was employed by Ningtyas et al. (2023), who also reported good reliability. The confidence interval used in this study was 0.05. Table 2 shows the results of the normality test where the significance of all data for men and women is $p > 0.05$.

Table 3 shows that all variables are significantly different ($p < 0.05$) between men and women, with the mean value for men being greater than that for women. These results are largely similar to those of previous studies on various populations (Astuti et al. 2022; Fekonja and Čretnik 2022; Indira et al. 2012; Kurniawan et al. 2023; Maloth et al. 2017; Mehta et al. 2020; Rad et al. 2020; Saini et al. 2011; Sairam et al. 2016; Sambhana et al. 2016). The greater value in men is due to the gender differences in the vertical growth of the mandible: the growth and development in men are approximately 2 years longer than that in women (Proffit et al. 2019).

All the variables have been proven to differ significantly between men and women and therefore can be used in establishing sex estimation equations. Discriminant function analysis was employed for creating equations because the data distribution prerequisite has been met. This method has been widely used to estimate sex in certain populations with good accuracy, making it useful in forensic cases (Bertsatos et al. 2019; Sambhana et al. 2016).

Discriminant function analysis produced several equation models as shown in Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13, including the equations with all the variables (Table 4), equations with all the variables initially used and then eliminated using stepwise analysis (Table 5), equations with five variables on the right side (Table 6), equations with five variables on the left side (Table 7), and equations for each type of linear measurement that combines both sides (Tables 8, 9, 10, 11, 12, 13). As shown in Table 14, various accuracies are obtained in the range of 63.6–94.4%. A high percentage of over 90% is achieved for the equations that use all the variables. The equation using five measurement variables obtained for each side has better accuracy than the equation using one variable on both sides. The accuracy of the equation can increase if two or more variables are used cumulatively for sex estimation (Mehta et al. 2020). All the equations in Table 14 have achieved accuracies above 80%, except for the equations using MiRW and MxRW with percentages of 63.6% and 65.1%, respectively. A sex estimation equation is acceptable and considered meaningful if it produces an accuracy of > 80% (Ekizoglu et al. 2021; Mello-Gentil and Souza-Mello 2022).

Previous studies have combined one or more of the variables in this research to form sex estimation equations through discriminant function analysis. Maloth et al. (2017) used five variables on the mandibular ramus, including PHR and MiRW, and achieved an accuracy of 74% in an Indian population. Sairam et al. (2016) conducted research with an Indian population using the parameters on the mandibular ramus to form equations and achieved an accuracy of 77–79.5%. Fekonja and Čretnik (2022) showed that MSH and MCH were significantly different between the gender. Sambhana et al. (2016) also obtained a similar accuracy value for MCH at 64%. Mehta et al. (2020) used discriminant function analysis for six mandibular linear measurements, namely, MxRW, MiRW, PRH, condylar height, and gonial angle, and obtained an overall accuracy of 75% for each variable. MxRW and MiRW have the highest accuracies in estimating sex (77.2% and 76.7%, respectively). Indira et al. (2012) conducted similar research by utilizing five linear measurements of the mandible, namely, MxRW, MiRW, CH, PRH, and condylar height, resulting in an equation accuracy of 76%. Maloth et al. (2017) reported a 74% accuracy in estimating sex for the linear measurements of the mandible, including MxRW and CH.

The equation for estimating sex is specific to certain populations (Toneva et al. 2021). An equation that gives accurate results in one population may give inaccurate results for another population. Differences in the accuracy of equations could be due to the variations in sexual dimorphism patterns in skull bones among different populations. These variations in dimorphism patterns can be reflected in the percentage of male and female dimorphism in the same population in bone thickness between populations (Techataweewan et al. 2021). The level of accuracy can differ between one population and another due to variations in the skeletal morphology of people in different geographical conditions. Thus, the mathematical equation for estimating the sex of a population is specific and cannot be applied for other populations because it can cause inaccurate results (Astuti et al. 2022). Therefore, this study used six variables, namely, MiRW, PHR, MxRW, CH, SH, and MCH, which have been proven to be dimorphic, to form a sex-specific estimation equation for the Indonesian population. The findings contribute to the forensic identification of victims in the Indonesian region.

