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Original Article

# Morphometric measurements of mandible to determine stature and sex: A postmortem study

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**Abstract**

**Objectives:** Identification of humans has medicolegal relevance in civil issues involving property inheritance, marriage, contested sex, admission to educational institutions, and the disappearance of individuals. To determine the sex of human remains, forensic anthropologists usually use morphologic and metric approaches. This study was conducted to determine stature and sex according to mandibular dimensions in postmortem autopsy samples.

**Methods:** A total of 150 mandibles from people 18–65 years of age were studied. Stature and sex were noted, and six mandibular measurements were taken with Vernier calipers, flexible measuring tape, a protractor, and a graduated autopsy table. Statistical analysis of the measured parameters was conducted in SPSS software. Statistical parameters, such as mean, standard deviation, Spearman's correlation coefficient, multiple linear regression, stepwise regression, and Mann–Whitney U test were analyzed.

**Results:** Bicondylar width was the stature estimation predictor with the strongest correlation ($r = 0.439$). The other parameters significantly associated with stature were bigonial width ($p = 0.000$), mandibular angle ($p = 0.004$), and mandibular arch length ($p = 0.000$), according to Spearman's correlation coefficient. The mandibular angle had the greatest dimorphic statistical significance ($p = 0.004$) according to the Mann–Whitney U test.

**Conclusion:** Bicondylar width may serve as a valuable tool for estimating stature, and mandibular angle can be used to identify sex. Our findings may help forensic

**المخلص**

**أهداف البحث:** في القضايا المدنية التي تتضمن ارث العقارات، الزواج، الجنس المتنازع عليه، القبول في المؤسسات التعليمية، واختفاء الأفراد، يكون التعرف على الهوية ذا أهمية قانونية طبية. لتحديد جنس البقايا البشرية، يستخدم عادة العلماء الجنائيون النهج المورفولوجي والمتري. لذلك، تم إجراء هذه الدراسة لتحديد القامة والجنس من أبعاد الفك السفلي بين العينات ما بعد الوفاة التي تم فحصها بواسطة التشريح.

**طرق البحث:** تمت دراسة 150 فك تتراوح أعمارها بين 18 - 65 سنة. تم تسجيل القامة والجنس وتم أخذ 6 قياسات للفك السفلي باستخدام المعيار فيرنيير، شريط القياس المرن، الدوائر المنسدلة، وجدول التشريح المتدرج. تم تحليل القياسات المسجلة إحصائيا. تم تحليل المؤشرات الإحصائية مثل المتوسط، الانحرافات المعيارية، معامل ارتباط سبيرمان، الانحدار الخطي المتعدد، انحدار الخطوة واختبار مان-ويتني.

**النتائج:** وجدت الدراسة أن عرض الفك السفلي يعد واحدا من المؤشرات لتقدير القامة مع أقوى ارتباط. القياسات الأخرى التي أظهرت ارتباطا كبيرا بالقامة كانت عرض الفك السفلي، وزاوية الفك، وطول قوس الفك باستخدام معامل ارتباط سبيرمان. عرضت زاوية الفك أكبر أهمية إحصائية ثنائية في تحليلنا في اختبار مان-ويتني.

**الاستنتاجات:** أبرزت هذه الدراسة أن عرض الفك السفلي يمكن أن يكون أداة قيمة لتقدير القامة. يمكن استخدام زاوية الفك لتحديد الجنس. لذا، ستساعد نتيجة دراستنا العلماء الجنائيين في تقدير القامة وتحديد البقايا البشرية.

**الكلمات المفتاحية:** التشريح؛ الفك السفلي؛ بقايا الجسم؛ القامة؛ الجنس

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anthropologists estimate stature and identify human remains.

