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Research Article

Radiological Evaluation of Forearm Bones in Anatolian Population

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Abstract

Objectives: A better understanding of the anatomy of the radius and ulna is valuable in fracture fixation and reconstructive surgery. Morphometric values of bones differ between populations. This study aims to reach the mean morphometric values of the forearm bones in the Anatolian population.

Methods: Through Computed Tomography Angiography images, Radius length, radius width, the distance between the lateral and medial edges of the distal end of the radius (AD) width, caput ulna width, ulna length, and caput radii width measurement data, including age and gender were collected.

Results: A total of 81 images, 28 female and 53 male, were included in the study. When the general data of the study were evaluated, it was found that radius length (cm) was 23.39±1.82, radius width (mm) was 30±2.9, AD width (mm) was 25.8±3, caput ulna width (mm) was 16.4±2.2, ulna length (cm) was 25.33±1.88, caput radii width (mm) was 19.1±2.5. There was a significant difference between the genders in the measured parameters.

Conclusion: The lengths and distal widths of the radius and ulna differ in the Anatolian population compared to other populations. For this reason, anatomical values of the populations should be considered in forearm fracture surgery applications.

Keywords: Forearm morphometry, forearm fractures, forearm surgery, ulna, radius

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The forearm is an essential component of upper limb function in humans. The radius and ulna, which have complex anatomical structures compared to other extremity bones, are parallel long bones with a natural spring.[1] The radius and ulna have unique osteology that allows a wide range of rotational motion in multiple planes. These two bones exhibit an interconnected anatomy, and rotational deformities can significantly impair forearm functions.[2] Due to the complicated anatomical structure of the forearm bones, malunions may occur in the forearm bones after severe diaphyseal fractures.[1] In conventional surgery, radiographs and cross-sectional images are used in preoperative procedures to characterize deformities arising from broken forearm bones and to plan appropriate reduction surgery.[1]

The radius consists of a sagittal arc and a coronal arc. Fractures are often treated with anterior plating in the coronal plane. However, the sagittal angle of the proximal radius shaft is often overlooked. This is particularly important in the proximal third of the radial shaft, where the sagittal arc is more prominent. Altering the normal anatomy will affect

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the biomechanics of rotation between the radius and ulna. This change has been extensively demonstrated in studies on rotation, along with changes in the coronal arc.[3]

A better understanding of the anatomy of the radius and ulna is valuable in fracture fixation and reconstructive surgery. Any degree of forearm deformity can cause a significant loss of range of motion.[2] Caput fractures of the radius are common elbow injuries and account for approximately 30% of all elbow fractures. Surgical treatment in comminuted radius caput fractures includes osteosynthesis or implantation of a radius caput prosthesis.[4]

Radius caput prostheses have been proven to restore the kinematics of the radiocapitellar joint and have shown satisfactory clinical results. Therefore, it has become an established treatment tool.[5] The radial caput anatomy is complex, making a perfectly fitting prosthesis difficult. The size and shape of the radial caput prosthesis should mimic natural anatomy as closely as possible to avoid degenerative changes or loss of motion. In addition, the ulna that is too long or short may be responsible for the symptoms around the wrist, and surgical treatment may be indicated.

A relatively long ulna may be congenital or post-traumatic, usually after a distal radial fracture. Short ulna may be secondary to excessive surgical resection.[6] A literature review indicated the lack of published articles on morphological variations of the ulna.[7]

In recent years, anatomically pre-shaped plates have become increasingly available and sold by the industry. Using these preformed plates in daily clinical practice has shown that, in many cases, these plates do not fit the ulna or radius as promised by the term "anatomically preformed plate".[7]

Full-length ulnar and radial osteology has not been described, as previous studies on the radius and ulna did not consider the entire bone and instead focused on the proximal third, where the proximal arc is well defined in the apex-dorsal and apex-radial directions.[2] Radius and ulna length studies are identification studies and do not give exact values of bones since they are measured with soft tissue. Our study aimed to evaluate the caput and lengths of the radius and ulna according to gender in the anatomy of the forearm by focusing longitudinally on the radius and ulna in the Anatolian population through radiological images.

