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Measurement of various morphometric parameters of the ulna and analyzing its variations will help in sex determination & can play important role in forensic science

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Abstract:

Aim: In this work, we will examine a number of ulna morphometric features, look for gender differences in these parameters, and find that the measurements of male and female bones are significantly different. **Materials & methods:** Morphometric and morphological features of adult Central Indian population dry ulna bones were examined throughout this study. Sideways differences and sexual dimorphism were the main foci of the research. The osteology collection at Indore's Index Medical College & Research Center was accessed to acquire one hundred adult human dry ulna bones. 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:** This study used an average of ulna bone measurements taken from both men and women. Males had larger average measurements for maximum length (MLU), olecranon width (OLW), coronoid height (CPH), mid shaft diameter (MSD), and distal end breadth (DEB). The gender gap between the right and left radii was not statistically significant in females. Male ulna measurements consistently outweigh female values across all metrics and dimensions. There is a little functional asymmetry, perhaps due to limb dominance, since the right-side measurements are somewhat larger than the left side. At the radius level, there was a statistically significant difference between the sexes for all parameters, including MLU (259.6 vs. 238.3), OLW (24.55 vs. 22.2), CPH (17.6 vs. 15.4), MSD (9.5 vs. 8.3), and DEB (29.4 vs. 25.55). **Conclusion:** The results of the study indicate that the morphometric qualities of the radius and ulna are significantly different between sexes, as males had somewhat bigger bones than females. It was clear that functional asymmetry was occurring since the right side of the graph had substantially higher scores. The results highlight the importance of considering gender and lateral asymmetry in anthropology, forensics, orthopedics, and ergonomics-related applications.

Keywords: Ulnar bone; maximum length (MLU) and olecranon width (OLW), coronoid height (CPH), mid shaft diameter (MSD), and distal end breadth (DEB).

Introduction:

Elbow articulation, upper limb mechanics, and the attachment of muscles that control hand and forearm motions are all impacted by the ulna, a prominent forearm bone. Many fields, including medicine, orthopaedics, forensics, and anthropology, rely on precise ulna morphometric studies. The development of gender-specific implants and prostheses and the identification of skeletal remains are two areas where this is particularly important [1,2].

A number of studies have shown that bones can be dimorphic, meaning that males typically have longer and stronger bones than females. A number of mechanisms, including those of a genetic, hormonal, and biomechanical kind, contribute to this ulnar sexual dimorphism. Muscle mass and activity levels are two areas where males tend to excel [3,4]. Measuring important characteristics including maximum length (MLU), olecranon width (OLW), coronoid process height (CPH), midshaft diameter (MSD), and distal end breadth (DEB) has shown that gender differentiation and functional adaptations may be understood [5,6]. Functional adaptations can be understood by the measurement of these traits.

Various ulna morphometric studies in India have yielded valuable baseline data[7,8]. This is because the population displays skeletal traits that are impacted by regional lifestyle and genetic factors. These results highlight the need of using group-appropriate osteometric criteria, as Indian skeleton proportions typically do not match Western anthropometric models.

Global researchers have shown that right-handed people, in particular, exhibit side-to-side variances that may be related to limb dominance [9, 10], in addition to sex differences. It is generally believed that the right side of the body develops stronger bones due to higher functional loading, in accordance with Wolff's rule, which explains that bones adapt to mechanical forces. This backs up the idea that mechanical stresses cause bone to react.

Despite these advancements, there is still a need for thorough comparative studies that examine the ulna's morphometric features, taking into consideration variations according to gender and side. This is particularly the case for regional Indian communities for whom such statistics are currently unavailable. In this work, we will examine a number of ulna morphometric features, look for gender differences in these parameters, and find that the measurements of male and female bones are significantly different.