**Keywords:** Autopsy; Body remains; Mandible; Sex; Stature



## Introduction

Identification is defined as "determining the individuality of a person either living or dead." Establishing identity is very important, because misidentification can result in a range of medical and legal issues.[1]

Identification has medicolegal importance in various cases, including issues related to property inheritance, marriage, disappearance of individuals, assault, sexual assault, murder, rape, interchanging of infants, and natural catastrophes affecting large populations.[1] In India, approximately 627 people went missing in 2019, and many cases were unreported. According to a census of unidentified bodies in Italy up to 2011, 832 unidentified bodies have been recovered since 1974. Identification of individuals is very important in such cases.[2]

Failure to identify deceased bodies can have legal and ethical issues and potentially affect the mental health of the loved ones of the deceased.[3] Hence, identification of dead people is essential. A forensic anthropologist is consulted to recreate the individual's biological profile at the time of death.

During investigation of disintegrated, mutilated, or burned bodies, forensic experts focus on stature,[4] a person's height or body length. Stature has been estimated from skeletal remains with reasonable accuracy, with regression formulas and equations based on long bones and fragmented bones.[5]

Various parts of the body and long bones have been used to estimate stature, including the skull, cephalo-facial measurements, vertebrae, sternum, hip bones, hands, long bones of the limbs, and small bones of the feet and hands.[6–9]

The dimensions of various parts of the body vary among men and women.[10] Sex distinctions become challenging in intersex individuals; bodies in advanced putrefactive states; and mutilated, fragmented, and skeletonized remains.

Krogman and Igcan have summarized adult sexing accuracy from isolated bones, i.e., the complete pelvis (95%) and skull alone (90%), as well as combinations of bones consisting of skull plus pelvis (98%), long bones plus pelvis (95%), long bones plus skull (90–95%), and long bones alone (80–90%).[11]

In highly decomposed or mutilated bodies, invaluable information related to sex, age, and stature can be derived from skeletal remains.[4] To determine the sex of human remains, forensic anthropologists usually use morphologic and metric approaches. Although many studies have attempted to identify stature from various bones of the body, systematic studies on the determination of sex and stature by using the mandible are lacking.[10]

Therefore, this experimental research attempted to determine stature and sex from mandibular dimensions in postmortem autopsy samples.

## Materials and Methods

Study type: Observational study.

Sample size: A total of 150 mandibles were studied, belonging to cadavers of people 18–65 years of age undergoing autopsy. Of these, 105 mandibles were from males, and 45 were from females. All cadavers were from southern India.

Study period: April 2021 to September 2022.

Inclusion criteria:

- Cases with an intact, undamaged mandible.

Exclusion criteria:

- Age below 18 years, developing mandible
- Fracture or dislocated mandible
- Dentures
- Genetic disorders

Instruments used: The materials used for the various measurements included Vernier calipers, flexible measuring tape, a protractor, and a graduated autopsy table.

The bicondylar width and bigonial distance were measured according to standard anthropometric procedures with Vernier calipers (least count 0.01 mm). The condylar-gonian distance, gonian–gnathion distance, and length of the mandibular arch were measured with flexible measuring tape. The mandibular angle was measured with a protractor. For prevention of intra-observer bias, the measurements were taken by one researcher three times to increase the accuracy of the measurements. For prevention of inter-observer bias, the same measurements were taken by another researcher three times. The average measurement collected by both researchers was used as the final value.

The following measurements were considered, as shown in Figure 1:

1. Stature or length: The length of the body from vertex to heels. The length of the body was measured on the graduated autopsy table. The back of the head, buttocks, and heels were rested on the table. The length was documented in centimeters.
2. Bicondylar width: The linear distance between the tip of two condyles of the head of the mandible (Co–Co).
3. Bigonial distance: The linear distance between two gonia, i.e., the tip of the ramus of the mandible (Go–Go).
4. Gonion–gnathion distance: The linear distance between the gonion (ramus of the mandible) and gnathion, the lowermost point on the chin along the midline (Go–Gn).
5. Mandibular angle: The angle (gonial angle) located at the posterior border at the junction of the lower border of the ramus of the mandible.
6. Condylion–gonion distance: The linear distance between the tip of the condylar process and gonion ramus of the mandible (Co–Go).

