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Original Article

Anatomy Section

Morphometric Analysis of Distal End of Dry Human Radius in Northern India and its Clinical Implications in Relation to Wrist Joint and Inferior Radioulnar Joint Arthroplasty: A Cross-sectional Study

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ABSTRACT

Introduction: The lower end of the radius is involved in the formation of the wrist joint and inferior radioulnar joint. Its morphometry is crucial for surgical procedures related to wrist arthroplasty.

Aim: To measure the various morphometric parameters of the distal end of the radius and the distal articular surface of the radius.

Materials and Methods: The present cross-sectional study was conducted in the Department of Anatomy, Rohilkhand Medical College and Hospital, Bareilly, Uttar Pradesh, India, from April 2023 to July 2023. The following parameters were measured: Length (LR) and Weight of Radius (WR), Length of Styloid Process (L-SP), Anteroposterior Length (APL-UN), Height (H-UN) and Depth (D-UN) of Ulnar Notch, Transverse Width (TW-DR), Oblique Width (OW-DR) and Anteroposterior Diameter (APD-DR) of the Distal Radius, Dorsal Tubercle Distance from the styloid process (DTD-SP) and from the Ulnar Notch (DTD-UN), Anteroposterior Length (APL-SF) and Transverse Length (TL-SF) of Scaphoid Facet, Anteroposterior Length (APL-LF) and Transverse Length (TL-LF) of Lunate Facet, Radial Inclination (RI) and Palmar Tilt (PT). Statistical analysis was performed using International Business Machines (IBM) Statistical Package for the Social Sciences (SPSS) software version 22.0. The values of the right and left sides were compared with a Student's t-test.

Results: Various morphometric parameters were measured on 80 dry adult radii (44 right and 36 left). The mean LR was 23.27±2 cm, WR was 39.24±9.84 gm, and L-SP was 10.9±2.40 mm. APL-UN, H-UN and D-UN were 14.29±1.80 mm, 7.75±2.07 mm and 1.68±0.63 mm, respectively. TW-DR, OW-DR and APD-DR of the distal end of the radius were 27.22±3.55 mm, 29.17±3.09 mm and 18.29±2.36 mm, respectively. The mean DTD-SP and DTD-UN were 20.66±2.40 mm and 16.29±2.53 mm, respectively. Mean values of the scaphoid facet and lunate facet were 11.75±1.44 mm (APL-SF), 15.16±2.165 mm (TL-SF), and 15.96±1.92 mm (APL-LF), 10.20±1.52 mm (TL-LF), respectively. The mean angles of RI and PT were 24.48±5.06° and 10.91±3.179°, respectively. No significant difference was found between the right and left side values (p-value >0.05). Among the 80 radii, 43.8% had four grooves, 42.5% had three grooves, and 13.8% had only two grooves present on the dorsal surface of the lower end of the radius. Out of 262 observed grooves in 80 radii, 50 (19.09%) were vertical and 212 (80.91%) were oblique. The groove medial to the dorsal tubercle was oblique in 70 (87.5%) radii and vertical in 10 (12.5%) radii. A highly positive correlation was found between the oblique and transverse width of the distal radius (r-value=0.74 and p-value=0.01).

Conclusion: The present study found no significant difference between the values of the right and left sides. The parameters identified may assist surgeons in selecting the appropriate size of the prosthesis or in corrective surgeries related to the lower end of the radius.

Keywords: Distal end radius, Dorsal tubercle, Lunate facet, Palmar tilt, Radial inclination, Scaphoid facet, Ulnar notch

INTRODUCTION

The radius is the preaxial long bone of the forearm. Its distal end forms a wrist joint with the proximal row of carpal bones. In the upper limb, body weight is directly transmitted from the wrist joint to the radius, making the anatomy of the lower end of the radius of great significance [1]. Fractures of the distal end of the radius are very common, especially in menopausal women [2]. During growth, metaphyseal fractures may arrest the growth of the lower end of the radius, and in adults, a history of previous lower end radius fractures increases the risk of osteoporosis-related fractures [3].