Methods

This retrospective descriptive study was conducted at the İzmir Bakırçay University Çiğli Training and Research Hospital between January 2021 and November 2021. Ethics committee approval was obtained for the study. Evaluations and measurements were made on the images of individuals who applied for CT angiography at the Study Training and Research Hospital and were not found to have a fracture or mass in the forearm. For each patient, Radius length, radius width, the distance between the lateral and medial edges of the distal end of the radius (AD) width, caput ulna width, ulna length and caput radii width measurement data, and demographic data including age and gender were collected. To preserve authenticity, all morphometric measurements were made by a single independent staff member. Each parameter was measured thrice, and the average value taken was used to reduce the within-observer error.

All images showing structural deformity and irregularities due to pathological conditions (such as arthritis) were excluded, as they could be responsible for inaccurate measurement.

Data were analyzed using SPSS Statistical software version 21 for Windows. Pearson correlation analysis and student t-tests were used to evaluating the data. A probability value of $p<0.05$ was considered statistically significant.

Figures of radius length, radius width, AD width, caput ulna width, ulna length, and caput radii width measurements are given in figures 1-6.

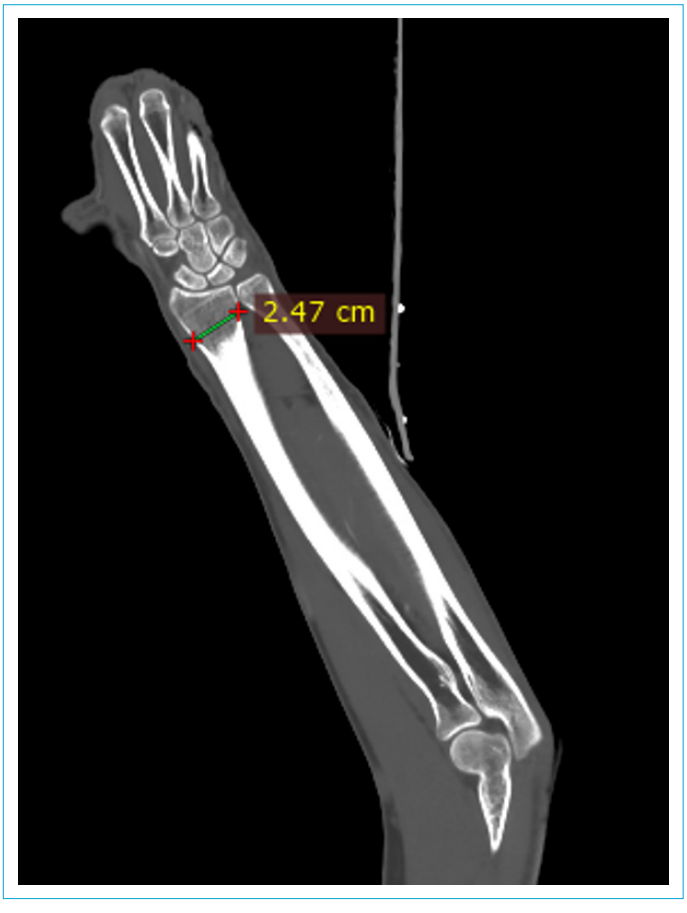

Figure 1. FAD length measurement.

AD length measurement: Point A is the radial corner of the border fed by the arteries. Point D is the ulnar corner of the edge fed by the arteries. Length AD is the length between points A and D.