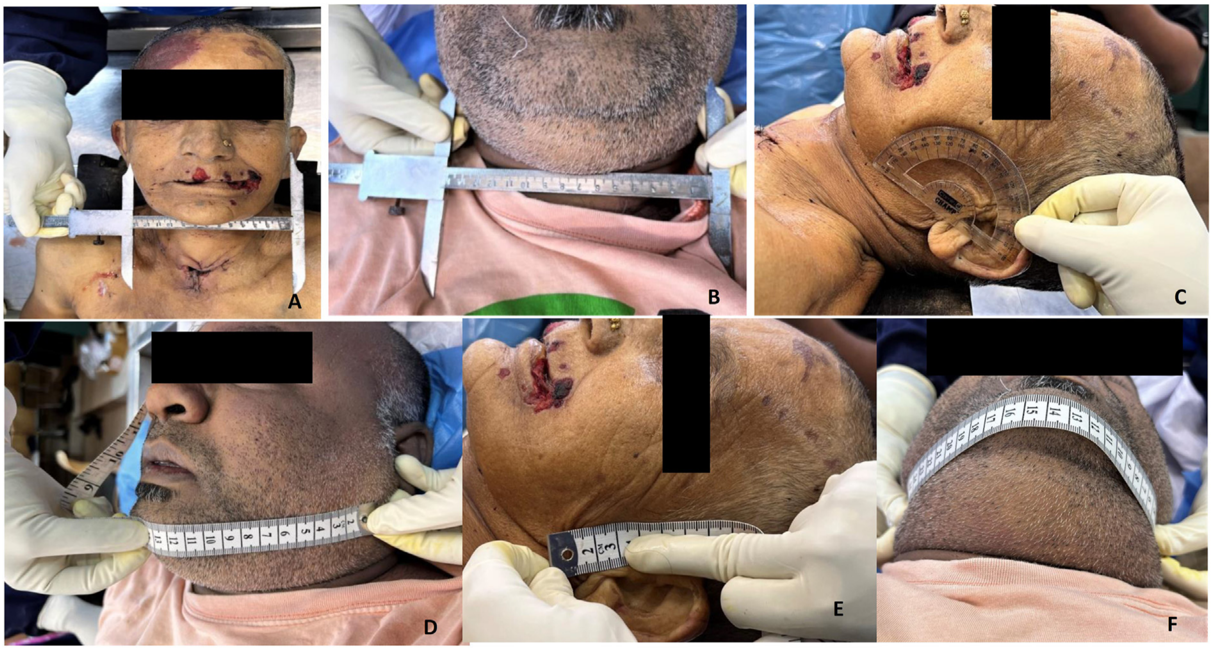


**Figure 1:** Measurements on the mandible. A. Measurement of bicondylar breadth (Co−Co). B. Measurement of bigonial breadth (Go−Go). C. Measurement of mandibular angle. D. Measurement of gonion−gnathion distance (Go−Gn). E. Measurement of condylion−gonion distance (Co−Go). F. Measurement of length of the mandibular arch.

7. Length of the mandibular arch: The length between the mandibular angles at the ramus of the mandible.

After selecting the cases for study, we recorded the stature, sex, and mandibular measurements before postmortem examination.

The mandibular measurements, stature, and sex of the participants were quantified and analyzed statistically in Statistical Software R programming to derive regression formulas and the linear discriminant function. Statistical parameters including means and standard deviations were calculated in IBM SPSS Statistics for Windows Version 20.0 (USA). Spearman's correlation coefficient was used to determine correlations between stature and mandibular parameters (with a positive r value indicating a positive correlation, a negative r value indicating a negative correlation, and a p-value $<0.05$ considered significant). Multiple linear regression and stepwise regression were performed to derive regression equations to determine stature from those parameters. Mann−Whitney U test was used to correlate parameters between men and women (p-value $<0.05$ was considered significant).

## Results

We investigated 150 samples: 105 from men and 45 from women (Table 1).

A bar plot indicating the age distribution of the population from 18 to 65 years and the number of individuals in various age groups is shown in Figure 2.

The length of the mandibular arch, bicondylar width, bigonial distance, and angle of mandible significantly correlated with stature ($p < 0.05$; Table 2).