The treatment modalities differ in lower end radius fractures and depend on several factors. Minimally displaced fractures of the lower end radius, treated conservatively, have changes of <5 degrees in Radial Inclination (RI), <10 degrees in dorsal angulation and <2 mm height loss. Surgical treatments are preferred for unstable fractures of the lower end of the radius [4,5].

Styloid fractures of the radius are usually associated with the displacement of the lunate bone. For surgical fixation of the styloid process, the first dorsal compartment approach is used. Evaluation of articular reduction is carried out by radiocarpal arthrotomy through the space between the fourth and second dorsal compartments, distal to the dorsal tubercle [6,7]. The distance between the tip of the styloid process and the dorsal tubercle is an important parameter for the treatment of lower end radius fractures.

Supination and pronation are key movements for the optimum functional positioning of the hand, occurring at the radioulnar joint [8]. Involvement of the distal radioulnar joint is most common in distal radius fractures, which may lead to disability of the wrist joint. Fractures involving the ulnar notch at the distal end of the radius may produce stiffness and arthritis of the joint. With proper diagnosis and treatment, the outcome is satisfactory even in severe injuries [9].

Clinically, the morphometric anatomy of the lower end of the radius is important for orthopaedic surgeons in planning conservative and surgical procedures for radius, wrist joint and inferior radioulnar joint injuries. The kinematics of the wrist joint, strength of grip and supination-pronation depend on the length and dorsal angulation of the radius [10]. In radiological morphometry of Palmar Tilt (PT) in the lateral view, a rotation of 50 degrees can change the PT by 1.60 degrees [11]. Therefore, the morphometry of the angulation of the lower end of the radius of dry human bones is more reliable.

Very few studies have been done on dry/cadaveric radius [10-13]. Most studies on the morphometry of the distal end of the radius were done radiologically [14,15]. In radiological studies, soft tissue shadow or angulation during imaging can alter the measured values [11]. So for accurate measurement, the authors chose dry radius for morphometric study. The aim of the present study was to measure the various morphometric parameters of the distal end of the radius and the distal articular surface of the radius.

MATERIALS AND METHODS

The present cross-sectional study was conducted in the Department of Anatomy, Rohilkhand Medical College and Hospital Bareilly, Uttar Pradesh, India, from April 2023 to July 2023, after obtaining permission from the Institutional Ethical Committee (certificate number: IEC/RMCH/02/2023/APR).

Sample size calculation: The calculated sample size was 74 ($N=Z^2 \times SD^2/E^2$ where Z was 1.96 (95% confidence interval), SD was 0.22 (Gupta C et al.,) [12], and E was 5%). In the present study, a total of 80 adult, dry radius bones of both sides with unknown sex were measured.

Inclusion criteria: Well-preserved dry radius bones of both sides with unknown sex were included in the study.

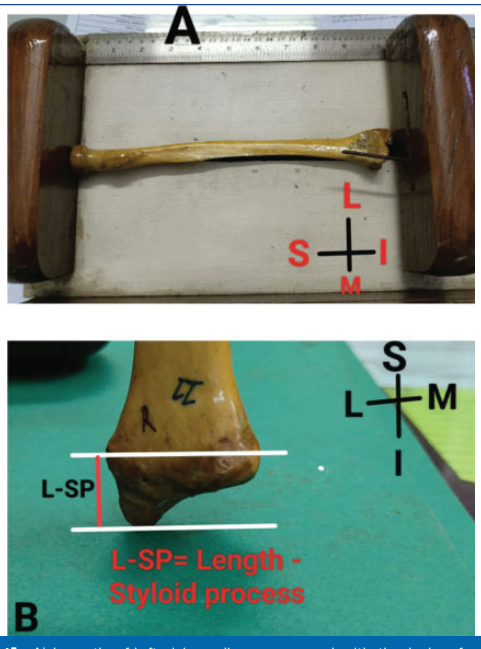
Exclusion criteria: Damaged radius or bones with pathological changes were excluded from the study.

Study Procedure

The following morphometric parameters were measured, as done by Mittal A et al., and Prithishkumar IJ et al., [10,13].

