Original Article

Osteometric Assessment of the Radius for Sex Estimation in a Western Rajasthan Population: A Study of Sexual Dimorphism and Classification Accuracy

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Abstract

Background: Sex estimation is an important component of forensic skeletal identification. Although the pelvis and skull are considered the most reliable skeletal elements, long bones such as the radius can provide useful information when these bones are unavailable or damaged. Population-specific osteometric standards are particularly important because skeletal dimensions vary between geographical and ethnic populations. **Material and Methods:** The present study was conducted on 50 adult right radii obtained from cadavers belonging to the Western Rajasthan population at the Department of Anatomy, Dr. S. N. Medical College and associated hospitals, Jodhpur. Twenty-five male and 25 female radii were examined. Bones with pathological changes, fractures, or non-union of the epiphysis were excluded. Four morphometric parameters were recorded in millimetres: maximum length, distal breadth, minimum mid-shaft diameter, and maximum mid-shaft diameter. The measurements were statistically compared between males and females, and sensitivity, specificity, and overall accuracy were assessed. **Results:** All four radial measurements were significantly greater in males than females ($p<0.0001$). Mean maximum radial length was 249.24±10.77 mm in males and 221.52±10.27 mm in females. Mean distal breadth was 33.02±2.93 mm in males and 27.06±2.43 mm in females. Minimum mid-shaft diameter measured 11.87±0.93 mm in males and 9.79±0.94 mm in females, whereas maximum mid-shaft diameter measured 15.53±1.26 mm and 13.10±0.97 mm, respectively. Maximum mid-shaft diameter demonstrated the highest overall accuracy (92%), followed by maximum radial length (90%), distal breadth (88%), and minimum mid-shaft diameter (88%). **Conclusion:** The present study demonstrates significant sexual dimorphism in the radius of the Western Rajasthan population. Maximum mid-shaft diameter showed the highest classification accuracy among the parameters studied. These measurements may provide useful supplementary information for sex estimation in forensic and medico-legal investigations, particularly when other diagnostic skeletal elements are unavailable.

Keywords: Radius; Osteometry; Sexual dimorphism; Sex estimation; Forensic anthropology; Western Rajasthan; Skeletal identification; Morphometry.

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Introduction

Sex estimation is one of the fundamental steps in establishing the biological profile of unidentified skeletal remains and is therefore an important component of forensic anthropology and medico-legal investigations. It becomes particularly valuable when bodies are decomposed, mutilated, burned, or otherwise unsuitable for conventional identification. Although the pelvis and skull generally provide the highest reliability for sex estimation, long bones can also provide useful information when these elements are unavailable or incomplete. The accuracy of skeletal sex estimation is influenced by population, ancestry, age, environmental factors, and secular variation; therefore, population-specific standards are preferable to applying generalized standards across different populations.[1,2]

Long bones have traditionally been investigated because their measurable dimensions show varying degrees of sexual dimorphism. The radius is particularly suitable for osteometric assessment because it is relatively compact, has well-defined anatomical landmarks, and may remain identifiable even in fragmentary skeletal remains. Previous original studies have demonstrated significant differences between male and female radii in measurements involving the radial head, shaft, distal end, and total bone length.[3-6]

Jongmuenwai et al., in a study of a Thai population, evaluated

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radial measurements for sex estimation and reported significant sexual dimorphism, with distal end width and radial head measurements providing high classification accuracy.[3] In an Indian population, Waghmare et al. studied 198 radii and demonstrated significant sex-related differences, with discriminant analysis of radial shaft and tuberosity measurements providing approximately 90% correct classification.[4] More recently, Reddy et al. evaluated the morphology and morphometry of the radius in freshly frozen Indian cadavers and reported significantly greater radial dimensions in males, including radial length and shaft measurements.[5] Gupta et al. also demonstrated significant morphological and morphometric differences in the proximal and distal ends of adult dry radii.[6]

The importance of population-specific osteometric standards is particularly relevant in India because considerable regional variation exists in skeletal morphology. Studies of other skeletal elements have similarly demonstrated that discriminant functions developed for one Indian population cannot necessarily be applied directly to another.[7,8] This regional variation has also been demonstrated in Western Rajasthan. Devi et al. studied the upper end of the right radius in a Western Rajasthan sample and reported significant sex-related differences, with classification accuracies ranging from 86% to 92%.[9]

Evidence from the same geographical and institutional setting also supports the presence of marked sexual dimorphism in other long bones. Devi et al. studied the epiphyseal ends of the humerus in a Western Rajasthan sample comprising 50 right humeri, including 25 males and 25 females. Male measurements were significantly greater than female measurements, and vertical head diameter demonstrated an accuracy of 92% for sex estimation.[10] These findings emphasize the value of developing region-specific osteometric standards for skeletal identification in Western Rajasthan.