**Table 1: Sex distribution of the total population studied.**

| Population | Frequency | Percentage |
|---|---|---|
| Male | 105 | 70 |
| Female | 45 | 30 |
| Total | 150 | 100 |

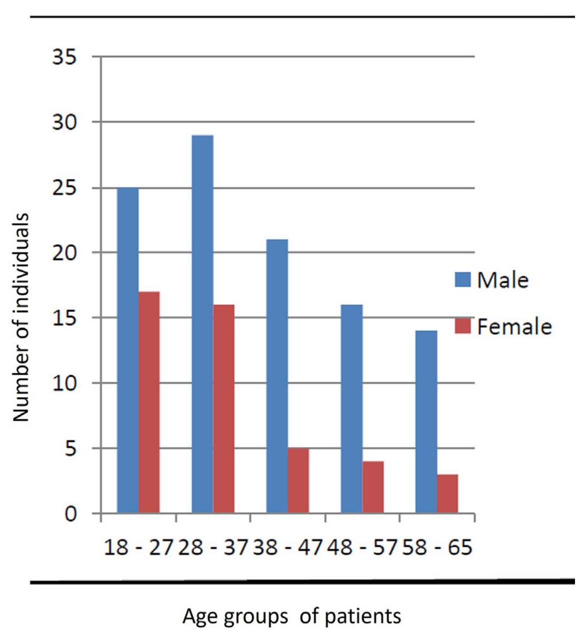


**Figure 2:** Bar plot showing the age distribution of the population 18−65 years of age and the number of individuals in various age groups.

**Table 2: Correlation between stature and mandibular measurements.**

| | Length of mandibular arch | Bicondylar width | Condylion−gonion | Bigonial distance | Gonion−gnathion | Angle of mandible |
|---|---|---|---|---|---|---|
| Correlation coefficient | 0.286 | 0.439 | 0.135 | 0.361 | 0.065 | −0.235 |
| p-value | 0.000* | 0.000* | 0.100 | 0.000* | 0.430 | 0.004* |

*Significant, $p < 0.05$.

Spearman's rank correlation coefficient was used to establish the strength of associations, because measures were nonparametric. Scatter plots indicating the correlation between stature and mandibular measurements are shown in Figure 3. The mandibular angle showed a negative correlation, i.e., a decrease in mandibular angle with increasing stature, according to the negative r value (correlation value = −0.235). Bicondylar width, bigonial width, and mandible length showed positive correlations, i.e., an increase in bicondylar width, bigonial width, and mandible length with increasing stature (correlation values = 0.439, 0.361, and 0.286, respectively).

Because other parameters significantly correlated with stature were associated with one another, bicondylar width was selected as the best predictor for stature estimation.

Regression analysis was performed, and a regression equation was created to predict an individual's stature. The regression formula for stature prediction in men was as follows:

