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Original Article

Dentistry Section

Mandibular Ramus as an Indicator of Chronological Age Estimation and Gender Determination using Cone Beam Computed Tomography: A Retrospective Cross-sectional Study

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ABSTRACT

Introduction: Age and gender estimation from skeletal remains is vital in forensic identification. The mandible, being strong, durable and sexually dimorphic, provides reliable information. Cone Beam Computed Tomography (CBCT) enables accurate Three-Dimensional (3D) evaluation of mandibular structures. Existing two-dimensional (2D) imaging methods are affected by image distortion, while population-specific variations influence mandibular morphology; therefore, CBCT-based reference standards are warranted. The present study focuses on establishing population-specific reference values for forensic age and gender determination.

Aim: To evaluate mandibular ramus dimensions using CBCT for forensic age estimation and gender determination.

Materials and Methods: This retrospective cross-sectional study was conducted in the Department of Oral Medicine and Radiology at Karpaga Vinayaga Institute of Dental Sciences from March 2025 to June 2025. A total of 100 CBCT scans that clearly visualised the mandible and met the primary inclusion criteria of individuals aged 7-58 years were selected using consecutive retrospective sampling. CBCT images (CS 9600, Carestream Dental LLC) were reviewed using Digital Imaging and Communications in Medicine (DICOM) software, and five mandibular ramus parameters-coronoid height, condylar height, ramus height, maximum ramus breadth, and minimum ramus breadth-were measured in millimetres (mm). Age and gender were recorded as demographic variables. Statistical analysis was performed using IBM Statistical Package for Social Sciences (SPSS) version 27.0. Student's t-test/Welch's t-test and Analysis of Variance (ANOVA) were used for group comparisons; Pearson correlation and linear regression were used for age association, and discriminant function analysis (Wilks' Lambda) was applied for gender prediction. A significance level of $p \leq 0.05$ was considered statistically significant.

Results: Males showed higher mean coronoid height (61.51±4.42 mm) and condylar height (70.48±6.00 mm) compared to females (55.78±4.19 mm and 64.70±4.28 mm, respectively). Discriminant function analysis correctly classified 78% of individuals, with 34/40 females (85%) and 44/60 males (73.3%) correctly identified. Mandibular ramus height showed a weak and statistically non significant association with chronological age ($R=0.206$, $p=0.121$), indicating limited predictive value for age estimation in the studied population.

Conclusion: CBCT-derived mandibular ramus measurements showed significant sexual dimorphism with 78% accuracy for gender determination. However, ramus height demonstrated a weak, non significant association with age, limiting its value for age estimation. Further large-scale studies are warranted.

Keywords: Adult skeleton, Forensic anthropology, Mandibular anatomy

INTRODUCTION

Skeletons have long been used in forensic, anthropological, odontological, and genetic research on both living and deceased individuals [1]. Age and gender have traditionally been determined mainly from the skull and pelvis [2]. Assessing morphometric differences to identify a person is the first step in forensic analysis, and several studies have shown that male and female skulls and other bones, as well as those from different age groups, differ from one another [1-4]. Since subsequent techniques for estimating age and stature are Gender-dependent, gender determination is typically the initial step in the identification of an adult skeleton. The reliability of gender determination depends on the degree of sexual dimorphism present in the population and the completeness of the remains [5].