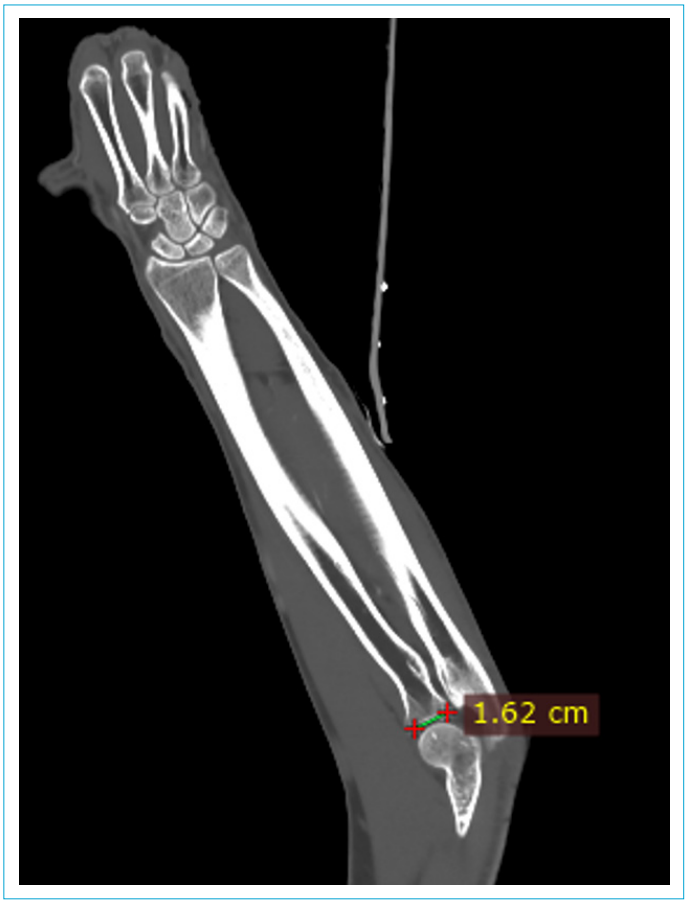

Figure 2. Caput radii width measurement.

Caput radii width measurement: It is the length between the medial and lateral border of the caput radii.

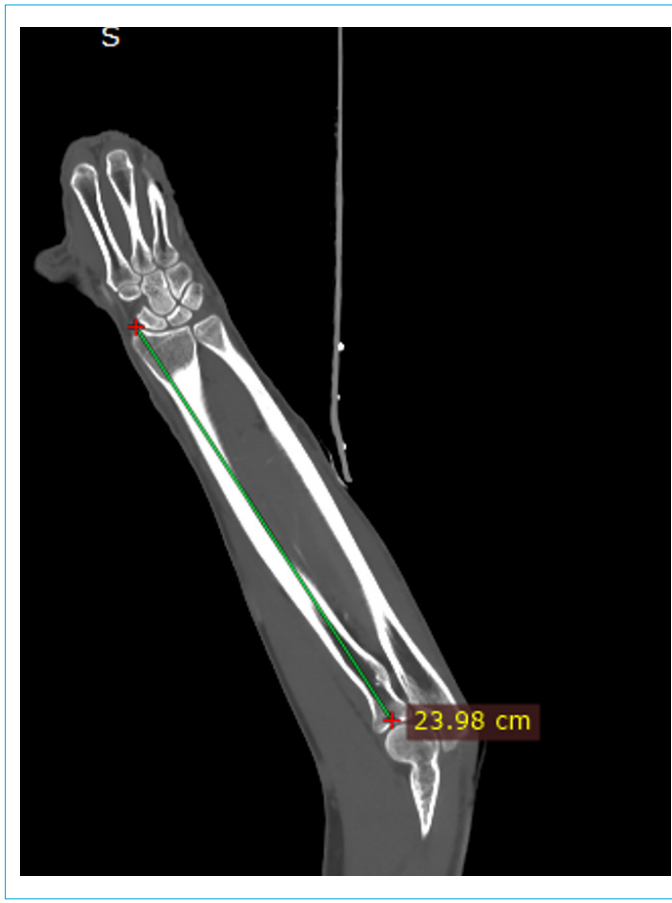

Figure 3. Radius width measurement.

Radius width measurement: The line length starts from the medial border of the distal of the radius and is drawn perpendicular to its lateral border.

Results

81 computed tomography (CT) angiography images were used in the study. Of the images included in the study, 28 belonged to female patients, and 53 were male patients. The age range of the patients was between 18 and 84, and the mean age was 45.30±18.42 years. When the general data of the study were evaluated, radius length (cm) was 23.39±1.82, radius width (mm) was 30±2.9, AD width (mm) was 25.8±3, caput ulna width (mm) was 16.4±2.2, ulna length (cm) was 25.33±1.88, caput radii width (mm) was 19.1±2.5 (Table 1).

Radius length, radius width, AD width, caput ulna width, ulna length, and caput radii width each showed significant correlations among themselves ($p<0.001$) (Table 2).

When the data are evaluated according to gender, The radius length (cm) in women is 21.63±1.08, while it is 24.32±1.39 in men. Radial width (mm) in women is 27.1±2.4, while in men, it is 31.6±1.8. AD width (mm) in women is 22.8±2.3, while 27.4±2.1 in men. While the width of the caput ulna (mm) in women is 15.0±1.9, it is 17.1±2.0 in men. ulna length (cm) in women is 23.58±1.32, while in men, it is 26.25±1.42. While the caput radii width (mm) was 16.9±1.6 in females, it was 20.2±2.0 in males (Table 3).

In women, radius length, radius width, AD width, ulna length, caput ulna, and caput radii width were also very significantly correlated with each other ($p<0.001$). However, there was a significant correlation between radius length and caput ulna width ($p<0.05$) (Table 4).