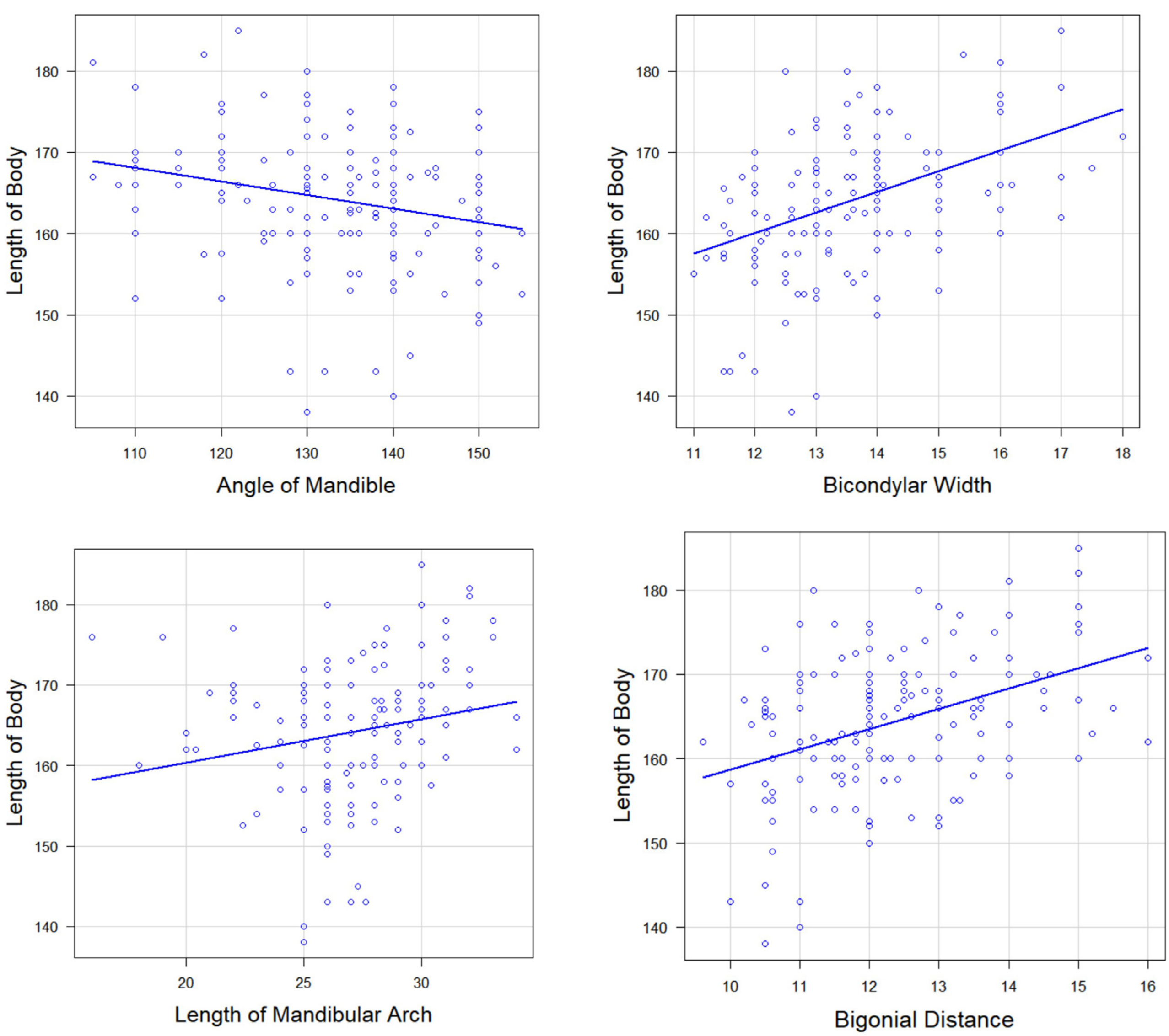


**Figure 3:** Scatter plots showing correlations between stature and mandibular measurements.

Y = 136.893 + 2.1797*X

where Y denotes stature, and X denotes bicondylar width.

The regression formula for stature prediction in women was also derived. The formula is given by:

Y = 129.03 + 2.1797*X

where Y denotes stature, and X denotes bicondylar width.

The distribution of mandibular measurements in men and women is shown in boxplots in Figure 4. The median mandibular angle in women and men was 135° and 130°, respectively, with a range of 110°–155° in women and 105°–140° in men. The median bicondylar width in women and men was 13 and 13.5 cm, respectively, with a range of 11–18 cm in women and 11–17.5 cm in men. The median bigonial distance in women and men was 11.8 and 12.2 cm, respectively, with a range of 9.5–16 cm in women and 10.5–16 cm in men. The median condylion–gonion distance in women and men was 4 cm; the range was 2–6 cm in women and 2–7 cm in men. The median gonion–gnathion distance in women and men was 13 and 13.2 cm, respectively, with a range of 7–17 cm in women and 6–17 cm in men. The median mandibular arch length in women and men was 26.5 and 27.5 cm, respectively, with a range of 18–30 cm in women and 16–34 cm in men.

Mann–Whitney U test was performed to compare the mandibular measurements between sexes. The measurements, length of the mandibular arch, condylion–gonion, gonion–gnathion, and mandibular angle significantly differed between men and women ($p < 0.05$; Table 3).

The results are summarized as follows.