Gender can be identified with 100% accuracy when the complete adult skeleton is available for examination; however, in mass disaster situations, where fragmented bones are usually encountered, gender cannot be determined with 100% accuracy and is largely dependent on the skeletal segments that are available [5-7]. With an accuracy of up to 92%, the skull is the most dimorphic and easily sexed part of the skeleton after the pelvis [7]. However, because the mandible is the largest, strongest, and most dimorphic bone in the skull, it may be crucial for gender determination in situations where a complete skull is not available [5-8]. Owing to its thick layer of compact bone, the mandible is more resilient than many other bones and is therefore better preserved. The size and shape of the mandible reflect its dimorphism [7]. In general, male bones are larger and stronger than those of females [5]. Male and female masticatory forces differ; hence, it is known that the relative development (size, strength, and angles) of the masticatory muscles affects how mandibular dimorphism manifests [9]. The mandibular condyle and ramus exhibit the greatest morphological alterations, indicating sexual dimorphism in the mandible compared to the mandibular body [9,10]. Gender may be determined with accuracy using methods based on measurements and morphometry. An essential component of medicolegal practice is the chronological age evaluation. Age determination processes are intricate and take into account a wide range of variables [4]. Bones are significant among the hard tissues because they change during pregnancy and the postnatal period, and these changes in composition and form persist into old age and even after death. As a result, bones are a trustworthy source of data about growth and changes in growth. At particular ages, the skeletal growth of the bones, cranial sutures, and teeth is typically well defined. However, general health, genetics, and other environmental factors have a considerable impact on these alterations [11]. As maturity increases, age determination gets more challenging. A result on foetal material can be obtained with an accuracy that can be measured in a matter of days. When people become older, things stay mostly fine until they stop growing and, more importantly, stop changing their teeth. By the time they are 20 or 25 years old, all growth markers are no longer useful. The margin of error in age estimation increases with advancing age, making assessment more challenging in middle-aged and older individuals [11]. Numerous techniques have been put forth to determine age. Clinical, radiological, histological, and chemical analysis are the four groups into which they might be divided. When a person's real age is unknown or needs to be verified, any or all of the aforementioned techniques can be used to estimate their age. However, post-mortem alterations such as decomposition, mutilation, or skeletonisation may make identification increasingly challenging, if not impossible, in the case of a deceased person [12]. In forensic and physical anthropology, the mandible has been used to determine age and gender since it can hold its shape [13]. One of the first bones in the body to begin ossifying is the mandible, which is special in that it exhibits both intramembranous and endochondral ossification patterns. While the coronoid and condyloid processes ossify endochondrally, the mandibular body ossifies intra-membraneously. Morphological and dental changes, such as the timing and order of tooth eruption, can be used to estimate age up until the third decade of life [14]. The osseous elements of the mandible change significantly with age in both genders [15]. The Three-Dimensional (3D) radiography techniques like Computed Tomography (CT) and CBCT, can be used to assess the mandibular ramus. Due to the superimposition issue, Two-Dimensional (2D) conventional radiographs, such as panoramic and cephalographic images, have difficulties when assessing the mandibular ramus [16]. A 3D diagnostic tool designed especially for the maxillofacial area is called CBCT. For an appropriate diagnosis, treatment plan, and prognosis, it offers thorough diagnostic data together with a craniofacial anatomical image. The CBCT pictures can focus on the targeted area or display a large portion of the facial bones [17]. The primary benefit of CBCT is its capacity to provide 3D images, which solves the overlapping issue of anatomical features that arises with 2D imaging. With its high contrast and image clarity, CBCT is perfect for imaging the craniofacial region because it allows for a detailed view and assessment of the surrounding bone and bone structures. Furthermore, it is highly accurate and comparable to the true size, form, and structure of the teeth and bones [18-21]. The present study is based on the rationale that there is limited evidence on the use of CBCT-derived mandibular ramus measurements for age and gender estimation in the target population, and establishing such data may enhance the accuracy of forensic identification.

Hence, the study aimed to evaluate mandibular ramus dimensions using CBCT for forensic age and gender estimation. The primary objective is to assess sexual dimorphism in mandibular ramus dimensions using CBCT, while the secondary objectives are to evaluate the correlation between mandibular ramus height and chronological age and to determine the accuracy of discriminant function analysis in predicting gender-based on mandibular ramus measurements. The study is guided by the following hypotheses:

The null hypothesis (H_0) states that mandibular ramus measurements do not significantly differ between males and females and do not correlate with chronological age.

The alternate hypothesis (H_1) proposes that mandibular ramus measurements significantly differ between genders and show a correlation with chronological age.

MATERIALS AND METHODS

This retrospective cross-sectional study was conducted in the Department of Oral Medicine and Radiology, Karpaga Vinayaga Institute of Dental Sciences, over a period of four months from March 2025 to June 2025. Ethical clearance for the study was obtained from the Institutional Ethics Committee (IEC) of Karpaga Vinayaga Institute of Dental Sciences, and the approval number is KIDS/IEC/2025/I/019.