In men, radius length, radius width, AD width, ulna length, caput ulna, and caput radii width were also very significantly correlated with each other ($p<0.001$). However, there was a significant correlation between caput radii width, radius width, and AD width ($p<0.05$) (Table 5).

Radius length, radius width, AD width, ulna length, caput ulna, and caput radii width values showed a significant difference between the genders ($p<0.001$) (Table 6).

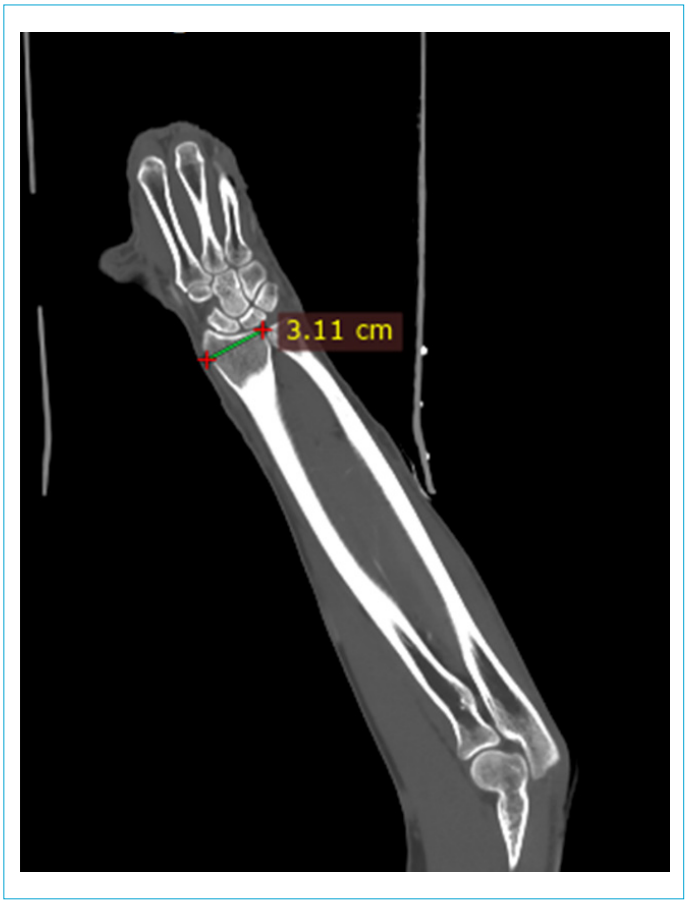

Figure 4. Radius length measurement.

Radius length measurement: The length of the line drawn from the processus styloideus radii to the central point of the fovea capitis radii.

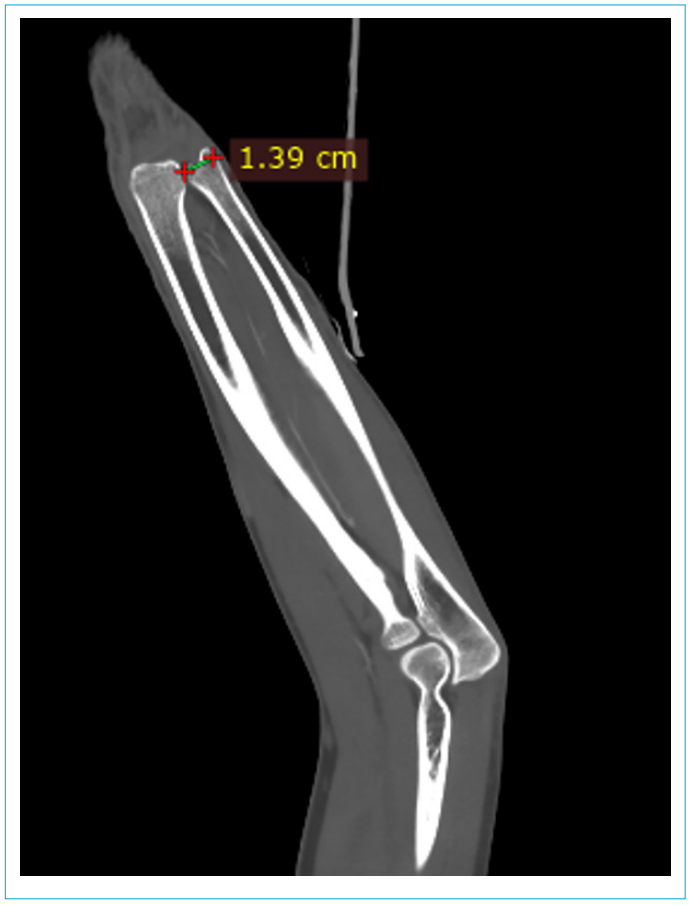

Figure 5. Ulna width measurement.

