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Radiographic Evaluation of Gender Dimorphism in Mandibular Ramus Morphometry Using Digital Orthopantomograms in a Central India

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Abstract
Background: Gender estimation is a crucial aspect of forensic identification, particularly when fragmented skeletal remains are encountered. The mandible, owing to its durability and resistance to postmortem changes, serves as an important anatomical structure for gender determination. Digital orthopantomography (OPG) provides a reliable and non-invasive method for evaluating mandibular morphometric parameters.
Aim: To evaluate gender-related differences in mandibular ramus morphometry using digital orthopantomograms in a Central Indian population and to assess their utility in forensic identification.
Materials and Methods: A cross-sectional observational study was conducted on 380 digital OPGs obtained from adults aged 18 years and above. Morphometric parameters including maximum ramus breadth, minimum ramus breadth, condylar height, projective ramus height, coronoid height, gonial angle, and selected dental measurements were evaluated using DICOM-based image analysis software. Statistical analysis was performed using SPSS version 26.0, and $p < 0.05$ was considered statistically significant.
Results: Of the 380 OPGs analyzed, 198 (52.1%) belonged to males and 182 (47.9%) to females. The widths of the right and left mandibular lateral incisors were significantly greater in males than females ($p < 0.05$). Females exhibited a significantly greater gonial angle, whereas males showed higher intergonial width ($p < 0.001$). Discriminant analysis revealed that projective ramus height (0.71) had the highest contribution to gender differentiation, followed by condylar height (0.58) and coronoid height (0.52).
Conclusion: Mandibular ramus morphometric parameters, particularly projective ramus height, condylar height, and coronoid height, demonstrate significant gender-related differences and can serve as reliable indicators for forensic gender estimation using digital orthopantomograms.

Keywords: Gender estimation, Mandibular ramus, Orthopantomogram, Forensic identification, Morphometry, Digital radiography.

Introduction

Gender estimation constitutes a fundamental component of forensic identification and biological profiling. Accurate determination of gender significantly narrows the pool of potential identities and facilitates subsequent anthropological and medico-legal investigations [1,2,3]. The mandible is recognized as one of the most dimorphic bones of the human skeleton and exhibits marked morphological and morphometric variations between males and females [4]. Owing to its dense cortical structure and high resistance to postmortem degradation, the mandible is frequently preserved even in fragmented skeletal remains, making it a valuable anatomical structure for forensic analysis [5].

The mandibular ramus, in particular, demonstrates considerable gender-related differences as a result of differential growth patterns, functional loading, and hormonal influences [6]. Morphometric parameters such as ramus height, condylar height, coronoid height, and ramus breadth have been reported to exhibit significant differences between males and females and are widely employed in forensic anthropological studies for gender estimation [7,8].

Digital Orthopantomography (OPG) is a non-invasive and reliable imaging modality that provides a panoramic visualization of the maxillofacial complex [9]. The technique offers standardized radiographic images with minimal radiation exposure and enables precise linear measurements of mandibular structures. Consequently, digital OPG has emerged as an important tool for the evaluation of craniofacial morphometry in both clinical and forensic settings [10,11].

Since craniofacial characteristics vary among different ethnic and geographic populations, the establishment of population-specific reference data is essential for improving the accuracy of gender determination [12]. Therefore, the present study was undertaken to evaluate gender-related differences in mandibular ramus morphometric parameters using digital orthopantomograms in a Central Indian population and to assess their potential applicability in forensic identification and anthropological investigations [13].

Materials and Methods

This cross-sectional observational radiographic study was conducted in the Department of Anatomy in collaboration with the Department of Oral Medicine and Radiology, Index Medical College, Hospital and Research Centre, Indore, Madhya Pradesh, from July 2023 to July 2026 to evaluate the morphological and morphometric characteristics of the mandible, maxilla, and teeth using digital Orthopantomograms (OPGs). The study population comprised adult individuals aged 18 years and above who underwent routine digital OPG examination and fulfilled the predefined eligibility criteria. Both male and female subjects were included in the study.