Sample size and sampling technique: The sample size for the present study was calculated using G*Power software version 3.1.9.2 for comparison of two independent means (two groups) using a two-tailed t-test. Based on a previous study evaluating the projective height of the ramus [22], the mean values obtained for the two groups were 48 and 53, with standard deviations of 7.2 and 8.7, respectively. The calculated effect size (Cohen's d) was 0.626.

The statistical parameters were set as follows:

- Confidence level (α error probability)=0.05
- Power (1-β error probability)=80%
- Allocation ratio (N2/N1) =0.66, estimated based on the ratio of female and male CBCT cases taken in the areas of study set-up.

Using these parameters, the minimum required sample size was estimated to be 52 participants in Group 1 and 34 participants in Group 2, giving a total sample size of 86 participants, which was further approximated to 100. The achieved actual power was 0.801.

Inclusion criteria: The CBCT scans of individuals aged 7-58 years with DICOM images demonstrating complete visualisation of the mandible and adequate quality for accurate linear measurements were included in the study.

Exclusion criteria: Scans showing pathological conditions such as cysts, tumours, or other lesions affecting the mandible; a history of mandibular trauma, fractures, or surgical interventions; as well as poor-quality, distorted, or incomplete DICOM images were excluded from the analysis.

Study Procedure

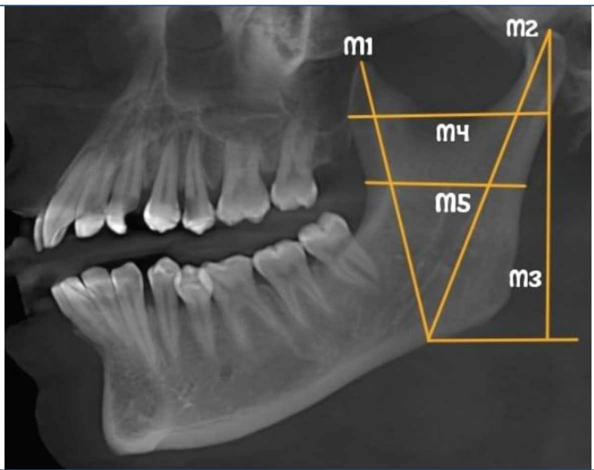
All scans were acquired using a dental CBCT unit (CS 9600, Carestream Dental LLC). The Digital Imaging and Communications in Medicine (DICOM) files were retrieved and evaluated using standard imaging software. Five mandibular ramus parameters, coronoid height, condylar height, ramus height, maximum ramus breadth, and minimum ramus breadth, were identified using predefined anatomical landmarks and measured in millimetres. Measurements were taken on the left-side.

Demographic parameters: Age (in years) and gender (male/female) were documented for each participant and used for subgroup analysis. The mandibular variables are listed in [Table/Fig-1] and markings are shown in [Table/Fig-2]. Standardised lateral CBCT reconstructed images were used for all mandibular measurements. To ensure consistency, measurements were made on the left-side. The left-side was selected to standardise measurements and avoid inter-side variability. Previous studies have shown minimal bilateral variation in mandibular ramus dimensions. All values were expressed in millimetres (mm). Established anatomical landmarks documented in the literature served as the foundation for definitions [6,23].

Examiner calibration was performed before the study. Two examiners independently measured the mandibular ramus parameters on CBCT images. To evaluate reliability, measurements were repeated after a two-week interval. Inter- and intra-examiner reliability were

Measurement	Abbreviation	Definition	Unit
Coronoid height	M1	Linear distance from the most superior point of the coronoid process to the lowest point of the mandibular notch along the vertical plane, measured on the lateral CBCT view [22].	mm
Condylar height	M2	Vertical distance from the highest point of the mandibular condyle to the deepest point of the sigmoid notch, measured on the lateral CBCT view [22].	mm
Mandibular ramus height	M3	Perpendicular distance between the most superior point of the mandibular condyle and the gonion, measured on the lateral CBCT view [22].	mm
Maximum ramus breadth	M4	Maximum anteroposterior width of the ramus measured between the most anterior point and a line touching the most posterior point of the mandibular ramus [22].	mm
Minimum ramus breadth	M5	Minimum anteroposterior width of the mandibular ramus at the narrowest mid-ramus region [22].	mm