International research further supports the forensic usefulness of the radius. A study of Portuguese skeletal collections demonstrated that individual radial measurements could achieve substantial classification accuracy, while multivariable models performed better than individual measurements.[11] Similarly, studies using radiographic and osteometric approaches have demonstrated that radial dimensions can be useful for sex assessment when conventional complete-bone osteometry is not possible.[12] These findings suggest that measurements obtained from different regions of the radius may provide complementary information for sex estimation.

Despite these observations, data on radial dimensions in specific Indian regional populations remain limited. In particular, there is a need to evaluate the usefulness of total radial length, distal breadth, and mid-shaft dimensions in the Western Rajasthan population. The present study was therefore undertaken to assess sexual dimorphism in four morphometric parameters of the right radius—maximum length, distal breadth, minimum mid-shaft diameter, and maximum mid-shaft diameter—and to determine their sensitivity, specificity, and overall accuracy for sex estimation.

Materials and Methods

The present work was conducted on 50 Radius which belonged to individuals of Western Rajasthan population. These bones were obtained from the Department of Anatomy, Dr. S. N. Medical College & associated groups of hospitals, Jodhpur. The bone samples were dissected and extracted from adult cadavers. Samples with any pathological changes, fractures, or the non union of the epiphysis of the head were excluded. Only right sided upper limb bones were considered for this study. The socio-economical status of the individuals whose bones were taken up for the study was not established. As there are no acceptable sex estimation methods for immature remains to date only adult remains have been utilized for this research.

All measurement were taken with-

A digital sliding caliper,

An osteometric board and

A steel measuring tape.

Metric data of each bone had been collected while using different anthropometric measurements as described below:

Measurements of the radius: Four radial measurements were obtained. All measurements were recorded in millimetres. Each measurement was as follows:

- **Maximum length of the radius:** It measures the greatest length between the most proximal point on the margin of the head of radius and the tip of the styloid process. This measurement is taken without any regard to the longitudinal axis of the bone.
- **Distal breadth:** It measures distance from the most medial point of the ulnar notch to the most lateral point of the styloid process.
- **Sagittal diameter at mid-shaft or minimum mid-shaft diameter:** It is the distance between the anterior and posterior surfaces of the mid-shaft. It measures the diameter of the shaft exactly at the same position and at right angle to the transverse diameter of the mid-shaft.
- **Transverse diameter at mid-shaft or maximum mid-shaft diameter:** It measures the maximum diameter of the shaft, measured at the greatest development of the interosseous crest.

Results

Table 1: Distribution of radius according to mean length (in mms)

Group	Maximum length Mean± S.D.
Male	249.24±10.77
Female	221.52±10.27
p value	<0.0001 (HS)
t value	9.311

*HS = Highly Significant

Table 2: Distribution of radius according to mean distal breadth (in mms)

Group	Distal breadth Mean± S.D.
Male	33.02±2.933
Female	27.06±2.426
p value	<0.0001 (HS)
t value	7.831