The sample size was calculated using the formula $n = Z^2 \times p \times q/d^2$, where $Z = 1.96$ at a 95% confidence level, $p = 50\%$, $q = 50\%$, and $d = 5\%$ absolute precision. The calculated sample size was 374.16. To compensate for possible exclusions and incomplete radiographs, a total of 380 subjects were included in the study. Individuals aged 18 years and above with high-quality digital OPGs showing clearly visible mandibular, maxillary, and dental structures and complete permanent dentition excluding third molars were included. Subjects with congenital craniofacial anomalies, cleft lip and palate, craniofacial syndromes, a history of maxillofacial trauma or orthognathic surgery, extensive jaw pathologies, severe periodontal disease, edentulism, previous orthodontic treatment, or poor-quality radiographs were excluded from the study.

Ethical approval was obtained from the Institutional Ethics Committee prior to the commencement of the study. Written informed consent was obtained from all participants, and confidentiality and anonymity were maintained throughout the study.

Digital panoramic radiographs were acquired using the KaVo OP 3D Pro Digital Orthopantomography System available in the Department of Oral Medicine and Radiology. Prior to image acquisition, participants were instructed to remove all metallic objects, including jewellery, eyeglasses, and removable prostheses. Radiographs were obtained according to the manufacturer's guidelines with standardized exposure parameters adjusted according to patient characteristics. The average exposure settings included a tube voltage of 68–73 kV, tube current of 10–11 mA, and an exposure time of approximately 18 seconds. Proper patient positioning was achieved using the bite block and positioning guides to minimize image distortion and magnification errors. All radiographic images were stored in Digital Imaging and Communications in Medicine (DICOM) format for subsequent analysis.

Image analysis was performed using DICOM-compatible software that enabled image magnification, brightness and contrast adjustment, edge enhancement, and precise linear and angular measurements. All measurements were recorded directly on high-resolution digital images following standardized anatomical landmarks and measurement protocols to ensure accuracy and reproducibility.

Morphological assessment included bilateral evaluation of the mandibular condyle and coronoid process. The shapes of the condylar and coronoid processes were categorized according to their radiographic appearance, and the frequency distribution of each morphological type was recorded.

Mandibular morphometric assessment included measurement of maximum ramus breadth, minimum ramus breadth, condylar height (maximum ramus height), coronoid height, gonial angle, and angle of the mandible on both sides. Maximum ramus breadth was defined as the distance between the most anterior point of the mandibular ramus and a line connecting the most posterior point of the condyle, whereas minimum ramus breadth represented the shortest distance between the anterior and posterior borders of the ramus. Condylar height was measured from the highest point of the mandibular condyle to the most inferior point of the ramus, while coronoid height was measured from the tip of the coronoid process to the lower border of the mandible. Gonial angle and angle of the mandible were determined using standard angular measurement techniques.

Maxillary morphometric analysis included measurements of inter-canine distance, inter-first premolar distance, inter-second premolar distance, inter-molar distance, maxillary depth, palatal height, and palatal index. Interdental distances were measured between the centroids of corresponding teeth. Maxillary depth was determined as the distance from the midpoint of the labial surface of the maxillary central incisors to the midpoint of a line joining the distal surfaces of the maxillary first molars. Palatal height and palatal index were calculated using standard morphometric methods. The morphology and dimensions of the maxillary sinus, including sinus height and width, were also evaluated wherever clearly visualized on the radiographs.

Dental morphometric assessment included measurement of mesiodistal crown widths of maxillary central incisors, maxillary lateral incisors, mandibular central incisors, mandibular lateral incisors, and canines. Variations in tooth shape and crown morphology were also recorded and categorized according to predefined criteria.

Additional craniofacial measurements included zygomatic arch width, jugal width, and bigonial width. Zygomatic arch width was measured as the distance between the centers of the right and left zygomatic arches, jugal width as the distance between the right and left jugal processes, and bigonial width as the distance between the right and left antegonial protuberances.