[TableFig-1]: Description of mandibular ramus variables assessed on CBCT.
Note: All measurements were recorded in millimetres (mm) using standardised lateral CBCT reconstructed images on the left-side. Anatomical landmarks and definitions were adopted from previously published literature



[Table/Fig-2]: Mandibular ramus measurements.

assessed using the Intraclass Correlation Coefficient (ICC, two-way random effects model, absolute agreement - ICC (2,1)). The intra-examiner reliability ranged from 0.91 to 0.96, while inter-examiner reliability ranged from 0.88 to 0.94, indicating excellent agreement between measurements.

STATISTICAL ANALYSIS

Statistical analysis was performed using IBM SPSS Statistics for Windows (version 27.0). Descriptive statistics were computed for all variables. The Student's t-test and Welch's t-test were used for gender-based comparisons, and ANOVA was applied for multigroup comparisons. Pearson's correlation and linear regression analyses were used to assess the association between ramus height and chronological age. Discriminant function analysis with Wilks' Lambda was applied for gender prediction. A p-value ≤0.05 was considered statistically significant.

RESULTS

Mandibular ramus height was compared between males and females within each age group using the Independent samples t-test. Welch's correction was applied when the assumption of homogeneity of variances was violated, and results were expressed as mean±standard deviation with corresponding t and p-values. In the 7-17 years age group, only male participants were available (n=6); therefore, statistical comparison between genders was not performed. In the 17-58 years age group, males demonstrated significantly greater mandibular ramus height compared to females (t=4.78, p<0.001) [Table/Fig-3].

Age group (years)	Gender	n	Mean±SD (mm)	t-value	p-value
7-17	Male	6	65.46±3.53	NA	NA
7-17	Female	0	NA	NA	NA
17-58	Male	54	65.53±6.11	4.78	<0.001*
17-58	Female	40	60.30±4.66	-	-

[Table/Fig-3]: Mandibular ramus height according to age group and gender.
Note: Values are expressed in millimetres (mm). An independent samples t-test was performed only for the 17-58 years age group due to the absence of female participants in the 7-17 years group. *p≤0.05 considered statistically significant. N: Number of participants; SD: Standard deviation; NA: Not applicable

The similarity between the mean ramus height values of the 7-17 years and 17-58 years age groups is due to the rapid mandibular growth occurring during adolescence, where condylar growth and ramus remodelling contribute significantly to vertical mandibular development. By the late teenage years, much of the ramus height reaches near-adult dimensions. Additionally, the small sample size in the younger age group (n=6) and the absence of female participants may have influenced the mean value. Because of limited sample, statistical comparison between genders in the younger age group was not performed.

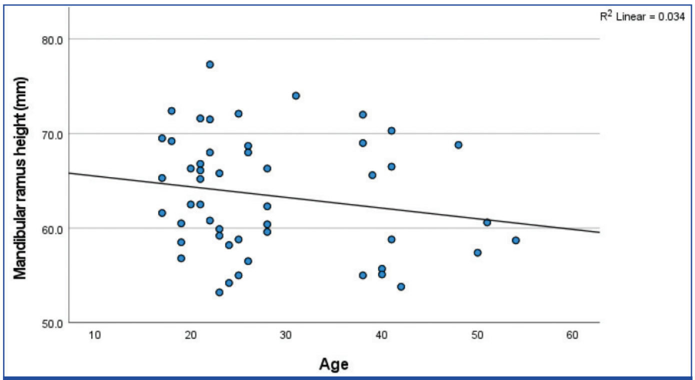
Predicted values of √ln(age) was derived using linear regression analysis with ramus height and gender as predictors. The model showed a weak and statistically non significant association with chronological age (R=0.206, R^2=0.043, adjusted R^2=0.023; F=2.158, p=0.121). The regression coefficient for ramus height was not statistically significant (β=–0.015, p=0.948), indicating limited utility of ramus height as an independent predictor of age in this population [Table/Fig-4].