Ulna width measurement: The length of the line starts from the caput ulnae's medial border and is drawn perpendicular to its lateral border

Discussion

It is thought that extending our knowledge about linear body proportions from axial length measurements to intraosseous geometric dependencies will be beneficial in anthropology/forensic medicine and medicine/biomechanics.[8]

The radius is one of the long bones, and its distal part is more comprehensive than its proximal part. The shaft of the radius expands rapidly towards its distal end, and its distal part is concave anteriorly.[9] A few morphological studies of the radius have been conducted in forensic anthropology and orthopedics.[2, 8, 10] In forensic anthropology, several researchers have examined the radius specifically for sex determination using the entire length and head diameter of the radius or surface area and volume from three-dimensional (3D) radius models.[7, 11]

Radiographic morphometry of the distal radius has been studied in depth in medical studies. Still, few have reported on the morphology of the distal radius, and the dependence on intraosseous geometry has not been mentioned much in the literature.[12, 13] In addition, most studies on bone biomechanics have been performed on single-bone models, ignoring inter-patient variability in bone geometry.[4] Despite the research, there is still a lack of morphological information about the anterior surface of the distal radius.

The central end of the radius is vast, and its anterior surface is concave.[10] This anterior surface is clinically significant because the distal radius plate must be firmly placed on the anterior surface during distal radius surgery.[14] Our literature review determined that there was a lack of morphometry studies that specifically analyzed the anterior surface of the distal radius, the proximal end of the radius, and its entire length. Also, there was little information about the relationship between the humerus and ulnar bone anatomy for the design of total elbow arthroplasty.[15]

Celbis et al. (2006) found the length of the ulna (cm) to be 26.4±4.8 and the radius to be 24.5±4.7 in men in their measurements from cadavers in the Anatolian population.[8] In this study, the length of the ulna (cm) in men was

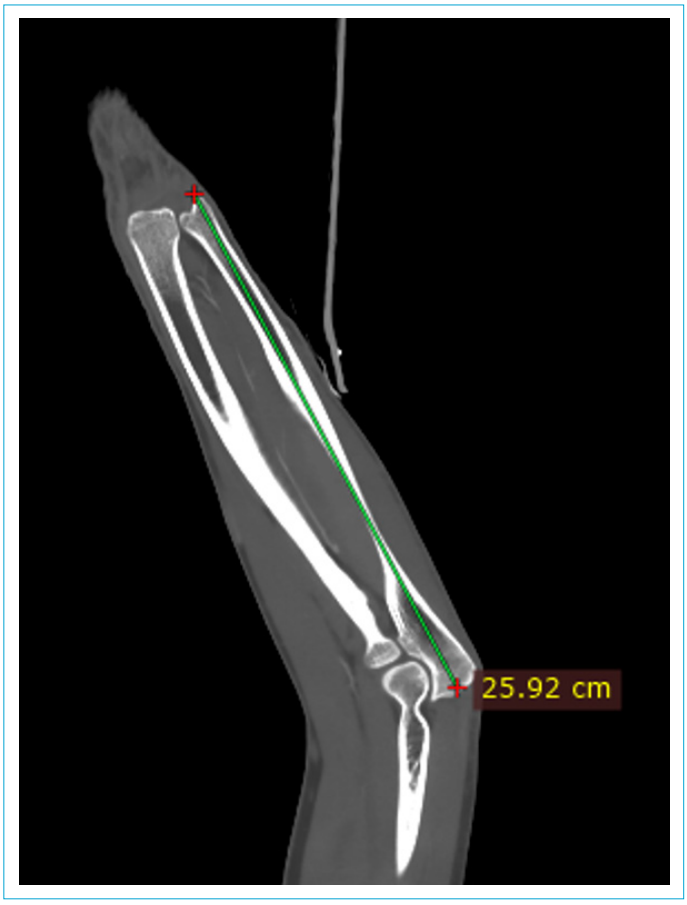

Figure 6. Ulna length measurement.

Ulna length measurement: The line length extends from the processus styloideus ulnae to the upper border of the extremitas proximal ulnae.

