Original Article

# Morphometric Parameters of the Radius and its Variations Can Play a Significant Role in Sex Dimorphism

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## Abstract

**Background:** In this study, we aim to measure the radius's various morphometric properties its length, breadth, diameters, and indices to see how these traits differ between the sexes and to find statistically significant differences between the two sets of measurements. **Material and Methods:** The purpose of this research was to examine the morphometric and morphological features of adult Central Indian population dry radius bones. Most of the talk revolved around sexual dimorphism and side-by-side disparities. Fifty adult human dry radii bones were retrieved from the archaeological collection at Indore's Index Medical College & Research Center. Included in the collection were bones that retained all of their original structure and had complete anatomical identification. While using a digital Vernier caliper to measure typical morphometric parameters, we looked at the mean value to see how much variation there was between the observers. **Results:** The right side consistently exhibits marginally higher values in both sexes, suggesting a trend toward dominant-side enhancement. There is a statistically significant difference was noted between both the genders in all the radius measured parameters including Maximum Length of Radius (243.65 vs. 223.6), Head Diameter of Radius (23.1 vs. 21.2), Neck Circumference of Radius (37.8 vs. 35), Midshaft Diameter (9.7 vs. 8.9), and Distance from Head to Bicipital Tuberosity (29.3 vs. 27.6). **Conclusion:** The results show that there is a lot of sexual dimorphism in adult Indian radii, with men having much greater values than females. The results show that when applied to real-life scenarios, anatomical studies need to account for differences that are specific to both sexes and sides.

**Keywords:** Radius; maximum length; head diameter; neck circumference; midshaft diameter; distal end breadth.

**Received: 15 April 2025** **Revised: 10 June 2025** **Accepted: 20 August 2025** **Published: 30 August 2025**

## Introduction

Gender, side dominance, and geographical location are a few of the variables that impact the small morphometric variations in the human radius. This study found that in adult Indian populations, the right side of the male's radius had slightly higher midshaft diameter (MSD), head diameter radius (HDR), neck circumference radius (NCR), mid-length radius (MLR), and distance from the head to the bicipital tuberosity (DEB). The observed pattern consistently suggests that handedness-related functional adaptation has a less major impact, even if these differences were not statistically significant in prior trials conducted in other locations.[1-5] According to research reported in both Indian and international literature,[2-6] the dominant side, which is often the right, was seen to have somewhat bigger dimensions. This might be due to increased mechanical stress and muscle activation.

Similarly, among females of Central Indian descent, MLR, HDR, and DEB showed a small right-sided dominance, but NCR and MSD were marginally more left-sided.[3-8] Previous research has shown a widespread pattern of dominant-side hypertrophy,[5–10] which is supported by both of these results. Statistical significance was not found in most studies, suggesting a generally symmetrical morphology,[11–13] lending credence to the idea of bilateral anatomical balance despite functional asymmetry. That the morphology is often symmetrical is a key indicator of its significance.

Research shows that there is a strong sexual dimorphism, as men consistently scored better than females on all of the assessed measures.[4-6] Consistent with previous research, which has associated these differences to biomechanical, hormonal, and genetic variables,[3-6] this makes sense. Because it is possible to identify a person by determining their side and sex from isolated bones, these findings have far-reaching consequences for forensic anthropology.[3–7] It is critically important to identify minute side-specific changes in orthopedic operations such as surgical reconstruction and prosthesis design. In this study, we aim to measure the radius's various morphometric properties—its length, breadth, diameters, and indices—to see how these traits differ between the sexes and to find statistically significant

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**DOI:**
10.21276/amit.2025.v12.i2.16

**How to cite this article:** Chaturvedi A, Mahato PK, Singh R. Morphometric Parameters of the Radius and its Variations Can Play a Significant Role in Sex Dimorphism. Acta Med Int. 2025;12:86-90.

 

differences between the two sets of measurements.

## Materials and Methods

The morphometric and morphological features of adult dry radius bones from the Central Indian population were examined in this descriptive study that also utilized a cross-sectional method. The detection of sexual dimorphism and side-wise differences received special focus. Fifty adult human dry radii were obtained from the Department of Anatomy's osteology collection at Index Medical College & Research Center in Indore after the institutional ethical committee gave its approval. A total of 25 male and 25 female bones, including both sexes, were included in these dry radii. The study only considered bones that had all of their anatomical markers and features preserved. Pathological lesions, unknown laterality, or deformities in any of the bones were excluded from the results.