**Table 3: Group descriptives of parameters with the results of Mann–Whitney U test.**

| | Group | N | Mean | Median | SD | p value |
|---|---|---|---|---|---|---|
| Length of mandibular arch (cm) | Female | 45 | 26.54 | 26.00 | 2.282 | 0.015* |
| | Male | 100 | 27.48 | 28.00 | 3.389 | |
| Bicondylar width (cm) | Female | 45 | 13.34 | 13.00 | 1.464 | 0.058 |
| | Male | 100 | 13.77 | 13.60 | 1.417 | |
| Bigonial distance (cm) | Female | 45 | 12.02 | 11.80 | 1.416 | 0.056 |
| | Male | 100 | 12.44 | 12.20 | 1.357 | |
| Condylion –gonion distance (cm) | Female | 45 | 3.91 | 4.00 | 0.868 | 0.015* |
| | Male | 100 | 4.30 | 4.00 | 0.846 | |
| Gonion –gnathion distance (cm) | Female | 45 | 11.90 | 13.00 | 2.546 | 0.015* |
| | Male | 100 | 12.93 | 13.50 | 2.520 | |
| Angle of mandible (°) | Female | 45 | 137.27 | 136.00 | 10.543 | 0.004* |
| | Male | 100 | 130.54 | 130.00 | 12.155 | |

*Significant, $p < 0.05$.

**Linear Discriminant Function**: 0.065 × length mandibular arch + 0.4756 × condylion–gonion + 0.299 × gonion–gnathion − 0.0969 × angle of mandible.

To determine whether a particular sample was male or female, we used the above linear discriminant function. According to the above LDA rule, 75% of the cases were correctly classified, and the accuracy increased with cross-validation. The mid-point of the mean values of the discriminant function for the male and female groups was −5.543. Discriminant function values greater than this