Table 1. Mean and standard deviation values of the parameters

	Mean	Std. Deviation	n
Radius length (cm)	23.39	1.82266	81
Radius width (mm)	30. 08	.29710	81
AD width (mm)	25.86	.30966	81
Caput Ulna width (mm)	16.40	.22504	81
Ulna length (cm)	25.33	1.88172	81
Caput Radii width (mm)	19.11	.25069	81

26.25±1.42, and the radius length (cm) was 24.32±1.39. Celbis et al. (2006), while the length of the ulna (cm) was 23.6±4.3 and the radius length (cm) was 21.7±3.5 in women, in our study, it was found that the length of the ulna (cm) was 23.58±1.32 and the radius length (cm) was 21.63±1.08 in women.[8] When the two studies are compared, the values are consistent. Akhlaghi et al. (2012) found the radius length (cm) to be 20.87±1.77 in females and 24.49±2.1 in males in a cadaver study conducted in Iranians.[16] In the study of Holman and Bennett (1991), radius length (cm) was given as 24.3 in men, 21.9 in women, and ulna length (cm) as 27.1 in men and 24.5 in women.[17] Hong et al. (2021), in their study on CT images, the radius length (cm) in women was 21.1±1, and the ulna length (cm) was 22.7±1, while in men, the radius length (cm) was 22.8±1.1, and the length of the ulna (cm) was 24.5±1.1.[1] Srivastava et al. (2013), while the length (cm) of the ulna was 26.2±1.39 in men, it was 23.6±0.9 in women.[18] Mall et al. (2001) found the radius length (cm) as 24.6±1.25 in men, 22.0±1.03 in women, and 26.5±1.54 in men and 23.8±1.07 in women.[19] Singh et al. (1974) found the length of the ulna to be 26.2 cm in men and 23.4 cm in women in a study conducted on Indians.[20] Madden et al. (2012) measured the length of the ulna (cm) in their research on different races and found it to be 26.6±1.0 Asian, black 29.3±1.5, white 27.5±1.2 in men, 24.7±0.7 Asian, black 26.3±1.8, and white 24.7±1.4 in women.[21] There are differences between the populations.

Berrizbeitia (1989) found the caput radii width (mm) in the Caucasian race to be 24.23 in men and 20.74 in women.[22] Mall et al. (2001) found the caput radii width to be 26±0.17 in men, 22±0.12 in women, and the distal radius width as 36±0.3 in men and 32±0.22 in women.[19] In this study, the caput radii width (mm) was found to be 16.9±1.6 in women, 20.2±2.0 in men, while the distal radius width (mm) was 27.1±2.4 in women, and 31.6±1.8 in men. There is a difference between the values found in this study and other studies.

Weber et al. (2020), in their dry bone study, found the average radius length (cm) to be 20.6±1.6 and the ulna length (cm) to be 24.2±1.7.[2] In this study, approx. radius length (cm) is 23.39±1.82, and mean ulna length (cm) was 25.33±1.88. In the study conducted by Srivastava et al. (2013) on dry bones, the width of the caput ulna in men (mm) was found to be 16.47±1.25 in men and 14.5±1.09 in women.[18] In this study, the caput ulna width was 17.1±2.0 in men and 15.0±1.9 in women. Caput ulna width differs between studies.

Rigor mortis has been accepted as an essential factor causing shortening and hardening.[23] The difference between the radiological and dry bone measurements is a possible result of the measurements being different since the bones will decrease in length due to the drying of the bones.

Raush et al. (2019) CT images taken from embalmed specimens, radius mean length (cm) 23.8±1.6, approx. they found the ulna length (cm) as 23.0±1.6 and the radius caput width (mm) as 22.5±2.0.[4] Compared to this study, the ulna length differed while the radius length was similar. The distal ulna was 19.1±2.5. Shin et al. (2017) found the distal ulna width (mm) to be 15.64±1.72, while it was found to be