Ramus height (mm)	Gender	Predicted √ln(age)	Lower 90% CI (√ln age)	Upper 90% CI (√ln age)	Predicted mean age (years)	Lower 90% CI (years)	Upper 90% CI (years)
45	Female	1.835	1.786	1.885	29.03	24.26	34.91
55	Female	1.827	1.803	1.850	28.12	25.82	30.65
60	Female	1.823	1.795	1.851	27.73	25.05	30.75
45	Male	1.814	1.747	1.881	26.85	21.17	34.35
55	Male	1.805	1.776	1.835	26.01	23.40	28.96
65	Male	1.798	1.775	1.820	25.34	23.38	27.49

[Table/Fig-4]: Predicted mean age and 90% confidence intervals based on mandibular ramus height (mm).
Note: Ramus height was measured in millimetres (mm). Predicted ages and confidence intervals are expressed in years. CI: Confidence interval. √ln(age) values were back-transformed to obtain predicted mean age. A 90% confidence level was applied

A scatter plot was generated to evaluate the relationship between age and mandibular ramus height. Regression analysis demonstrated a weak and non significant linear association (R^2=0.043, p=0.121), indicating that ramus height does not meaningfully vary with age in the studied sample. The relationship between mandibular ramus height and chronological age was further assessed using correlation and regression analyses, which confirmed that mandibular ramus height alone is not a reliable predictor of chronological age in this population. Although predicted ages were calculated for different ramus height values, the regression model lacked statistical significance, suggesting limited utility of ramus height measurements for forensic age estimation [Table/Fig-5].

Males demonstrated significantly higher coronoid height, 61.51±4.42 mm, and condylar height, 70.48±6.00 mm, compared to females, 55.78±4.19 mm and 64.70±4.28 mm, respectively. In terms of breadth measurements, males also showed significantly greater maximum and minimum ramus breadths, 36.31±3.62 mm



[Table/Fig-5]: Scatter plot showing the relationship between age and mandibular ramus height (M3). The fitted regression line demonstrates a weak and statistically non significant linear association (R^2=0.043).
Note: N=100. Some data points overlap due to similar measurement values

and 30.45±3.31 mm, respectively, than females 32.65±3.38 mm and 27.61±2.61 mm. Multivariate analysis using Wilks' Lambda confirmed statistically significant sexual dimorphism across the assessed mandibular ramus parameters [Table/Fig-6].

Variables	Mean±SD	Mean±SD	Wilks' Lambda	Test statistic (t/F)	p-value
Coronoid height	55.78±4.19	61.51±4.42	0.701	6.471	<0.001
Condylar height	64.70±4.28	70.48±6.00	0.659	5.259	<0.001
Mandibular ramus height	60.30±4.66	65.53±6.11	0.696	4.588	<0.001
Maximum ramus breadth	32.65±3.38	36.31±3.62	0.628	5.089	<0.001
Minimum ramus breadth	27.61±2.61	30.45±3.31	0.624	4.562	<0.001

[Table/Fig-6]: Descriptive statistics of mandibular ramus parameters between males and females.
Note: All measurements are expressed in millimetres (mm). Group comparisons between males and females were performed using appropriate statistical tests. Wilks' Lambda was used to assess multivariate discrimination between groups. A p-value <0.05 was considered statistically significant. SD: Standard deviation

The discriminant function model demonstrated an overall classification accuracy of 78.0%. Among female participants, 34 of 40 cases (85.0%) were correctly identified (sensitivity), while six cases (15.0%) were misclassified. Among male participants, 44 of 60 cases (73.3%) were correctly identified (specificity), with 16 cases (26.7%) incorrectly classified as females. The positive predictive value was 68.0% for females and 88.0% for males, indicating good discriminatory performance of mandibular ramus measurements for gender prediction [Table/Fig-7].

Actual gender	Predicted female	Predicted male	Total
Female (n=40)	34	6	40
Male (n=60)	16	44	60
Total	50	50	100

[Table/Fig-7]: Classification results of discriminant function analysis for gender prediction.