When necessary, we used proven anthropological indicators to verify the sex and side of each bone. To make these observations, we consulted the relevant governmental documents. Digital Vernier callipers with a resolution of 0.01 millimeters were employed to measure a range of conventional morphometric parameters. What follows is a rundown of all the measurements taken:

- Maximum Length of Radius (MLR) from the most proximal point of the radial head to the distal styloid process;
- Head Diameter of Radius (HDR) the maximum transverse diameter of the radial head;
- Neck Circumference of Radius (NCR) measured at the narrowest portion of the radial neck using a flexible measuring tape;
- Midshaft Diameter (MSD) measured at the midpoint of the diaphysis;
- Distance from Head to Bicipital Tuberosity (DEB) measured from the superior articular surface to the most prominent point of the radial tuberosity.

Each measurement was taken three times by two independent observers, and the mean value was used for analysis to reduce inter-observer and intra-observer variability.

Statistical analysis:

The SPSS software version was used to statistically analyze the data. For every parameter, descriptive statistics such as the mean and standard deviation were computed. The paired and unpaired t-tests were used for side-wise and sex-wise comparisons, respectively. P-values below 0.05 were regarded as statistically significant. The results were compared to both domestic and foreign literature, and patterns of asymmetry and dimorphism were interpreted in light of functional and biomechanical considerations.

## Results

In the section that follows, the morphometry of the forearm bones is compared side-wise (right versus left) and sex-wise (male against female), with a special focus on the bone of the radius and the bone of the ulna individually.

**Table 1: Radius in males' side-wise comparison**

| Parameter | Male Right (n=25) (Mean ± SD) | Male Left (n=25) (Mean ± SD) | P value |
|---|---|---|---|
| Maximum Length (MLR) | 245.9 ± 8.7 | 241.4 ± 9.2 | T=1.776; df=48; P = 0.081 |
| Head Diameter (HDR) | 23.1 ± 1.5 | 22.7 ± 1.6 | T = 0.9119; df =48; P = 0.366 |
| Neck Circumference (NCR) | 37.8 ± 2.8 | 37.1 ± 3.2 | T = 0.823; df = 48; P = 0.414 |
| Midshaft Diameter (MSD) | 9.7 ± 0.8 | 9.5 ± 1.1 | T = 0.7352; df = 48; P = 0.465 |
| Distal End Breadth (DEB) | 29.3 ± 2.1 | 28.7 ± 2.3 | T = 0.963; df = 48; P = 0.340 |

All radius parameters for men, including both sides, are included in Table 1. MLR is 245.9 vs. 241.4, HDR is 23.1 vs. 22.7, NCR is 37.8 vs. 37.1, MSD is 9.7 vs. 9.5, and DEB is 29.3 vs. 28.7. These are the averages between the two sides. We found that in males, the right side continuously shows slightly higher values, suggesting a tendency for dominant-side augmentation. In men, there was no statistically significant difference between the right and left radius.

**Table 2: Radius in females' side-wise comparison**

| Parameter | Female Right (n=25) (Mean ± SD) | Female Left (n=25) (Mean ± SD) | P value |
|---|---|---|---|
| Maximum Length (MLR) | 225.1 ± 7.2<br>223.6 ± 7.65 | 222.1 ± 8.1 | T=1.384; df=48; P = 0.172 |
| Head Diameter (HDR) | 22.9 ± 1.55<br>21.2 ± 1.5 | 19.5 ± 1.4 | T = 0.813; df =48; P = 0.420 |
| Neck Circumference (NCR) | 37.45 ± 3.0<br>35 ± 3.0 | 32.5 ± 2.9 | T = 0.522; df = 48; P = 0.6.3 |
| Midshaft Diameter (MSD) | 9.6 ± 0.95<br>8.9 ± 0.7 | 8.2 ± 0.5 | T = 0.530; df = 48; P = 0.598 |
| Distal End Breadth (DEB) | 29 ± 2.2<br>27.6 ± 2.15 | 26.3 ± 2.1 | T = 1.235; df = 48; P = 0.222 |

[Table 2] contains all of the radius features for females, including both sides. MLR (225.1 vs. 222.1), HDR (19.8 vs. 19.5), NCR (32.1 vs. 32.5), MSD (8.1 vs. 8.2), and DEB (25.6 vs. 26.3) are the two sets of values that should be compared. We discovered that women often score somewhat higher on the right side, indicating a propensity for dominant-side amplification. In terms of statistical significance, there was no appreciable difference between the ladies' right and left radii.