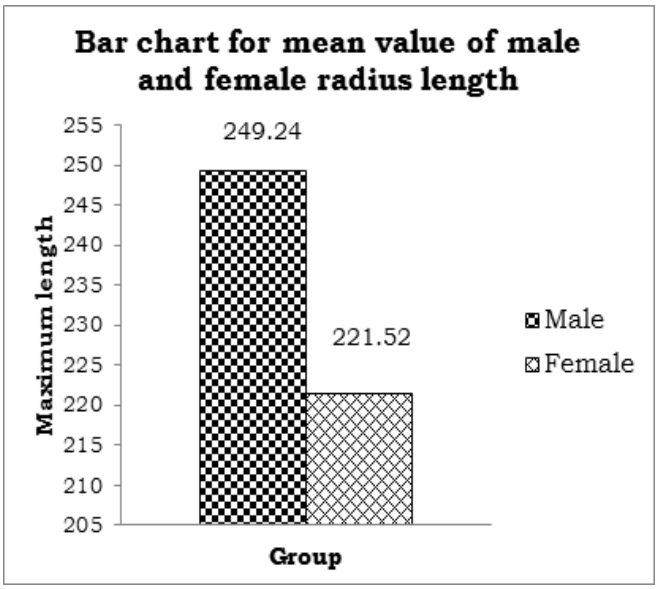
*HS = Highly Significant

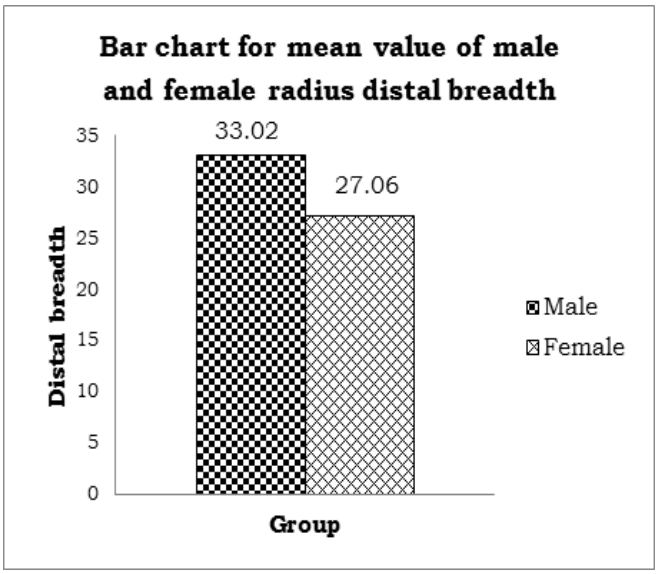
Table 3: Distribution of radius according to mean mid-shaft diameter (in mms)

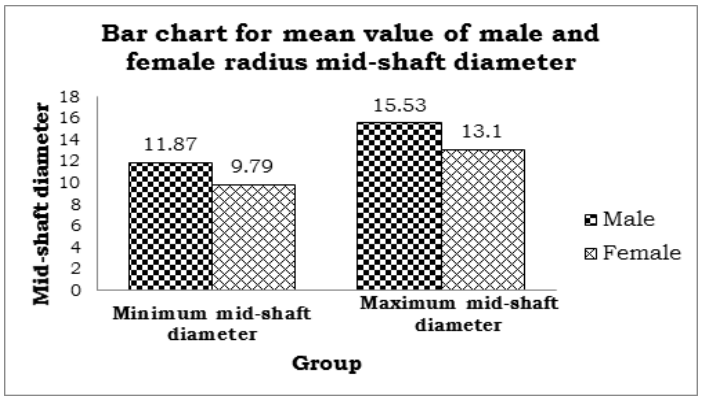
Group	Minimum mid- shaft diameter Mean± S.D.	Maximum mid-shaft diameter Mean± S.D.
Male	11.87±0.93	15.53±1.261
Female	9.792±0.942	13.10±0.966
p value	<0.0001 (HS)	<0.0001 (HS)
t value	7.849	7.649

Table 4: Sensitivity, Specificity, and Accuracy of Radial Measurements for Sex Estimation

Variables	Sensitivity %Males (25)	Specificity %Females(25)	Accuracy%
Maximum length	88 (22)	92 (23)	90
Distal breadth	92 (23)	84 (21)	88
Minimum mid-shaft diameter	88 (22)	88 (22)	88
Maximum mid-shaft diameter	96 (24)	88 (22)	92







Discussion

The present study demonstrated marked sexual dimorphism in the morphometric parameters of the right radius in the Western Rajasthan population. All four parameters showed significantly higher mean values in males than females, with p<0.0001 for each comparison. The maximum length of the radius was 249.24±10.77 mm in males compared with 221.52±10.27 mm in females. Similarly, distal breadth, minimum mid-shaft diameter, and maximum mid-shaft diameter were consistently greater in males. These findings support the usefulness of radial osteometry for sex estimation in this population.

The greater dimensions observed in male radii are consistent with previous morphometric studies demonstrating sexual dimorphism of long bones. In a Northern Thai population, male radii showed significantly greater dimensions, and maximum head diameter and distal end width provided classification accuracies of approximately 90% or more.[3] Similarly, Waghmare et al., in a study of 198 Indian radii, found substantial sexual dimorphism and reported that anteroposterior mid-shaft diameter was the strongest individual predictor, with approximately 90.4% correct classification.[4] The agreement between these findings and the present study suggests that shaft dimensions may provide useful information for sex estimation even when proximal or distal portions of the radius are

unavailable.

Maximum radial length showed a highly significant difference between males and females in the present study, with a t-value of 9.311. The mean male value was approximately 28 mm greater than the female value. This finding is comparable with recent Indian osteometric data, in which male radii were also substantially longer than female radii. A recent Central Indian study reported mean radial lengths of 243.65 mm in males and 223.60 mm in females, with significant sex-related differences across several radial parameters.[5] The slightly different absolute values may reflect regional variation, differences in sample characteristics, and measurement methodology, emphasizing the importance of population-specific reference standards.