According to Mello-Gentil and Souza-Mello (2022), the accuracy that is considered acceptable and valuable for sex estimation equations is > 80.0%. Table 14 shows that when the proposed equation was used to estimate the same sample used in forming the equation itself (training sample), the accuracy exceeds this minimum value. Differences in accuracy can be caused by several factors, namely the type of linear measurement of the mandible, variations in characteristics within a population, and number of parameters used (Astuti et al. 2022).

As shown in Table 14, the percentage of similarities in the estimates for men is lower than for women. These differences indicate that the variance in parameter sizes in men is higher than that in women (Kongkasuriyachai et al. 2022). The percentage of test results that is generalized to the population is the average percentage of estimated results for men and women. When applied to populations, the equation is expected to provide confirmation and information about the sex of individuals that is previously unknown (Qaq et al. 2019).

The formation of sex estimation equations always ends with validation and generalization to other populations. Equations formed using discriminant function analysis tend to provide a low accuracy when applied to new samples. Discriminant function analysis uses the principle of discriminant comparison of the cut-off point in separating men or women so that the resulting sex estimation appears to be dichotomous (separating two opposing groups) (Bartholdy et al. 2020). This process is important because even in the same population, the percentage of sexual dimorphism patterns can differ between men and women and consequently affect the validity of the sex estimation equation (Techataweewan et al. 2021). Ningtyas et al. (2023) proved that even for a testing sample with the same criteria and population as the training sample, the percentage of correct results from the gender estimation equation tends to decrease. As shown in Table 15, the percentage of similarities in providing correct results differ for male and female gender estimates. The percentage accuracy of the equation in the testing samples tends to be lower than in the training samples.

The limitations of this study are as follows. First, the following factors cannot be controlled because the radiograph samples were taken retrospectively: nutritional, socioeconomic, and hormonal (endocrine growth factors). These factors influence bone development and dimorphism (Indira et al. 2012; Mehta et al. 2020; Sambhana et al. 2016). In addition, the limited number of samples and the age distribution of the patients are less varied. Further study with a wide age range and a large sample size is needed.

Conclusions

The accuracy of sex estimation tends to be high when using all the linear measurements on panoramic radiographs, with accuracies of 93.8% for the training sample and 73.5% for the testing sample. However, if measurements cannot be made on both contralateral sides in cases where a panoramic radiograph is used to image an incomplete mandible, then sex estimation can still be carried out using the measurements on one side with accuracies of approximately 88.7–89.7% for the training sample and 76.5–80.0% for the testing sample. Several mandibular linear measurements can be used for sex estimation, but their accuracy for the training sample is lower than that of sex estimation using several linear measurements on panoramic radiographs. This research was carried out using only panoramic radiographs with good quality. Therefore, the position of the patient's head is an important factor that must be considered to obtain linear measurements and accurate sex estimation results using panoramic radiographs.

Abbreviations

MiRW Minimum ramus width
PHR Projective height of ramus
MxRW Maximum ramus width
CH Coronoid height
SH Symphysis height
MCH Mandibular corpus height

Acknowledgements

This article is a part of the thesis conducted by Selcaria Istna Datau, Sekar Khansa Aisha, and Nurulita Fida Aulia as their final project in the undergraduate degree of Bachelor of Dental Medicine under the supervision of the other author.

Authors' contributions

SID, SKA, and NFA performed the investigation, data curation, formal analysis, and visualization and composed the original draft. RW was responsible for the conceptualization, resource collection, supervision, validation, and project administration and managed the reviewing and editing of the manuscript. RDY and RRS conducted the supervision and methodology verification and supported the manuscript's reviewing and editing. MM supported the reviewing and editing of the manuscript. All the authors have read and approved the manuscript.

Funding

This work was supported by Universitas Gadjah Mada under the grant of Final Project Recognition 2024, Ref. No. 5286/UN1.P1/PT.01.03/2024.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Ethical clearance was obtained from the Ethical Commission of the Faculty of Dentistry and Prof. Soedomo Dental Hospital Universitas Gadjah Mada (Ref. No. 70/UN1/KEP/FKG-RSGM/EC/2023). Sample (radiograph) authorization was limited to ensure participant confidentiality.

Consent for publication

Not applicable. Samples were collected retrospectively from an existing database.

Competing interests

The authors declare that they have no competing interests.