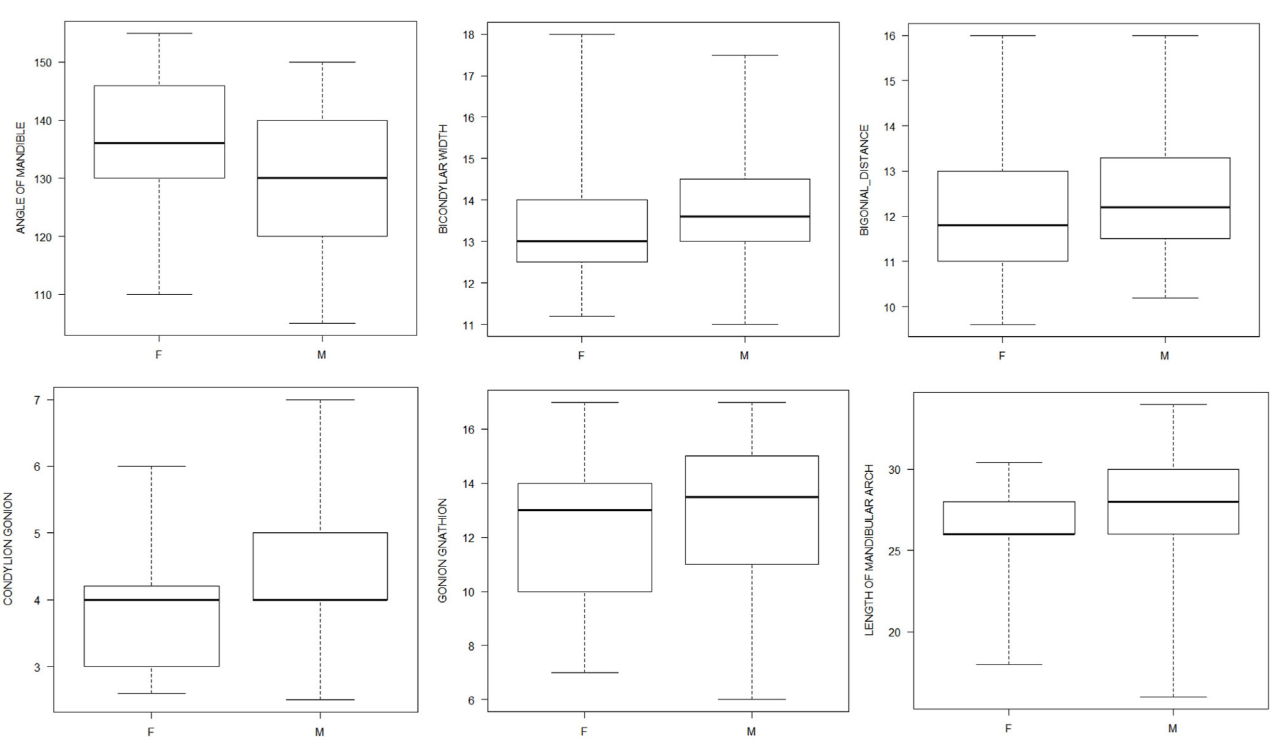


**Figure 4:** Boxplot showing the distribution of mandibular measurements in men and women.

midpoint indicated that the sample was male, whereas values below this point indicated that the sample was female.

## Discussion

Sex identification according to the human mandible has always been difficult through observation alone, because features including the size, weight, and prominence of muscular markings display little sexual dimorphism.[12] Therefore, studying the features of these bones in detail is essential in developing a standardized method to identify sex and stature.

In this research, the length of the mandibular arch significantly correlated with stature, with a coefficient value of 0.286. However, this correlation was weaker than that that found in a prospective study by Chimurkar et al. demonstrating a strong correlation ($r = 0.71$) between the length of the mandibular arch and height. With their regression equation, stature can be estimated with small standard error of about 3.91 cm. These differences in findings might have been because Chimurkar et al. focused on to a single factor and evaluated only a male population,[13] whereas we considered the average of both sexes herein.

The present study findings indicated a significant correlation between bicondylar width and stature ($r = 0.439$); consequently, bicondylar width was selected as the best predictor for stature estimation. Bigonial width also showed a correlation that was significant ($r = 0.361$) but lower than that for bicondylar width. However, Yadav et al. and Arago et al. have reported that bigonial width ($r = 0.445$) is the best predictor of height variation in men: the width, with standardized beta = 0.200, accounted for the height variation.[14,15] Our study yielded different results, possibly because of our sample pooling, i.e., consideration of both sexes.

This study correctly classified 75% of cases by using the linear discriminant function. Four parameters with $p < 0.015$ were included in the computation to account for the possibility of a 75% accuracy rate. Loth and Henneberg have tested the mandibular ramus flexure for sexual dimorphism, and found that flexure or straightness of the ramus is diagnostic in 99.1% of men and 98.8% of women, thus yielding a 99.0% accuracy rate.[11] A combined approach to investigations may strengthen the validity of the results.

Our observations indicated that the length of the mandibular arch, condylion–gonion, gonion–gnathion, and mandibular angle significantly differ between men and women, with p-values of 0.015, 0.015, 0.015, and 0.004, respectively, and a total accuracy rate of 75%. Saini et al. have reported that coronoid height is the most accurate measure, with an accuracy of 74.1%, and other parameters (coronoid height, projective height, condylar height, and maximum and minimum ramus breadth) demonstrate significant sexual dimorphism ($p = 0.001$ in all cases).[16] Saini et al. observed that mandibular body height had the highest overall sexing accuracy, at 67.4%.[17]

This prospective evaluation performed with a majority of South Indian participants suggested that mandibular angle had most significant association ($p < 0.004$) with sex and therefore is a reliable source for sex determination. In contrast to a study by Sambhana et al. measured ten mandibular parameters and found that, except for the gonial angle, all mandibular factors were reliable for forensic sex determination in South Indians.[18] This finding contradicts our findings on gonial angle, possibly because of differences in data collection methods between studies.

Our study revealed that the bicondylar width was insignificant in sex identification. Tunis et al. have conducted a retrospective study on the Israeli population, in which the condyle width demonstrated 10% dimorphism, whereas the complete mandible displayed 90.8% dimorphism.[19] The lack of association may be attributable to the difference in population as their study was done in Israeli population and our study was done in Indian population.

Additionally, our research indicated a significant difference between sexes in the length of the mandibular arch, condylion–gonion, gonion–gnathion, and angle of the mandible ($p < 0.05$). Previous research by Singh has demonstrated that men and women have comparable bicondylar width, bigonial width, mandibular symphyseal height, and height of the left ramus and mandibular arch. The mean standard deviation of 3.5 was used to construct the range with 100% precision.[7] This result further validates the findings regarding mandibular arch length, and does not support an influence of population specificity or food habit.