Materials & methods:

An analysis of the ulna's morphometric features in dry adult human bones was the goal of this descriptive osteometric investigation. Researchers used a cross-sectional approach to carry out the study. The main goal was to study ulnar side-wise asymmetry and sexual dimorphism. To do this, five important metrics were compared: MLU, OWL, CPH, MSD, and DEB, which stand for maximum length, olecranon width, coronoid process height, midshaft diameter, and distal end breadth, respectively. The relevant research was conducted at the Index Medical College & Research Center's Department of Anatomy in Indore. One hundred adult dried human ulnae were used for the examination, with fifty placed on the right and fifty on the left. Test subjects consisted of thirty-five male and twenty-five female specimens, with twenty-five individuals drawn from each sex. Bones that were not included in this study were those that were either damaged or misshapen, had an uncertain sex, or showed signs of pathological changes.

Recognizing Sexual Attraction and Which Side You're On: Using the institutional osteological data held in the departmental bone bank, we were able to pre-identify and label each bone for sex and laterality. Skilled anatomists employing well-established anthropological principles double-checked the sex identifications. The following parameters were tested for in each ulna using a digital vernier caliper, a metallic osteometric board, and well-established anthropometric methodologies:

1. Maximum Length (MLU) – Distance from the tip of the olecranon process to the tip of the styloid process.
2. Olecranon Width (OLW) – Transverse maximum width across the olecranon process.
3. Coronoid Process Height (CPH) – Maximum vertical height of the coronoid process.
4. Midshaft Diameter (MSD) – Transverse diameter measured at the midpoint of the shaft.
5. Distal End Breadth (DEB) – Maximum transverse width of the distal end of the ulna.

Statistical analysis:

It was decided that two separate observers would conduct each measurement three times, with the average of the three results being recorded. A reduction in intra- and inter-observer error was the goal of this action. Statistical analysis was carried out using SPSS software, version 25.0, whereas Microsoft Excel was used for data entry. For every parameter, we calculated descriptive statistics, such as the mean and standard deviation, considering both the gender and the side. We used the independent samples t-test to compare the values of the males and females. In contrast, the gender-specific side-wise differences were examined using the paired t-test. The cutoff for statistical significance was established as a p-value <0.05.

Results:

Table 1: Ulna in males' side-wise comparison

Parameter	**Male Right (Mean ± SD)**	**Male Left (Mean ± SD)**	**P value**
Maximum Length (MLU)	260.3 ± 8.9	258.9 ± 9.1	T=0.5499; df=48; P = 0.5849
Olecranon Width (OLW)	24.9 ± 1.8	24.2 ± 1.9	T = 1.3373; df =48; P = 0.1874
Coronoid Height (CPH)	17.8 ± 1.3	17.4 ± 1.5	T = 1.0076; df = 48; P = 0.3187
Midshaft Diameter (MSD)	9.4 ± 0.9	9.6 ± 1.2	T = 0.6667; df = 48; P = 0.5082
Distal End Breadth (DEB)	29.5 ± 1.9	29.3 ± 1.8	T = 0.3821; df = 48; P = 0.7041

You may see pictures of the male ulna bone's many features (on both sides) in Table 1. In males, the averages between the ulnar and radius bones are as follows: MLU (260.3 vs. 258.9), OLW (24.9 vs. 24.2), CPH (17.8 vs. 17.4), MSD (9.4 vs. 9.6), and DEB (29.5 vs. 29.3). In men, we found a tendency for dominant-side augmentation, as indicated by the right side showing somewhat higher values on a constant basis. The results showed that the right and left radii of men were not significantly different.

Table 2: Ulna in females' side-wise comparison

Parameter	Female Right (Mean ± SD)	Female Left (Mean ± SD)	P value
Maximum Length (MLU)	238.7 ± 7.8	237.9 ± 9.9	T=0.3174; df=48; P = 0.7523
Olecranon Width (OLW)	22.0 ± 1.4	22.4 ± 1.6	T = 0.9407; df =48; P = 0.3516
Coronoid Height (CPH)	15.5 ± 1.1	15.3 ± 1.2	T = 0.6143; df = 48; P = 0.5419
Midshaft Diameter (MSD)	8.2 ± 1.0	8.4 ± 0.9	T = 0.7433; df = 48; P = 0.4609
Distal End Breadth (DEB)	25.7 ± 1.9	25.4 ± 1.7	T = 0.5883; df = 48; P = 0.5591