Received: 10 June 2024 Accepted: 11 September 2024
Published online: 28 September 2024

References

Astuti ER, Iskandar HB, Nasutianto H, Pramatika B, Saputra D, Putra RH (2022) Radiomorphometric of the jaw for gender prediction: a digital panoramic study. Acta Medica Philippina 56(3):113–121. https://doi.org/10.47895/amp.vi0.3175

Aurizanti D, Suryonegoro H, Priaminiarti M (2017) Comparison of craniofacial linear measurements of 20-40 year-old males and females using digital lateral cephalometric radiography in Indonesia. J Phys Conf Ser 884(1). https://doi.org/10.1088/1742-6596/884/1/012046

Bartholdy BP, Sandoval E, Hoogland MLP, Schrader SA (2020) Getting rid of dichotomous sex estimations: why logistic regression should be preferred over discriminant function analysis. J Forensic Sci 65(5):1685–1691. https://doi.org/10.1111/1556-4029.14482

Bertsatos A, Athanasopoulou K, Chovalopoulou ME (2019) Estimating sex using discriminant analysis of mandibular measurements from a modern Greek sample. Egypt J Forensic Sci 9(1):1–12. https://doi.org/10.1186/s41935-019-0133-7

Brogdon BG (2011) Radiological identification anthropological parameters. In: Brogdon's forensic radiology, 2nd ed. Boca Raton, CRC Press. pp 91–96

Carabott R, Adams C, Evans S (2014) Brief introduction to forensic odontology. In: Forensic odontology: an essential guide. Carabot, John Wiley & Sons. p 1

Ekizoglu O, Hocaoglu E, Inci E, Karaman G, Garcia-Donas J, Kranioti E, Moghaddam N, Grabherr S (2021) Virtual morphometric method using seven cervical vertebrae for sex estimation on the Turkish population. Int J Legal Med 135(5):1953–1964. https://doi.org/10.1007/s00414-021-02510-5/Published

Fekonja A, Čretnik A (2022) Gender and age differences in mandibular ramus and body measurements: a radiographic study. J Hard Tissue Biol 31(1). https://doi.org/10.2485/jhtb.31.9

Indira AP, Markande A, David MP (2012) Mandibular ramus: an indicator for sex determination - a digital radiographic study. J Forensic Dent Sci 4(2):58–62. https://doi.org/10.4103/0975-1475.109885

Interpol (2018) INTERPOL-Disaster Victim Identification (DVI) guide

Kongkasuriyachai NP, Prasitwattanasereec S, Cased DT, Mahakkanukrauh P (2022) Craniometric estimation of ancestry in Thai and Japanese individuals. Aust J Forensic Sci 54(3):294–310. https://doi.org/10.1080/00450618.2020.1789219

Koo TK, Li MY (2016) A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 15(2):155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Krishan K, Kanchan T, Garg AK (2015) Dental evidence in forensic identification – an overview, methodology and present status. Open Dent J 9(1):250–256. https://doi.org/10.2174/1874210601509010250

Kumar R, Athota A, Rastogi T, Karumuri SK (2015) Forensic radiology: an emerging tool in identification. J Indian Acad Oral Med Radiol 27:416–422. https://doi.org/10.4103/0972-1363.170478

Kurniawan A, Sosiawan A, Nurrahman TF, Chusida A, Rizky BN, Prakoeswa BFWR, Nisrinaningtyas AH, Wijaya K, Yudianto A, Marya A (2023) Predicting sex from panoramic radiographs using mandibular morphometric analysis in Surabaya, Indonesia. Bull Int Assoc Paleodontol 17(1):32–40

Maloth KN, Kundoor VKR, Vishnumolakala SSLP, Kesidi S, Lakshmi MV, Thakur M (2017) Mandibular ramus: a predictor for sex determination - a digital radiographic study. J Indian Acad Oral Med Radiol 29(3):242–246. https://doi.org/10.4103/jiaomr.JIAOMR-170-16

Mehta H, Bhuvaneshwari S, Singh MP, Nahar P, Mehta K, Sharma T (2020) Gender determination using mandibular ramus and gonial angle on OPG. J Indian Acad Oral Med Radiol 32(2):154–158. https://doi.org/10.4103/jiaomr.jiaomr_169_19

Mello-Gentil T, Souza-Mello V (2022) Contributions of anatomy to forensic sex estimation: focus on head and neck bones. In: Forensic sciences research (Vol. 7, Issue 1, pp. 11–23). Taylor and Francis Ltd. https://doi.org/10.1080/20961790.2021.1889136