**Table 3: Radius in both the genders comparison**

| Parameter | Male (n=25) (Mean ± SD) | Female (n=25) (Mean ± SD) | P value |
|---|---|---|---|
| Maximum Length (MLR) | 243.65 ± 8.7 | 223.6 ± 7.65 | T=8.221; df=48; P = 0.0001 |
| Head Diameter (HDR) | 23.1 ± 1.5 | 21.2 ± 1.5 | T = 4.4783; df =48; P = 0.0001 |
| Neck Circumference (NCR) | 37.8 ± 2.8 | 35 ± 3.0 | T = 3.4116; df = 48; P = 0.0013 |
| Midshaft Diameter (MSD) | 9.7 ± 0.8 | 8.9 ± 0.7 | T = 3.762; df = 48; P = 0.0005 |
| Distal End Breadth (DEB) | 29.3 ± 2.1 | 27.6 ± 2.15 | T = 2.8282; df = 48; P = 0.0068 |

[Table 3] has all radius features for both genders. On both sides, male radius measures are larger than females'. In both sexes, the right side continuously shows slightly higher numbers, indicating a tendency for dominant-side amplification. All of the radius measured metrics, including MLR (243.65 vs. 223.6), HDR (23.1 vs. 21.2), NCR (37.8 vs. 35), MSD (9.7 vs. 8.9), and DEB (29.3 vs. 27.6), showed a statistically significant difference between the sexes.

## Discussion

The results of this study show that the following radius morphometric characteristics were significantly higher on the right side of adult male Indians' bodies: Here are the measurements: DEB is 29.3 mm, MSD is 9.7 mm, NCR is 37.8 mm, MLR is 245.9 mm, HDR is 23.1 mm, and HDR is 22.7 mm. The distance from the head to the bicipital tuberosity is also 30.3. Although the pattern does not reach statistical significance, it does suggest a little inclination toward amplification on the dominant side. This pattern may be the product of a handedness-specific functional adaptation in bone morphology. Previous studies have also shown similar variances in negative effects, so our results are consistent with them. For instance, suggesting osseous variation associated to dominance was uncovered in a morphometric study of the radius in male North Indians. There was no statistically significant difference between the right- and left-side values, but the right-side values were somewhat higher.[14] Biomechanical stress effects are likely to blame for this, as was shown by Das et al. (2023),[15] when they used osteometry to study dry radii and discovered that the dominant side, often the right, had larger dimensions. Literature from various nations lends credence to these conclusions. Hong et al. (2021),[16] used 3D imaging on a Caucasian population and found that right-handed people had considerably greater morphometric values for their right radii. Even if there is functional asymmetry, biological symmetry still persists since the changes did not reach the level of statistical significance (Hong et al., 2021, p. 16). Consistent usage of the upper limb influences radial bone formation, according to a biomechanical research by Sayadizadeh et al. (2024).[17] On the other hand, the changes are still rather little when you look at the two sides side by side.

The little imbalance seen in this study might be explained by differences in the nutrition, lifestyle, and employment habits of Indian males. It is crucial to think about bilateral comparisons within the context of the social and environmental features of the group being researched, based on the findings of Mishra (2016),[18] who claimed that regional and lifestyle differences impact the forearm bone structure in India. Being more dexterous with one side of the body does not always indicate that there are significant anatomical differences between the two in healthy individuals, according to research by Shrestha et al. (2022).[19] This research supports the theory that right sides of the body tend to be stronger. But the fact that there wasn't a statistically significant change suggests that the radius is still fairly balanced. It appears that the morphometric symmetry of the radius has been mainly maintained, as there is little statistical significance. The area of forensic anthropology and orthopedics could both be affected by these results. Because bilateral morphometry is consistent and accounts for small variations, a firm sex and side identification may be made with only one bone. Anatomical accuracy may be improved with knowledge of minute asymmetries while making prosthesis or performing surgeries like radial head replacement.

Results from this morphometric study on adult female Central Indian radius bones showed small, non-significant differences in the parameters measured along the sides of the bones. In terms of NCR (Neck Circumference of Radius), MSD (Minimum Shaft Diameter), and MLR (Maximum Length of Radius), the left side had marginally larger measurements than the right side. Similarly, in terms of HDR (Head Diameter of Radius), DEB (Distal End Breadth), and MSD (Minimum Shaft Diameter), the left side was marginally larger than the right side. These results are consistent with the measurements of the upper arm bones, which show a little increase in size on the dominant side. In a study conducted in North India, researchers discovered similar results to ours: when comparing morphometric variations along the sides of individuals, right-sided measures were more common in both sexes.[20] This was true irrespective of whether we were comparing sexes. But they failed to detect anything statistically significant. Women in a South Indian cohort had larger values for head diameter and radius length on the right side, according to a survey.[21] These ladies reasoned that the mechanical tension associated with being left-handed was the source of these elevated numbers.