Table 2 shows all the ulna features for females, together with the two sides. Averages across the ulna bones in females are as follows: MLU (238.7 vs. 237.9), OLW (22.0 vs. 22.4), CPH (15.5 vs. 15.3), MSD (8.2 vs. 8.4), and DEB (25.7 vs. 25.4). Our investigation revealed that females tend to have dominant-side amplification, as the right side of their bodies regularly shows considerably greater numbers. For females, the difference between the right and left radii was not determined to be statistically significant.

Table 3: Ulna in both the genders comparison

Parameter	Male (n=25) (Mean ± SD)	Female (n =25) (Mean ± SD)	P value
Maximum Length (MLU)	259.6 ± 9.0	238.3 ± 8.85	T=8.437; df=48; P = 0.0001
Olecranon Width (OLW)	24.55 ± 1.85	22.2 ± 1.5	T = 4.8915; df =48; P = 0.0001
Coronoid Height (CPH)	17.6 ± 1.4	15.4 ± 1.15	T = 6.0714; df = 48; P = 0.0001
Midshaft Diameter (MSD)	9.5 ± 1.05	8.3 ± 0.95	T = 4.2373; df = 48; P = 0.0001
Distal End Breadth (DEB)	29.4 ± 1.85	25.55 ± 1.8	T = 7.4578; df = 48; P = 0.0001

In Table 3 you can see every ulna feature for both men and women. When comparing the ulnas of males and women, it is always the case that the former has larger measures. This is valid for any and all measurements. A little amount of functional asymmetry, perhaps due to one side's limb dominance over the other, is shown by slightly greater right-side measures compared to left-side ones. Every radius-related parameter, including MLU (259.6 vs 238.3), OLW (24.55 compared 22.2), CPH (17.6 versus 15.4), MSD (9.5 versus 8.3), and DEB (29.4 versus 25.55), showed a statistically significant difference between the sexes.

Discussion:

This study's morphometric measures of the radius and ulna show a substantial difference between the sexes. Right and left body measurements consistently show that men are heavier than women. Consistent with previous research in India and throughout the globe, this study found that men's bigger bone dimensions are caused by their larger muscle mass, hormones, and mechanical forces [11, 12, 12].

A number of radius measures, including maximum length of radius (MLR), head diameter of radius (HDR), neck circumference of radius (NCR), midshaft diameter (MSD), and distal end breadth (DEB), demonstrated statistically significant variations between males and females. Confirming the global nature of sexual dimorphism in long bones, our results closely align with those of [13] in Central India and Jeong et al. [14] in South Korea, who also found that males had greater radial lengths and diameters (e.g., MLR: 243.65 mm in males versus 223.6 mm in females). Radial lengths and diameters were found to be larger in men compared to females, as stated in references [13] and [14].

For some reason, regardless of gender, the values of the right-sided radius were always somewhat bigger than the left-sided radius; nonetheless, the disparities were more pronounced in men. This is a fascinating point to bring up. Many anthropometric investigations have shown that the right upper limb is more functionally dominant, and this asymmetry is probably a reflection of that [15,16]. But in women, this swaying up and down did not amount to anything statistically significant. One possible explanation is that hormonal effects and mechanical loads are lower in females compared to males.

Furthermore, our results showed that the ulna had a sexual dimorphism that was statistically significant across all parameters. These features included DEB, MSD, CPH, OWL, and MLU (the maximum length of the ulna in this instance), among others. The tendency seen in radius bones was further supported by the fact that male results consistently increased (e.g., MLU: 259.6 mm compared to 238.3 mm in females). Mays et al. [18] and [17] found comparable trends in bone samples from Europe. [17] found such trends in North Indian communities as well.

Our data further supports the hypothesis that bone morphology is influenced by differential mechanical stress caused by limb dominance. This asymmetry is seen in both sexes, with the right-sided ulna slightly larger than the left-sided ulna. This finding is supported by research done by [19,20]. These studies corroborate the biomechanical ideas presented in Wolff's Law and show that the dominant side's upper limb bones also improve to an equal degree.