Length of Radius (LR): It was measured with the help of an osteometric board, as the distance between the proximal and distal point of the bone [Table/Fig-1] [10].

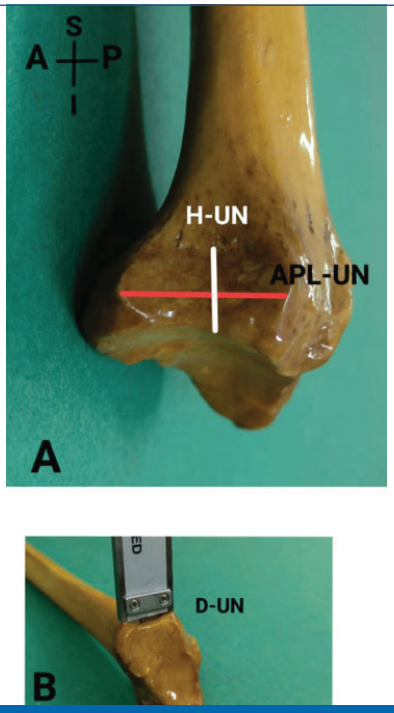
Weight of Radius (WR): Weight was taken with the help of a weighing machine (in grams) [10].



[Table/Fig-1]: A) Length of left side radius measured with the help of osteometric board; B) Lower end of right radius showing length of styloid process (S-superior, I-inferior, L-lateral and M-medial).

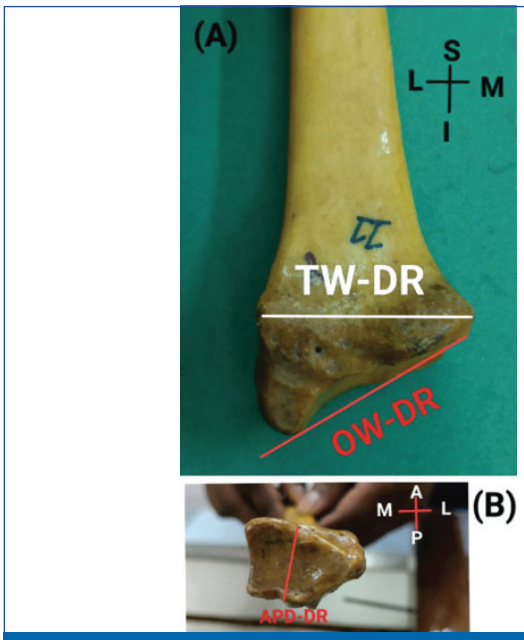
Length of the styloid process (L-SP): It was measured from its tip to a line perpendicular to the long axis of the bone at the medial margin of the distal end of the radius (in mm) by vernier calliper [Table/Fig-1] [10].

Ulnar Notch (UN): The following parameters were measured (in mm): 1) Anteroposterior length (APL-UN)- maximum anteroposterior distance was measured; 2) height (H-UN)- maximum height was measured; and 3) depth of the ulnar notch (D-UN)- maximum depth was measured by the backside, bar of the vernier calliper [10] [Table/Fig-2].



[Table/Fig-2]: A) Lower end of right radius, medial view showing morphometry of ulnar notch (H-UN=Height of ulnar notch, APL-UN=Anteroposterior length of ulnar notch; B) Depth of Ulnar Notch (D-UN), (A-anterior, P-posterior, S-superior and I-inferior).