Fisher's linear discriminant analysis achieved an overall classification accuracy of 78%, indicating good discriminatory ability between males and females based on mandibular ramus measurements. Based on CBCT-derived mandibular ramus parameters, subjects were classified using the derived discriminant functions. Coronoid height and condylar height contributed most strongly to gender discrimination, followed by maximum ramus breadth. Mandibular ramus height showed negative coefficients in both functions, indicating an inverse contribution to the discriminant score, whereas minimum ramus breadth demonstrated minimal predictive contribution. All measurements were recorded in millimetres (mm).

Fisher's Linear Discriminant Functions

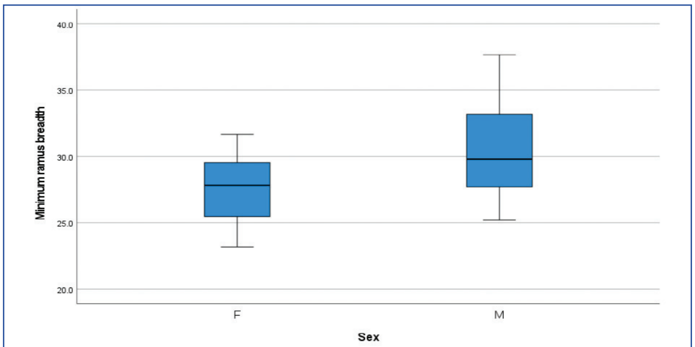
Female function ($D_{(F)}$): D=-105.201+(1.956×Coronoid height)+(1.891×Condylar height)-(1.027×Mandibular ramus height)+(1.170×Maximum ramus breadth)+(0.046×Minimum ramus breadth)

Male function ($D_{(M)}$): D=-127.489+(2.205×Coronoid height)+(2.075×Condylar height)-(1.181×Mandibular ramus height)+(1.366×Maximum ramus breadth)-(0.016×Minimum ramus breadth) [Table/Fig-8].

Classification function coefficients	Gender	
	Females	Males
Coronoid height	1.956	2.205
Condylar height	1.891	2.075
Mandibular ramus height	-1.027	-1.181
Maximum ramus breadth	1.170	1.366
Minimum ramus breadth	0.046	0.016
(Constant)	-105.201	-127.489

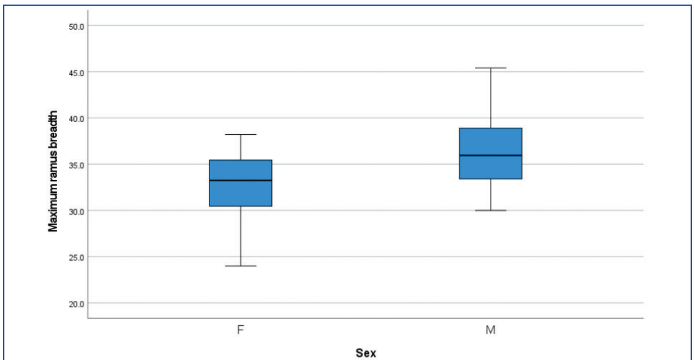
[Table/Fig-8]: Classification function coefficients for gender prediction.

A box plot comparing the distribution of minimum ramus breadth in males and females is shown in [Table/Fig-9]. Males had a greater median minimum ramus breadth (~30 mm) than females (~28 mm). Females had a narrower spread and wider interquartile range, indicating greater variability in ramus breadth. Males had a minimum ramus breadth of 25-38 mm, while females had a range of 23-32 mm. This indicates sexual dimorphism in mandibular morphology.



[Table/Fig-9]: Box plot showing the distribution of minimum ramus breadth among males and females.

The distribution of maximum ramus width in males and females is shown in [Table/Fig-10]. Males had a greater median maximum ramus breadth (~36 mm) than females (~33 mm). Females had a narrower range, while males had a wider interquartile range. Males had a maximum ramus width between 30 mm and 46 mm, while females varied between 24 mm and 38 mm. Males generally had higher central values and more dispersion.



[Table/Fig-10]: Box plot showing the distribution of maximum ramus breadth among males and females.