Nagare SP, Chaudari RS, Birangane RS, Parkarwar PC (2018) Sex determination in forensic identification: a review. J Forensic Dent Sci 10(2):61–66. https://doi.org/10.4103/jfo.jfds_55_17

Nagi R, Aravinda K, Rakesh N, Jain S, Kaur N, Mann AK (2019) Digitization in forensic odontology: a paradigm shift in forensic investigations. J Forensic Dent Sci 11(1):5–10. https://doi.org/10.4103/jfo.jfds_55_19

Ningtyas AH, Widyaningrum R, Shantiningsih RR, Yanuaryska RD (2023) Sex estimation using angular measurements of nasion, sella, and glabella on lateral cephalogram among Indonesian adults in Yogyakarta. Egypt J Forensic Sci 13(48):1–8. https://doi.org/10.1186/s41935-023-00368-9

Prasetiowati L, Yuliawati TH, Purwantari KE (2023) Determinasi Jenis Kelamin Menggunakan Parameter Morfologi dan Morfometrik pada Mandibula. In: Prosiding KONGRES XV & HUT KE – 52 PAAI 2023 – 4TH LUMMENS. pp 469–478

Proffit WR, Fields Jr HW, Larson BE, Sarver DM (2019) The development of orthodontic problems. In: Contemporary orthodontics, 6th ed. Philadelphia, Elsevier. pp. 35, 36, 86, 88, 109

Qaq R, Mânica S, Revie G (2019) Sex estimation using lateral cephalograms: a statistical analysis. Forensic Sci Int Rep 1:1–8. https://doi.org/10.1016/j.fsir.2019.100034

Rad FO, Javanshir B, Nemati S, Khaksari F, Mansoori R, Ranjzad H, Shokri A (2020) Evaluation of sexual dimorphism with mandibular parameters by digital panoramic radiography. Open Dent J 14(1):172–177. https://doi.org/10.2174/1874210602014010172

Saini V, Srivastava R, Rai RK, Shamal SN, Singh TB, Tripathi SK (2011) Mandibular ramus: an indicator for sex in fragmentary mandible. J Forensic Sci 56(81):13–16. https://doi.org/10.1111/j.1556-4029.2010.01599.x

Sairam V, Geethamalika M, Kumar P, Naresh G, Raju G (2016) Determination of sexual dimorphism in humans by measurements of mandible on digital panoramic radiograph. Contemp Clin Dent 7(4):434–439. https://doi.org/10.4103/0976-237X.194110

Sambhana S, Sanghvi P, Mohammed R, Shanta P, Thetay AR, Chaudhary V (2016) Assessment of sexual dimorphism using digital orthopantomographs in South Indians. J Forensic Dent Sci 8:180. https://doi.org/10.4103/0975-1475.195113

Techataweewan N, Hefnr JT, Freas L, Surachotmongkhon N, Benchawattananon R, Tayles N (2021) Metric sexual dimorphism of the skull in Thailand. Forensic Sci Int Rep 4:100236. https://doi.org/10.1016/j.fsir.2021.100236

Toneva D, Nikolova S, Agre G, Zlatareva D, Hadjidekov V, Lazarov N (2021) Machine learning approaches for sex estimation using cranial measurements. J Legal Med 135:951–966. https://doi.org/10.1007/s00414-020-02460-4

Verma R, Krishan K, Rani D, Kumar A, Sharma V, Shrestha R, Kanchan T (2020) Estimation of sex in forensic examinations using logistic regression and likelihood ratios. Forensic Sci Int Rep 2:1–6. https://doi.org/10.1016/j.fsir.2020.100118

Viner MD, Robson J (2017) Post-mortem forensic dental radiography - a review of current techniques and future developments. In: Journal of forensic radiology and imaging (Vol. 8, pp. 22–37). Elsevier Ltd. https://doi.org/10.1016/j.jofri.2017.03.007

Wankhede KP, Bardale RV, Chaudhari GR, Kamdi NY (2015) Determination of sex by discriminant function analysis of mandibles from a Central Indian population. J Forensic Dent Sci 7(1):37–43. https://doi.org/10.4103/0975-1475.150304

Zhang M (2022) Forensic imaging: a powerful tool in modern forensic investigation. Forensic Sci Res 7(3):385–392. https://doi.org/10.1080/20961790.2021.2008705

Publisher's Note