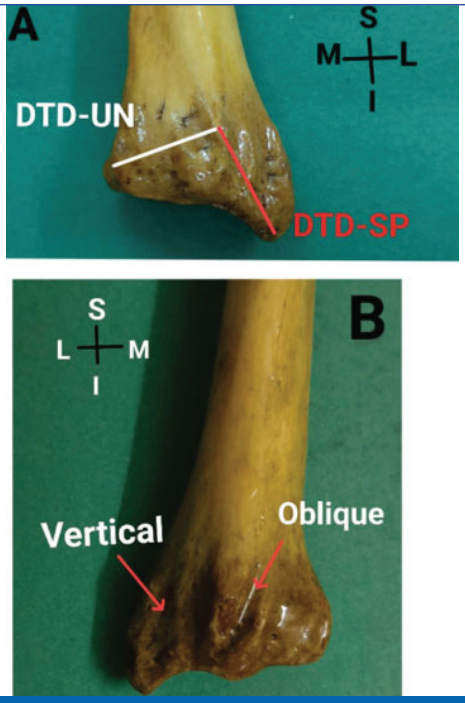
Distal end of radius width (DR): 1) Transverse width (TW-DR)- It was the maximum transverse width at the level of the medial edge of the radius, which was perpendicular to the long axis of the radius (in mm); 2) Oblique width (OW-DR)- It was the oblique width of the distal margin (in mm) [Table/Fig-3] [13].



[Table/Fig-3]: A) Lower end of right radius, anterior view, measuring TW-DR=transverse width of distal radius and OW-DR=oblique width of distal radius (L-lateral, M-medial, S-superior and I-inferior); B) Lower end of left radius, inferior view, measuring APD-DR=anteroposterior distance of distal radius (M-medial, L-lateral, A-anterior and P-posterior).

Anteroposterior diameter of the distal end of radius (APD-DR): It was measured as the maximum distance from the anterior margin to the posterior margin of the distal articular surface of the radius (in mm) [Table/Fig-3] [13].

Grooves on dorsal surface of lower end of radius: Morphology of grooves observed as: 1) presence or absence of grooves; 2) Number of grooves (1, 2, 3, etc.); and 3) Direction of grooves (oblique or vertical), as the dorsal aspect of the radius typically has three or four grooves. From lateral to medial, the first groove on the styloid process accommodates the tendons of the abductor pollicis longus and extensor pollicis brevis, the second groove for the tendons of extensor carpi radialis longus and brevis, the third groove, medial to the dorsal tubercle, for the tendon of extensor pollicis longus, with the dorsal tubercle acting as a pulley where this tendon changes its direction from medial to lateral. The fourth groove is indistinct and serves the tendons of the extensor indicis and extensor digitorum [Table/Fig-4] [10].



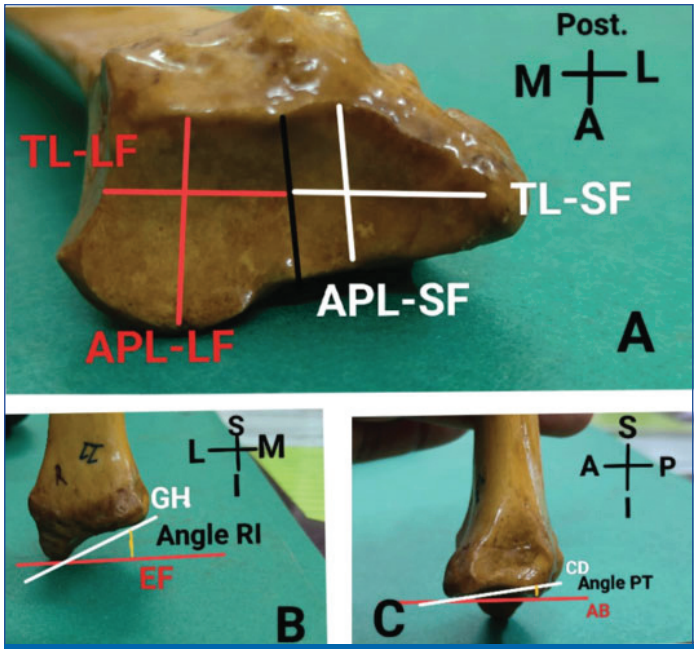
[Table/Fig-4]: A) Lower end of right radius, posterior view measuring DTD-SP=distance of dorsal tubercle from styloid process, DTD-UN=dorsal tubercle distance from ulnar notch; B) Lower end of left radius, posterior view, showing direction of grooves (L-lateral, M-medial, S-superior and I-inferior).