Table 2. Correlation of parameters

	Radius length	Radius width	AD width	Caput Ulna width	Ulna length	Caput Radii width
Radius length						
Pearson Correlation	1	.811**	.817**	.617**	.958**	.695**
Sig. (2-tailed)		.000	.000	.000	.000	.000
N	81	81	81	81	81	81
Radius width						
Pearson Correlation	.811**	1	.962**	.569**	.766**	.654**
Sig. (2-tailed)	.000		.000	.000	.000	.000
N	81	81	81	81	81	81
AD width						
Pearson Correlation	.817**	.962**	1	.588**	.772**	.675**
Sig. (2-tailed)	.000	.000		.000	.000	.000
N	81	81	81	81	81	81
Caput Ulna width						
Pearson Correlation	.617**	.569**	.588**	1	.635**	.718**
Sig. (2-tailed)	.000	.000	.000		.000	.000
N	81	81	81	81	81	81
Ulna length						
Pearson Correlation	.958**	.766**	.772**	.635**	1	.718**
Sig. (2-tailed)	.000	.000	.000	.000		.000
N	81	81	81	81	81	81
Caput Radii width						
Pearson Correlation	.695**	.654**	.675**	.718**	.718**	1
Sig. (2-tailed)	.000	.000	.000	.000	.000	
N	81	81	81	81	81	81

**. Correlation is significant at the 0.01 level (2-tailed).

16.4±2.2 in this study.[24] Singh et al. (1974) found the distal ulna width (mm) to be 19 mm in men and 17 mm in women in a study they conducted on Indians.[20] Mall et al., in their research, found the distal ulna width (mm) to be 22±0.19 in men and 18±0.16 in women.[19] When studies are compared, differences are observed between populations.

In our study, the parameter values of women were found to be smaller than men's. This result was similar in other studies.[8,16-20,22] At the same time, each parameter showed a significant correlation, and it was determined that no correlation analysis was performed for the morphometric measurements of the radius and ulna in the literature.

Table 3. Parameter values in women and men

	Gender	N	Mean	Std. Deviation	Std. Error mean
Radius length (cm)	W	28	21.6357	1.08876	.20576
	M	53	24.3298	1.39217	.19123
Radius width (mm)	W	28	2.7193	.24536	.04637
	M	53	3.1606	.18957	.02604
AD width (mm)	W	28	2.2832	.23022	.04351
	M	53	2.7468	.21044	.02891
Caput Ulna width (mm)	W	28	1.5046	.19706	.03724
	M	53	1.7117	.20651	.02837
Ulna length (cm)	W	28	23.5854	1.32250	.24993
	M	53	26.2532	1.42538	.19579
Caput Radii width (mm)	W	28	1.6932	.16951	.03203
	M	53	2.0270	.20619	.02832

Table 4. Correlation of parameters in women

	Radius length	Radius width	AD width	Caput Ulna width	Ulna length	Caput Radii width
Radius length						
Pearson Correlation	1	.754**	.760**	.393*	.922**	.607**
Sig. (2-tailed)		.000	.000	.039	.000	.001
N	28	28	28	28	28	28
Radius width						
Pearson Correlation	.754**	1	.947**	.484**	.672**	.546**
Sig. (2-tailed)	.000		.000	.009	.000	.003
N	28	28	28	28	28	28
AD width						
Pearson Correlation	.760**	.947**	1	.513**	.671**	.606**
Sig. (2-tailed)	.000	.000		.005	.000	.001
N	28	28	28	28	28	28
Caput Ulna width						
Pearson Correlation	.393*	.484**	.513**	1	.513**	.624**
Sig. (2-tailed)	.039	.009	.005		.005	.000
N	28	28	28	28	28	28
Ulna length						
Pearson Correlation	.922**	.672**	.671**	.513**	1	.617**
Sig. (2-tailed)	.000	.000	.000	.005		.000
N	28	28	28	28	28	28
Caput Radii width						
Pearson Correlation	.607**	.546**	.606**	.624**	.617**	1
Sig. (2-tailed)	.001	.003	.001	.000	.000	
N	28	28	28	28	28	28

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

While a significant correlation was observed between radius length and caput ulna among the parameters evaluated in women, a more significant correlation was observed between other parameters. In men, a significant correlation was observed between the radial, radial width, AD width, and radius width, while a more significant correlation was observed between other parameters. There was a significant correlation in the parameters between the genders. In previous studies, no study was found in which the morphometric measurements of the radius and ulna were correlated for each of the genders. Therefore, our study is the first in which morphometric measurements of radius and ulna are correlated.

In our study, the number of women and men was unequal, and fewer images were obtained from female patients. We believe that the data on the Anatolian population will be more meaningful when measurements are made on more images in future studies.

Length measurements made on long bones are mainly in the form of cadaver and dry bone studies. These measurements are essential for anthropological studies but do not give the exact bone length. Radiological measurements are of great importance in forearm fracture surgery. Compliance with anatomical measurements is required for rapid and uncomplicated recovery in reconstructive surgeries. Therefore, morphometric studies on radiological images should be considered. In addition, the plates used in radius and ulna fractures have standard sizes. However, studies have shown that the average bone length of each breed differs. In our literature review, there were not enough studies on radiological measurements of the Anatolian population's length and width of the ulna and radius.