To minimize measurement bias, all radiographs were evaluated by a single trained observer following standardized protocols. A subset of radiographs was re-evaluated after a two-week interval to assess intraobserver reliability.

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 26.0. Descriptive statistics were expressed as mean, standard deviation, frequency, and percentage. Inferential statistical analyses included Independent Student's t-test, Paired t-test, One-way Analysis of Variance (ANOVA), Chi-square test, Pearson correlation analysis, and multiple regression analysis wherever applicable. A p-value of less than 0.05 was considered statistically significant.

A total of 380 digital orthopantomograms were included in the study. Of these, 198 (52.1%) belonged to male subjects and 182 (47.9%) to female subjects, indicating a slightly higher representation of males in the study population.

Table 1: Distribution of OPGs According to Gender in the Central Indian Population (n = 380)

Gender	Number of OPGs (n)	Percentage (%)
Male	198	52.1
Female	182	47.9
Total	**380**	**100.0**

The mean width of both right and left mandibular lateral incisors was significantly greater in males than females. The right mandibular lateral incisor measured 5.98 ± 0.42 mm in males and 5.84 ± 0.40 mm in females (p = 0.028), while the left mandibular lateral incisor measured 5.96 ± 0.44 mm in males and 5.82 ± 0.41 mm in females (p = 0.031), indicating significant sexual dimorphism.

Table 2: Comparison of Mandibular Lateral Incisor Width between Male and Female Subjects (n = 380)

Position	Gender	Mean (mm)	SD	p-value	Result
Right Mandibular Lateral Incisor	Male	5.98	0.42	0.028	S
	Female	5.84	0.40		
Left Mandibular Lateral Incisor	Male	5.96	0.44	0.031	S
	Female	5.82	0.41		

S = Significant ($p < 0.05$)

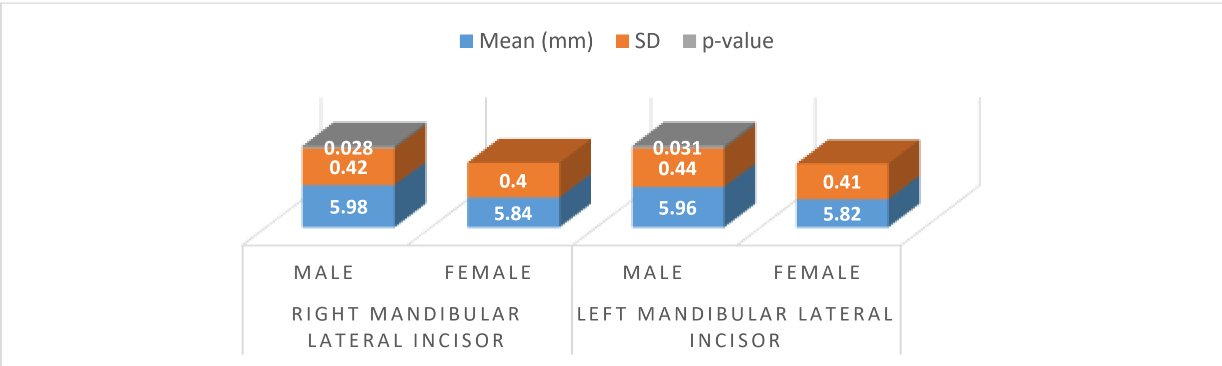

Figure 1: Comparison of Mandibular Lateral Incisor Width between Male and Female Subjects

The width of the mandibular lateral incisors was significantly greater in males than in females on both sides. The mean width of the right and left mandibular lateral incisors was 5.98 ± 0.42 mm and 5.96 ± 0.44 mm in males, compared to 5.84 ± 0.40 mm and 5.82 ± 0.41 mm in females, respectively. The differences were statistically significant ($p < 0.05$).