Distal breadth also demonstrated marked sexual dimorphism in the present study, with mean values of 33.02±2.93 mm in males and 27.06±2.43 mm in females. The difference was highly significant ($p<0.0001$), and the parameter demonstrated 92% sensitivity, 84% specificity, and 88% overall accuracy. The usefulness of distal radial dimensions is supported by research from Thailand, where distal end width was identified as one of the strongest individual indicators of sex, with classification accuracies of 91.5% for the right radius and 89.0% for the left radius.[3] Thus, distal breadth may remain useful even when the proximal portion of the radius is damaged or unavailable.

Both mid-shaft measurements in the present study also showed significant sexual dimorphism. The minimum mid-shaft diameter was 11.87±0.93 mm in males and 9.79±0.94 mm in females, while the maximum mid-shaft diameter was 15.53±1.26 mm and 13.10±0.97 mm, respectively. The maximum mid-shaft diameter demonstrated the highest overall accuracy among the four parameters, correctly classifying 92% of the specimens, with 96% sensitivity and 88% specificity. This finding is particularly relevant because Waghmare et al. also identified a mid-shaft measurement as the strongest predictor of sex in their Indian sample.[4] The consistency of these findings suggests that shaft morphology may be relatively robust for differentiating male and female radii.

The present findings are also supported by contemporary studies of radius morphology in Indian cadaveric material. A study of freshly frozen Indian cadavers found significant male-female differences in several radial measurements, including total radial length and multiple shaft dimensions, while side-to-side differences were generally not significant.[5] Another study of adult dry Indian radii reported significant differences between males and females in maximum length, head diameter, neck circumference, and mid-shaft diameter.[6] These observations reinforce the presence of consistent sexual dimorphism in radial dimensions across Indian populations, although the magnitude of dimorphism may vary between regions.

Of particular relevance is the previous Western Rajasthan study by Devi, which examined 50 right radii from the same general institutional setting, including 25 males and 25 females. That study reported highly significant differences in radial measurements and overall accuracies ranging from 86% to 92%, with maximum head diameter showing the highest accuracy.[9] The present study complements those findings by demonstrating high discriminatory ability using measurements of the entire radius and distal and mid-shaft regions. Maximum mid-shaft diameter in the present study achieved 92% accuracy, while maximum radial length and minimum mid-shaft diameter achieved 90% and 88%, respectively. This suggests that useful sex-related information is distributed throughout the radius rather than being confined to the radial head.

The overall accuracy obtained in the present study ranged from 88% to 92%. Maximum mid-shaft diameter showed the highest accuracy (92%), followed by maximum length (90%), distal breadth (88%), and minimum mid-shaft diameter (88%). These values are comparable with those reported in other population-based studies of radial sex estimation.[13] However, classification accuracy is population-dependent, and equations or sectioning points developed in one geographical population should not automatically be applied to another.[14] Population-specific skeletal standards are therefore important in forensic anthropology.[2,7]

The findings also have practical forensic significance. In cases where complete skeletal remains are not available, measurements from preserved portions of the radius may provide useful supplementary information for constructing the biological profile. The relatively high sensitivity and specificity observed for the studied parameters indicate that the radius can contribute meaningfully to sex estimation, particularly when used alongside other skeletal indicators rather than as an isolated determinant.

The present study has some limitations. The sample consisted of only 50 right-sided radii, with 25 males and 25 females, and therefore the findings should be validated in larger samples. Only the right radius was examined, preventing assessment of bilateral variation. The socioeconomic background of the individuals was not established, and information regarding age, stature, nutritional status, and occupational activity was not available. In addition, the study was restricted to a Western Rajasthan population; consequently, the findings may not be directly applicable to other Indian or non-Indian populations. Larger multicentric studies incorporating bilateral bones and multivariate discriminant analysis would help develop more robust population-specific standards.

Overall, the present study demonstrates significant sexual dimorphism in maximum radial length, distal breadth, minimum mid-shaft diameter, and maximum mid-shaft diameter in the Western Rajasthan population. Among the studied parameters, maximum mid-shaft diameter showed the highest accuracy of 92%, followed by maximum radial length at 90%. These findings support the usefulness of the radius as a supplementary skeletal element for sex estimation and provide region-specific osteometric data that may have applications in forensic anthropology, medico-legal identification, and anthropological research.

Conclusion

The study demonstrated significant sexual dimorphism in the right radius of the Western Rajasthan population, with males showing higher values across all measured parameters.

Maximum mid-shaft diameter showed the highest sex-classification accuracy (92%), followed by maximum radial length (90%). Radial osteometry can therefore serve as a useful supplementary method for sex estimation when other skeletal elements are unavailable or damaged. However, larger multicentric studies with bilateral measurements and multivariable analysis are needed to establish robust population-specific standards.

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Conflicts of interest

There are no conflicts of interest.

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