DISCUSSION

The determination of an individual's age and gender is crucial to their identity. Age and gender determination are interdependent. An individual's age can be determined by their gender, and their gender can be determined by their age [3]. A forensic odontologist can use facial bones, particularly the mandible, which is thought to be a stronger bone, to help determine age and gender [8,24]. The mandible demonstrates sexual dimorphism and is a durable bone for identification, as it's comprised of dense compact bone. It has been discovered that the masticatory force and the muscles of mastication affect the mandible's size, strength, and angulation [25]. The findings demonstrated a statistically significant difference in gender for each of the five parameters assessed on the mandibular ramus using 3D CBCT. It was discovered that the mandibular ramus had a significant rate of sexual dimorphism. The findings were consistent with other research. The regression model demonstrated limited predictive strength for chronological age estimation in the present study. Although significant sexual dimorphism was observed, mandibular ramus height did not demonstrate a statistically significant association with chronological age. According to these investigations, the mandibular ramus was particularly useful for determining gender, and the mandibular bone displayed sexual dimorphism. However, the use of panoramic radiography is absent from this research. The Orthopantomographs (OPG) method's drawbacks include geometric distortion and magnification, which lead to numerous errors. There was minimal change in the vertical dimension when compared to the horizontal dimension. Measurements made using the OPG approach are therefore unreliable [24-26].

The notion that the mandibular ramus was a powerful sexually dimorphic bone was reinforced by the results, which matched those of another study that employed the same criteria on the dry mandible in a North Indian population [13,27]. Muscle and hormonal variations are the cause of the statistically significant physical differences between males and females of this gender [7]. Analysing Multidetector CT (MDCT) pictures from the Turkish population revealed results that were comparable in terms of similar characteristics. The MDCT is more costly than the approach and consumes more radiation than the patient would receive from CBCT. One demonstrated that intraobserver CBCT measures were very reliable and that the results of CBCT measurements are quite close to the anatomic truth. According to another, the CBCT method can be used to measure anatomical structures that are challenging to measure using conventional methods. It can also be used to assess live things [6,23,27]. Future studies with larger, multicentric samples, prospective designs and control for biological and environmental confounders are recommended to improve the robustness and applicability of the findings.

The present study partially supported the hypothesis. The null hypothesis was rejected for gender determination because all mandibular ramus parameters showed significant sexual dimorphism. However, it could not be rejected for age estimation, as ramus height showed only a weak, non significant association with chronological age. Therefore, the alternative hypothesis was supported for gender determination but not for age estimation.

Limitation(s)

The sample was restricted to a single Institution which may limit the generalisability of the findings to broader populations. The study relied on retrospective CBCT scans obtained for various diagnostic purposes; therefore, potential confounding factors such as nutritional status, hormonal influences, mastication-related functional variations and systemic health conditions could not be assessed or controlled and their impact on mandibular morphology remains unknown. Measurements were also limited to static linear parameters without accounting for anatomical asymmetry or functional biomechanics. In addition, the age distribution of participants was uneven with a very small number of individuals in the younger age group reducing the strength of comparisons across age ranges. Additionally, the absence of a comparative analysis between the right and left sides of the mandible represents a limitation, as potential lateral asymmetry could not be evaluated. Standardisation of head position during CBCT acquisition could not be verified retrospectively, which may introduce minor variability in landmark identification. The absence of female participants in the younger age group limited gender-wise comparisons in that subgroup.

CONCLUSION(S)

The mandibular ramus emerged as a useful skeletal marker for CBCT-based gender determination in this retrospective study. With an overall classification accuracy of 78%, discriminant function analysis identified coronoid height, condylar height, and ramus breadth as strong predictors of gender. All measured parameters showed significant sexual dimorphism, with males consistently exhibiting higher values than females. In contrast, mandibular ramus height demonstrated only a weak and statistically non significant association with chronological age, indicating limited value for age estimation. Overall, these findings support CBCT-derived mandibular measurements as reliable tools for forensic gender determination. Further large, multicentric studies with balanced age distribution and advanced predictive modelling are recommended to enhance age estimation accuracy.

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