Table 3: Comparison of Mandibular Lateral Incisor Width between Male and Female Subjects (n = 380)

Position	Gender	Mean (mm)	SD	p-value	Result
Right Mandibular Lateral Incisor	Male	5.98	0.42	0.028	S
	Female	5.84	0.40		
Left Mandibular Lateral Incisor	Male	5.96	0.44	0.031	S
	Female	5.82	0.41		

S = Significant ($p < 0.05$)

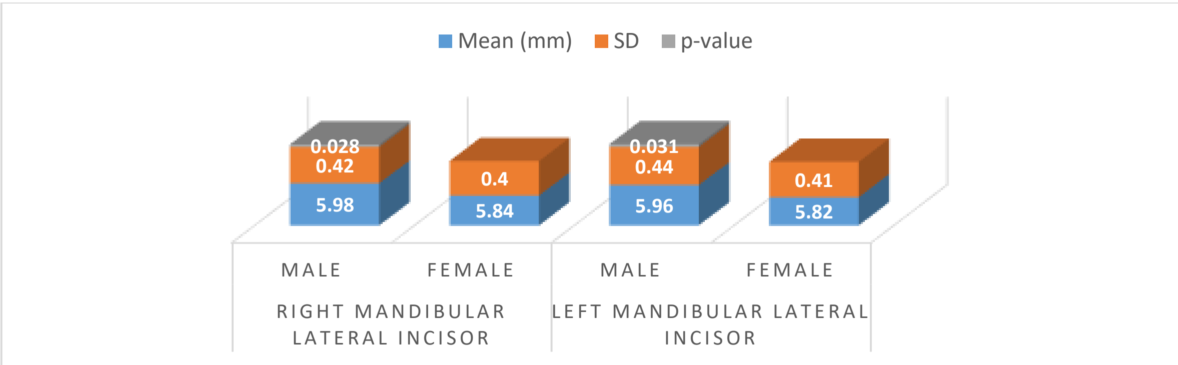

Figure 2: Comparison of Mandibular Lateral Incisor Width between Male and Female Subjects

Table 4: Comparison of Gonial Angle and Intergonial Width between Males and Females (n = 380)

Parameter	Male (n=198) Mean ± SD	Female (n=182) Mean ± SD	p-value
Gonial Angle (°)	119.6 ± 6.2	124.2 ± 5.9	<0.001
Intergonial Width (mm)	97.4 ± 6.5	92.6 ± 5.8	<0.001

Discriminant analysis revealed that projective ramus height showed the highest contribution to sex differentiation with a standardized discriminant coefficient of 0.71, followed by condylar height (0.58), coronoid height (0.52), maximum ramus breadth (0.39), and minimum ramus breadth (0.33). Gonial angle exhibited a negative discriminant coefficient (-0.24). The mean values of maximum ramus breadth, minimum ramus breadth, condylar height, projective ramus height, coronoid height, and gonial angle were 33.7 ± 3.4 mm, 28.8 ± 2.9 mm, 62.1 ± 6.0 mm, 57.4 ± 5.4 mm, 59.8 ± 5.6 mm, and 121.8 ± 6.4°, respectively.

Table 4: Discriminant Analysis of Different Parameters of Mandibular Ramus in the Overall Study Population

Parameter	Mean ± SD	Standardized Discriminant Coefficient
Maximum Ramus Breadth (mm)	33.7 ± 3.4	0.39

Minimum Ramus Breadth (mm)	28.8 ± 2.9	0.33
Condylar Height (mm)	62.1 ± 6.0	0.58
Projective Ramus Height (mm)	57.4 ± 5.4	0.71
Coronoid Height (mm)	59.8 ± 5.6	0.52
Gonial Angle (°)	121.8 ± 6.4	-0.24