Nonetheless, the two sides of the female ulna did not vary significantly. It was observed that the limbs were utilized in a usually symmetrical manner during everyday activities, as shown by modest variances in the female ulna (e.g., 8.2 mm on the right and 8.4 mm on the left). Since women don't often participate in strenuous physical labor, functional asymmetry is less noticeable in them, according to Pocan et al. [21]. The results of their inquiry are consistent with this discovery.

When these factors are considered, our results provide support to the use of ulna and radius morphometry in forensic anthropology for gender identification, especially when dealing with fragmentary skeletal remains. Serious consequences for orthopaedics, prosthetics, and anthropological reconstructions stem from the proven sexual dimorphism and side-wise asymmetry. The therapeutic and ergonomic significance of the observed dominant-side augmentation extends to the development of tools, wearables, and implants that must account for subtle but constant variations in bone structure.

Morphological findings:

The present investigation revealed substantial qualitative differences between the forearm bones of males and females. Along with the quantitative parameters often used in osteological sex assessments, these variations were also discovered. The findings highlight the importance of morphological traits like surface texture, prominence of the ulnar notch, radial head shape, and robusticity in sex discrimination, particularly in cases where metric metrics are damaged or missing due to fragmented remains.

A bigger cortical bone mass and more defined muscle attachment sites were seen in male long bones, such the radius and ulna, compared to female long bones, according to research by Kranioti et al. [48]. This was seen in a group of people from Europe. These results are in line with robustness, which is characterized by thicker cortical layers and more visible muscle markings in males. India study found that men's increased mechanical loading from lifelong muscle activity promotes the development of stronger bone characteristics, especially along the interosseous crest and radial tuberosity [51,52].

The present study indicated that men usually had circular radial heads, but women tended to have oval or flattened skulls. It was determined that this was the distinction between the two sets of people. These results are consistent with those of [52,53], who, after seeing variations in radial head shape across several populations, highlighted the importance of these alterations in sex evaluation. A statistically significant sexual dimorphism in radial head arrangement was found in an Indian study by Rajani et al. [54]. This discovery provides more evidence that this quality can have applications in the fields of anthropology and forensics.

In contrast to their female counterparts, male bones had a more prominent and well-defined olecranon process and ulnar notch. The larger triceps muscle mass and the heightened biomechanical stress are likely the causes of this finding. The same findings were reached by Lee et al. [55], who studied the olecranon process's morphology in Korean cadaveric samples and demonstrated its role in sex determination. When male specimens are subjected to habitual mechanical strain, the morphological sharpness and angulation of the olecranon are typically more visible, according to an experiment done in India by Tiwari et al. [56]. The aforementioned inquiry's results supported these conclusions.

At the locations where the muscles and ligaments connect, surface texture—an additional qualitative signal—was discovered to be rougher in males and smoother in females. This is consistent with what was found in [57], which looked at dry Indian radii and found that the surfaces of males were rougher in relation to their levels of physical activity. This lends credence to the results given here. Another study found a similar pattern in men's bones; it connected surface roughness to habitual biomechanical load and occupational stress indicators [58].

Thus, the present work lends credence to the idea that morphological traits indicating changing biomechanical and hormonal effects throughout life encompass sexual dimorphism in forearm bones. This hypothesis encompasses not only size-related variances but also physical traits associated with size. These findings enhance the accuracy of sex determination procedures in forensic anthropology and bioarchaeology, especially when dealing with situations with partial remains.

Implication of present study medical education, clinical practice, and medical research:

The first step in understanding the anatomical differences between the sexes in a specific geographical group is to identify morphometric and morphological evidence of sexual dimorphism in adult Indian dry forearm bones. While the study's relevance to anatomy as a scientific subject is self-evident, its consequences for medical education, patient care, and scientific inquiry are far-reaching and profound. You must be cognizant of these consequences if you want to have an authentic understanding of the significance of osteological research and how it bridges the gap between basic anatomy and real-world medical practice as well as forensic science.