In the prosthetic replacement of any joint, proper sizing of components is critical for proper function.[25] Kinematic changes in the radiohumeral joint can be demonstrated by shortening or lengthening the radius caput prosthesis.[26] In a series of forty-four patients, van Riet et al. (2020) found radiological signs of excessive lengthening before revision surgery in 25%.[27] Biomechanical studies revealed extreme stretching of the interosseous membrane with increased radial caput diameter. Such biomechanical changes may cause pain or loss of movement.[26] It is practically impossible to accurately estimate the size of the radius caput

Table 5. Correlation of parameters in men

	Radius length	Radius width	AD width	Caput Ulna width	Ulna length	Caput Radii width
Radius length						
Pearson Correlation	1	.578**	.583**	.519**	.924**	.396**
Sig. (2-tailed)		.000	.000	.000	.000	.003
N	53	53	53	53	53	53
Radius width						
Pearson Correlation	.578**	1	.909**	.361**	.486**	.287*
Sig. (2-tailed)	.000		.000	.008	.000	.038
N	53	53	53	53	53	53
AD width						
Pearson Correlation	.583**	.909**	1	.394**	.500**	.319*
Sig. (2-tailed)	.000	.000		.004	.000	.020
N	53	53	53	53	53	53
Caput Ulna width						
Pearson Correlation	.519**	.361**	.394**	1	.509**	.637**
Sig. (2-tailed)	.000	.008	.004		.000	.000
N	53	53	53	53	53	53
Ulna length						
Pearson Correlation	.924**	.486**	.500**	.509**	1	.462**
Sig. (2-tailed)	.000	.000	.000	.000		.000
N	53	53	53	53	53	53
Caput Radii width						
Pearson Correlation	.396**	.287*	.319*	.637**	.462**	1
Sig. (2-tailed)	.003	.038	.020	.000	.000	
N	53	53	53	53	53	53

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 6. Correlation of parameters between genders

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Radius length									
Equal variances assumed	.956	.331	-8.894	79	.000	-2.69410	.30290	-3.29700	-2.09120
Equal variances not assumed			-9.591	67.601	.000	-2.69410	.28090	-3.25468	-2.13351
Radius width									
Equal variances assumed	1.388	.242	-8.981	79	.000	-.44128	.04913	-.53908	-.34348
Equal variances not assumed			-8.298	44.421	.000	-.44128	.05318	-.54843	-.33413
AD width									
Equal variances assumed	.728	.396	-9.127	79	.000	-.46358	.05079	-.56467	-.36248
Equal variances not assumed			-8.875	50.943	.000	-.46358	.05223	-.56845	-.35871
Caput Ulna width									
Equal variances assumed	.208	.649	-4.359	79	.000	-.20706	.04750	-.30161	-.11250
Equal variances not assumed			-4.423	57.387	.000	-.20706	.04681	-.30078	-.11333
Ulna length									
Equal variances assumed	.449	.505	-8.209	79	.000	-2.66785	.32500	-3.31474	-2.02096
Equal variances not assumed			-8.403	58.808	.000	-2.66785	.31749	-3.30319	-2.03251
Caput Radii width									
Equal variances assumed	.504	.480	-7.348	79	.000	-.33377	.04543	-.42418	-.24335
Equal variances not assumed			-7.806	65.065	.000	-.33377	.04276	-.41916	-.24837

affected in multi-part fractures.[28] For this reason, it is essential to make morphometric measurements of the radius and ulna on populations by anatomical values in forearm reconstructive surgeries.

Our study is the first radiological study in which these measurements were made in the Anatolian population. It also shows the differences in the lengths and distal widths of the radius and ulna in the Anatolian population compared to others. For this reason, we think it will be informative in the production of osteosynthesis or prosthetic implants that will be applied in forearm fracture surgery that overlaps with the anatomical values of the populations and will bring the changing forearm biomechanics closer to normal.

Disclosures

Ethics Committee Approval: The study was approved by Izmir Bakircay University Ethics Committee For Non-Interventional Clinical Trials (Meeting date: 25.12.2020, Decision No:177 Research No:123). Since the study was retrospective, there was no patient consent and the study was conducted in accordance with the Declaration of Helsinki.

Peer-review: Externally peer-reviewed.

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