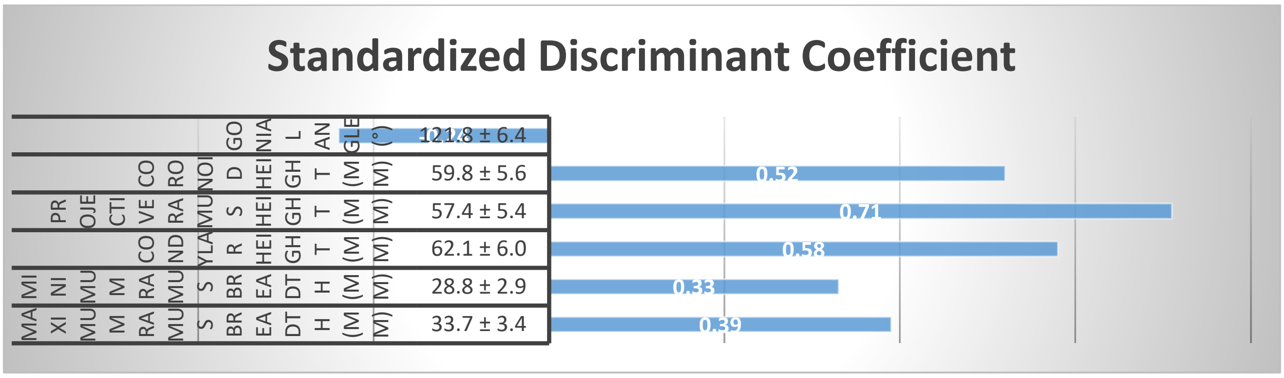

Figure 3- Discriminant Analysis of Different Parameters of Mandibular Ramus in the Overall Study Population

Discussion

The present study evaluated the role of mandibular ramus morphometry in gender estimation using digital orthopantomograms in a Central Indian population. Discriminant analysis revealed that projective ramus height exhibited the highest discriminatory value with a standardized discriminant coefficient of 0.71, followed by condylar height (0.58), coronoid height (0.52), maximum ramus breadth (0.39), and minimum ramus breadth (0.33). Gonial angle showed a negative discriminant coefficient (-0.24), indicating a relatively lower contribution to gender differentiation.

The findings of the present study are in agreement with those of Samatha et al. (2016) [14], who reported that projective ramus height, condylar height, and maximum ramus breadth were the most significant parameters for gender determination using digital orthopantomograms. Their study demonstrated that mandibular ramus measurements possess considerable discriminatory potential, with projective ramus height emerging as one of the strongest predictors of sex estimation.

In the present investigation, the mean projective ramus height was 57.4 ± 5.4 mm and the mean condylar height was 62.1 ± 6.0 mm. These observations support the findings of Saini et al. (2011) [15], who concluded that ramus height-related parameters are among the most reliable indicators for gender estimation in fragmented mandibles. The authors reported that vertical dimensions of the ramus demonstrated greater dimorphism than breadth measurements and significantly improved classification accuracy.

Coronoid height also showed substantial discriminatory ability in the present study, with a mean value of 59.8 ± 5.6 mm and a discriminant coefficient of 0.52. Similar observations were reported by the study of minimum ramus breadth and coronoid height in gender determination (2025) [16], where males exhibited significantly greater coronoid height values than females (80.67 ± 0.83 mm vs. 73.51 ± 1.26 mm; $p < 0.001$). The authors concluded that coronoid height is a valuable parameter for gender estimation using orthopantomograms.

The mean maximum ramus breadth and minimum ramus breadth in the present study were 33.7 ± 3.4 mm and 28.8 ± 2.9 mm, respectively. Although these parameters contributed to gender discrimination, their

discriminative power was lower than that of ramus height measurements. Similar findings have been reported by Samatha et al. (2016) [14], who observed significant differences in ramus breadth measurements between males and females but identified height-related parameters as superior predictors of gender.
The mean gonial angle observed in the present study was 121.8 ± 6.4°. Gonial angle demonstrated the lowest discriminative value among all studied variables, suggesting that linear ramus measurements are more reliable indicators of gender than angular measurements. This finding is consistent with previous forensic studies, which have reported greater variability in gonial angle compared with ramus height and breadth measurements.

Conclusion

The study demonstrated significant gender differences in mandibular ramus morphometric parameters. Projective ramus height, condylar height, and coronoid height were the most reliable indicators for gender determination. These findings suggest that mandibular ramus measurements on digital orthopantomograms can be effectively used for forensic gender estimation in the Central Indian population.

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