We observed that, except for the mandibular angle, which was substantially higher in women than men, with a standard deviation of 10.543, all other measurements were higher in men than women. Similar findings have been observed by Rajkumari et al., who have measured gonial angle, condylar height, coronoid height, projective ramus height, and maximal ramus breadth, and observed higher values in men than women.[20] Shah et al. have also suggested substantially greater values in men than women.[21]

The analysis did not reveal statistically significant differences in bigonial breadth between sexes. In contrast, Shah et al. have concluded that statistically significant sex-based differences exist in bigonial width and ramus height.[21] The combined stratification of samples according to sex rather than age distribution may explain the discrepancies in the results across studies.

Bigonial distance had no significance in sex discrimination. The linear discriminant function model had an accuracy rate of 75%; four parameters showed significance: length of the mandibular arch, condylion–gonion distance, gonion–gnathion distance, and mandibular angle. Dietrichkeit Pereira et al. have reported that the bigonial distance and mandibular ramus predict sex, and have provided a 90% accurate logistic regression model, wherein a value >0.5 indicates a male.[22] In contrast to previous research, unequal sample distribution, population specificity and the lack of a soft tissue correction factor may be sources of different parameters showing significance.

Hazari et al. have conducted a systematic review of whether the mandible can be used as a tool for detecting sexual dimorphism. Of 16 radiographic studies, 14 showed statistically significant results, thus suggesting that the adult mandible can be used with adequate sensitivity and objectivity to identify both sex and population affinity, as compared with other standard analytical techniques. Moreover, of 20 morphometric studies of the dry mandible, 15 showed a positive correlation between sexual dimorphism and mandibular parameters. Thus, the mandible can be safely used by forensic odontologists for identifying sex in cases in which other major bones, such as the skull and pelvis, are damaged or not found.[23]

In our study, bicondylar width was the predictor of stature estimation with the strongest correlation. We identified a linear discriminant function to determine whether a sample is male or female. By using our LDA rule, forensic anthropologists can identify whether a given mandible belongs to a man or woman with 75% accuracy; this accuracy can be increased through cross-validation. In this study, the mid-point of the mean values of the discriminant function for the male and female groups was −5.543. Discriminant function values greater than this mid-point indicated that a given sample was male, whereas values below this point indicated that the sample was female.

### *Limitations of the study*

1. Population- and sex-specific regression equations and linear discriminant functions cannot be used to other populations and sexes.
2. In this analysis, soft tissue correction factors were not included.
3. Unequal sex representation sample size for females.
4. Age constraints were not considered, and samples were pooled based on sex. It could lead to variations as mandible is affected by ageing.

## Conclusion

This study highlights bicondylar width as the predictor for stature estimation with the strongest correlation. This parameter emerged as a novel metric for estimating stature and demonstrated a positive association in the South Indian population. This parameter may serve as a valuable tool for estimating stature. The other parameters that had a substantial association with stature, and thus can be used to estimate stature, were bigonial width, mandibular angle and length of the mandibular arch.

Our study findings indicated that, in sex determination, parameters such as the length of the mandibular arch, condylion−gonion distance, gonion−gnathion distance, and mandibular angle can be used. The mandibular angle displayed the greatest sexually dimorphic statistical significance in our analysis.

Factors including ethnicity, race, and geographical variations must be considered when generalizing these parameters in assessing stature and sex, because they significantly affect anthropometric measures of the human body. Consequently, this study indicates a need for research on the determination of sex and stature according to morphometric mandibular measurements in various ethnic and racial groups.

Future studies may include radiological CT or MRI scans to further add to the above findings.

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## Conflict of interest

The authors have no conflict of interest to declare.

## Ethical approval

Institutional ethical clearance was granted under approval no: 79/2021. Date of approval: 12/1/2021.

## Authors contributions

VP: conceptualization, methodology, resources, writing (review and editing). CNH: data curation, formal analysis, project administration, writing (original draft). CG: supervision, validation, visualization, writing (review and editing). All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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