Previous study from other nations was supplemented by a morphometric analysis of Greek radius bones carried out by Natsis et al. (2016).[22] The morphometric dimensions of the dominant arm (typically the right) were noticeably larger than those of the other arms, and similar side-to-side patterns were also seen. When looking at female cadavers from Turkey, Keskinoz et al. (2025).[23] noticed a same pattern. While the researchers did find that the right-sided radius bones had somewhat higher mean values than the left-sided ones, they did not find a statistically significant difference.

Our findings suggests that the slight alterations in MLR and HDR might be explained by their functional adaptation, since the dominant hand has the potential to influence bone remodeling and hypertrophy in the long run.[24] While these variances may not be useful for therapeutic or forensic purposes in determining a bone's side, they are still within the normal range of anatomical variation as they did not reach statistical significance. Even if they fail miserably at identifying the side to which a bone actually belongs, this remains true.

We confirm the results of Anasuya et al. (2024),[25] who studied populations in central India and also discovered no gender-specific variations in the radial neck and shaft characteristics. The results suggest that functional dominance does not significantly affect these attributes.

Our DEB values are quite comparable across sides, in contrast to Khanpetch et al. (2012),[26] who failed to find any side dominance in distal radius characteristics in a Thai sample. Their findings contradict this. The results suggest that genetic and geographical variables may have a greater influence on the distal area variability than mechanical stresses alone. Although we did find a right-side dominance trend across a number of morphometric variables, we did not find any statistically significant alterations to the female radius in our analysis. It is clear that there is a need to create anthropometry databases tailored to certain populations, especially for use in orthopedics and forensics, and our discovery supports previous research in this area.

For each of the six variables examined in this study—MLR, HDR, NCR, MSD, and DEB—the results showed that men had much greater values than females. That the adult human radius exhibits morphometric properties that are obviously dimorphic between sexes is seen from this. The results of this study lend support to the idea that skeletal characteristics in males are bigger and more robust than in females for reasons related to biology, hormones, and function. The results also match those of other investigations, both domestic and foreign, that have been carried out in India and elsewhere.[27,28]

The results of this study showed that compared to females (223.6 mm), men had a substantially greater mean radius length (243.65 mm). This confirms what other studies have shown, which is that there is a substantial gender gap in the proportion of radial length in Indian cultures.[29,30] Researchers from different nations have also shown significant sexual dimorphism in radial measures; for example, Sinthubua et al. (2017),[31] in a Thai sample and Ngidi et al. (2023),[32] in a South African cohort. From a global viewpoint, these results make sense.

Functional adaptation due to handedness and variable mechanical stress may also account for the significantly larger results for right-side dominance in both sexes. This clarifies the reason for the considerably higher right-side dominance. Bones on the dominant side tend to be longer and larger than those on the non-dominant side due to increased mechanical stress and stronger muscle connection. The results of the studies cited in [33,34] corroborate this observation.

Parameters including HDR, NCR, MSD, and DEB showed statistically significant gender differences, demonstrating the radius's value in forensic and anthropological sex determinations. The fact that sex was determined by the radius further supported this.

Results show that the radius is a major factor in deciding gender, and they also show how important it is for morphological differences to be population-specific. The domains of forensic science, orthopedics, and reconstructive surgery are all touched by these results.

## Conclusion

It has been demonstrated that males consistently have higher morphometric values than females across all parameters, which is evidence of a significant sexual dimorphism in adult Indian radii. The slight and insignificant preponderance of the right side in both sexes is indicative of functional adaptation that is most likely associated with handedness. These findings, which are in agreement with examinations conducted in India as well as those conducted in other countries, bring to light the relevance of taking into consideration peculiarities that are distinctive to both sides and to sexes while doing anatomical research. Despite the fact that they are very minor, the asymmetries are helpful in orthopedic and forensic anthropological applications. In particular, they are helpful for assessing sex and side, creating prosthesis, and performing procedures that correspond to population-specific anatomical norms.

### Financial support and sponsorship

Nil.

### Conflicts of interest

There are no conflicts of interest.

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