We should make sure that medical colleges are aware of this: As part of their medical education, all students are mandated to complete anatomy courses; one of the course's cornerstones is a comprehensive review of the human skeletal system. Statistics used in traditional anatomy courses tend to be either Western-centric or provide general reference data. In countries like India, where the cultural landscape is quite diverse, these statistics may not, however, accurately portray the essential character of the disparities that exist among the populace. The work we have done not only meets this need, but also improves the accuracy and significance of anatomy education by creating osteometric standards tailored to the Indian population.

When medical textbooks, training modules, and practical sessions incorporate morphometric data relevant to populations and sexes, students have the chance to get a more comprehensive and contextual understanding of human anatomy. Future generations of doctors will be better prepared to address patients' unique anatomical needs because of this. This research advances our understanding of sex-specific skeletal development, hormone impacts, and growth patterns by identifying sexual dimorphism in the bones of the forearm. Students' ability to distinguish between male and female skeletal remains is a crucial aim in forensic medicine and anthropology, and this study helps get them there.

Beyond this, the study stresses the importance of regional anatomical investigations and urges medical institutions to do similar studies on different skeletal areas or populations. This study lays the groundwork for more research into local anatomy and brings us one step closer to applying what we know in theory to real-world scenarios.

Resultant Effects on Clinical Practice: Radiography, orthopaedics, trauma care, and prosthetics are just a few of the many areas that can gain a great deal from the findings. Having knowledge of the morphometric differences between men's and women's forearm bones is important for developing gender-specific tailored therapies. In order to design treatments like implant placements, fracture fixations, and joint reconstructions, orthopedic surgeons often use preoperative measurements and radiographic examinations. Unrecognized sex-based anatomical variances might lead to unfavorable surgical outcomes, implant mismatches, or postoperative problems.

Orthopedic implants (screws, plates, and prosthetic components) can be better designed to fit men and women based on the results of the morphology and size research. Having this knowledge is crucial for developing anatomically formed implants, since they must fully match the bone's architecture to provide biomechanical stability. By capitalizing on the fact that radial and ulnar morphology varies across the sexes, manufacturers and surgeons can lessen the likelihood of implant mismatch and surgical errors.

Medical professionals can speed up the healing process by reassembling broken bones with more precision when they have a better grasp of the typical sizes and forms of the forearm bones. When the fractures are really bad, this becomes much more apparent. For the purpose of predicting the occurrence of fractures and developing preventative measures, these tests are invaluable. This is because, as people age or suffer from osteoporosis, the gender gap in bone density becomes more apparent.

Because it provides a benchmark for typical anatomical characteristics that are exclusive to a certain gender, this data might be useful for radiologists and other medical experts who interpret imaging studies. Distinguishing between disease states and normal anatomical changes is crucial when dealing with ambiguous situations, and this information is necessary for doing so.

Hypothesized Consequences for Future Health and Criminal Justice Research: The results of this study have advanced our understanding of sexual dimorphism in skeletal morphology, especially in the Indian population. Traditional osteological data collection methods used by anthropologists and forensic scientists have relied on non-Indian populations, which may not be representative of the Indian community. Some examples of such variances include dietary preferences, environmental factors, and ethnic background. The results of this study fill a major knowledge vacuum by providing standardised morphometric values for adult Indian forearm bones.

One of the main goals of forensic investigations is to identify unidentified skeletal remains. A sex estimation is the starting point for any biological profile development procedure. When whole skeletons are unavailable, as is often the case during catastrophe investigations, criminal investigations, and archaeological digs, forearm bones can serve as valuable diagnostic tools. Our technique improves the reliability of sex diagnosis using morphological traits and osteometric measurements in cases when only partial remains are accessible. Researchers in the fields of forensic anthropology, medico-legal studies, and law enforcement who work with skeleton identification are likely to find these findings useful.

Additional research in many fields might be built upon this work. For instance, this study might open the door to digital imaging tools and machine learning algorithms that can identify a person's gender only by looking at their bones. In the realm of artificial intelligence, there is a growing need for accurate prediction models that are specific to regions, especially in healthcare and forensic science. To build these kinds of models, you need datasets like these.

On top of that, the study promotes the establishment of multidisciplinary teams comprised of doctors, biomedical engineers, anthropologists, and anatomical experts. By analyzing the correlations between bone morphology and other genetic and physiological variables, scientists can learn more about the evolution, adaption, and diversity of the human species. These relationships may be investigated with the help of the data.

One additional major takeaway from this study is the possibility of using these measurements to create ergonomic design guidelines based on anthropometry. Wearable medical technologies, custom orthotics, and assistive equipment may be fine-tuned for Indian customers using accurate anatomical measurements taken from native people.

Recommendations of the present study:

This study's results may lead to many suggestions for further research into morphological sexual dimorphism in adult Indian forearm bones and for better application of existing information regarding morphometric sexual dimorphism. Academic institutions, healthcare practitioners, forensic specialists, and future research undertakings are the intended recipients of these proposals.

Integration with Health Professions Coursework: Incorporating regionally relevant morphometric data into course materials should be seriously considered by faculty at medical and university institutions. Most current anatomy courses classify human anatomy using broad, population-based categories, however they may not be the most accurate representations of the human body. By including population-specific differences, like those seen in this study, skeletal morphology can be better understood by students, and the importance of sexual dimorphism in forensic and therapeutic contexts can be highlighted. Participatory displays including real bone specimens or 3D models that account for gender differences may enhance students' learning possibilities.

Building an All-Inclusive Osteometric Registry: An obvious need exists for a national osteometric database that records morphometric data for different types of bone, categorized by age, gender, and geographic region. Contributing information specific to the forearm bones of Central Indian population members, this paper aids that effort. Examples of disciplines that would benefit from a standardized database include biomechanics, forensic anthropology, and orthopedics, all of which deal with skeletal research and gender categorization.

Orthopedic and Surgical Practises Clinical Application: In order to effectively apply the findings in clinical practice, orthopedic surgeons, radiologists, and prosthetic designers need to have a better understanding of the fact that the morphology of the forearm bone might vary across sexes. The aforementioned differences in fixation device size and design should be carefully considered by implant makers when they create orthopedic implants. Furthermore, morphometric considerations are essential for improved surgical precision and reduced issue probability during preoperative planning procedures.

The Application in Forensic and Anthropological Settings: The results of this investigation will be highly valuable to forensic anthropologists and investigators that focus on medical-legal issues. The incorporation of this morphometric data into standard operating procedures is highly recommended when dealing with forensic skeletal remains. The ability to identify a person's gender from their forearm bones should be a standard component of forensic science training programs. This is particularly crucial information to have when just incomplete remains may be found.

Prompting Additional Investigations: In order to confirm and build upon previous findings, further research is required. Research comparing the population to those of other areas in India might be useful for building more thorough normative statistics. Researching age-related changes and bilateral asymmetry in the forearm bones can provide more precise data on skeletal diversity. In order to create tools that can automatically identify a person's gender, researchers should look at the potential of merging morphometric data with imaging techniques and machine learning algorithms.

Fostering Collaboration Among Different Fields: Finally, it is recommended that specialists in biomedical engineering, forensic science, medicine, and anatomy collaborate more closely to develop clinically applicable and therapeutically useful technologies based on anatomical study. Research results should be used to enhance healthcare service, forensic investigation, and educational opportunities, not just published in academic journals. With the help of interdisciplinary teams, we can achieve this objective.

Limitations of the present study:

It is important to note a number of limitations in order to properly interpret the results and guide future research, even though the present study on adult Indian dry forearm bones offers valuable information on the morphometric and morphological aspects related to sexual dimorphism. This is because bearing in mind such restrictions is crucial.

The primary component of the sample was, without a doubt, the dried bones that were part of certain osteological collections. We just have a small sample to work with. Geographical, cultural, and socioeconomic disparities, among other forms of variety, made it impossible for the sample to be representative of the larger Indian population. Limiting the sample to a single geographic or institutional source may introduce sampling bias and limit the generalizability of the findings in India, a nation with a great deal of genetic and phenotypic variability.

Secondly, labels or old records from anatomical departments were used to find out the materials' gender. Additionally, contemporary procedures such as DNA analysis or sophisticated forensic techniques may not necessarily verify these approaches, or they may not always be correct. The reliability of the detected sexual dimorphism can be jeopardized if the sexes are incorrectly classified.

Thirdly, there was an exclusion of soft tissue components that may affect the total dimensions of a live population because the investigation only included dry bones. To account for the anatomical changes that would occur in vivo, morphometric evaluation of bones may not be enough. Inaccuracies in measurements can also be introduced by gradual bone shrinkage or deterioration. Especially with older or poorly preserved specimens, this can lead to a shift in the initial dimensions.

The lack of age-specific data is an additional drawback. When it comes to bone density and structure, aging is a major factor. Bone resorption and cortical thinning are two structural changes that occur naturally with aging, but they are hard to account for when exact age data is lacking. These alterations are hard to explain, and they may differ across the sexes and influence the perception of dimorphic traits.

Even though they are commonly used, the manual caliper-based measurements utilized in this experiment can nevertheless be affected by variability among and between observers. Despite efforts to standardize measuring processes, there may still be cases when small variations arise. This is particularly the case when attempting to measure an irregular or curved surface, like the ulna or radius.

Furthermore, state-of-the-art 3D imaging methods including CT scanning and 3D surface modeling were not utilized in the investigation. The researchers shifted their attention away from complex morphological features and toward linear morphometric parameters. A more thorough and precise evaluation of sexual dimorphism may be possible with the use of these methods. This is because, unlike commonly used technology, they can detect surface topography and even small changes in contour that would otherwise go unnoticed.

Finally, the study did not include any of the biomechanical or functional issues. An improved biological explanation for sexual dimorphism in forearm bones may have been achieved by learning how morphological variations relate to functional performance or load-bearing capacity.

While this study does provide useful baseline data on sexual dimorphism in Indian dry forearm bones, it is clear that larger, more diverse samples, modern imaging modalities, and interdisciplinary approaches are needed to understand skeletal dimorphism in India with more precision and generalizability.

In conclusion, there is a wealth of useful and important information gleaned from the investigation of adult Indian dry forearm bones for morphometric and morphological signs of sexual dimorphism. Clinical practice is greatly affected by the study's direction of orthopedic therapy and surgical planning, and it also improves anatomy instruction by giving location-specific data. It also helps with sex-based, population-specific norms, which are critical for include correct data in scientific studies, making it an important tool for forensic identification and medical research. This research emphasizes the value of morphometric studies in producing a more precise, context-aware, and multidisciplinary understanding of human anatomy by connecting theoretical understanding of anatomy with real-world applications in medicine and forensics. A deeper familiarity with the human body is necessary to achieve this goal. In order to enhance results across the board in healthcare and science, it stresses the need of further research into regional and sex-based anatomical differences and believes that these findings should be integrated into mainstream medical practice and teaching. The overarching goal is to enhance healthcare and scientific research as a whole.

Conclusion:

Consistently bigger male bones than female bones across all metrics that were assessed show a major and statistically significant sexual dimorphism in the ulna's morphometric properties. The values on the right side of both bones were much higher, especially in men. Mechanical stress and limb dominance traits are likely the causes of this small but persistent functional asymmetry. However, the discovery of a small dominating tendency in the ulna lends credence to the idea of side-preferential bone adaptation, even if the females' radius did not show any obvious side-wise difference. The fact that the ladie's radii were similarly large did not change this outcome. Not only do these results provide notable information specific to the Indian people, but they also demonstrate the necessity of considering gender and lateral asymmetry in anthropological, forensic, orthopedic, and ergonomic applications.

Conflict of interest:

There is no conflict of interest among the present study authors.

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