Dorsal tubercle (Tubercle of Lister's) distance (DTD): The distance of the dorsal tubercle (Lister's Tubercle) was measured from the tip of the styloid process (DTD-SP) and the posterior border of the ulnar notch (DTD-UN) to the most prominent point on the tubercle [Table/Fig-4] [10].

The inferior articular surface was studied considering the following facets: The facet for the scaphoid (SF) was observed for shape (triangular/quadrangular); the anteroposterior length (APL-SF), being the maximum distance at the base of the triangle, and the transverse length (TL-SF) of the scaphoid facet: the maximum distance from the base of the facet to the tip of the styloid process were measured in millimeters using a vernier Caliper [Table/Fig-5] [10].

Facet for Lunate (LF): The facet for the lunate (LF) was also observed for shape (triangular/quadrangular); the maximum anteroposterior length (APL-LF) and the maximum transverse length of the facet (TL-LF) were measured in millimeters with a vernier calliper [Table/Fig-5] [10].

Angle of Radial Inclination (RI): It is the angle between a line perpendicular to the long axis of the radius and a line joining the medial edge of the distal end of the radius to the tip of the styloid process [Table/Fig-5] [13].



[Table/Fig-5]: A) Lower end of right radius Inferior view, showing measurements of scaphoid and lunate facet; APL-SF=anteroposterior length of scaphoid facet, TL-SF=transverse length of scaphoid facet, APL-SF=anteroposterior length of lunate facet and TL-SF=transverse length of lunate facet; B) Lower end of right radius, anterior view, measuring Angle of RI=radial inclination, GH=line passing from medial margin of lower end of radius to tipoff styloid process, EF=perpendicular line to long axis of radius; C) Lower end of right radius, medial view, measuring angle of PT=palmar tilt, CD=line passing from anterior margin to posterior margin of lower end of radius, AB=perpendicular line to long axis of radius (L-lateral, M-medial, A-anterior and P, Post.-posterior, S-superior and I-inferior).

Palmar Tilt (PT): It is the angle between the line perpendicular to the long axis of the radius and a line joining the centre of the anterior and posterior margins of the lower end of the radius [Table/Fig-5] [13].

All the above morphometric parameters were measured with a digital vernier calliper (least count: 0.001 mm), and the angles were measured with a goniometer. Each parameter was measured twice by two researchers on two different occasions, and the mean values were recorded.

STATISTICAL ANALYSIS

The measured values were tabulated in an Microsoft Excel worksheet and analysis was conducted using IBM SPSS software version 22.0. The data were expressed as mean, minimum and maximum values with standard deviation. The values from both the right and left sides were compared using the Student's t-test, and a p-value <0.05 was considered statistically significant. Pearson's correlation was performed, and a correlation was established between various parameters.

RESULTS

Morphometry of the lower end of the radius was performed on 80 dry adult radii (44 were of right side, 36 were of left side). The mean LR was 23.27±2.00 cm, WR was 39.24±9.84 gm, and L-SP was 10.9±2.40 mm. The mean values for the APL-UN, H-UN and D-UN were 14.29±1.80 mm, 7.75±2.07 mm and 1.68±0.63 mm, respectively. The mean values for the TW-DR, OW-DR and APD-DR were 27.22±3.55 mm, 29.17±3.09 mm and 18.29±2.36 mm, respectively. The mean distances of DTD-SP and DTD-UN were 20.66±2.40 mm and 16.29±2.53 mm, respectively. The shape of the scaphoid facet was found to be triangular, and the lunate facet was quadrilateral. The mean values of the parameters for the scaphoid and lunate facets were 11.75±1.44 mm (APL-SF), 15.16±2.165 mm (TL-SF) and 15.96±1.92 mm (APL-LF), 10.20±1.52 mm (TL-LF), respectively. The mean RI angle and PT were 24.48±5.06 degrees and 10.91±3.179 mm, respectively.

Morphometric parameters	Right side (n=44)			Left side (n=36)			t-value	p-value
	Minimum	Maximum	Mean±SD	Minimum	Maximum	Mean±SD		
LR (cm)	19.0	30.0	23.41±2.14	20.0	25.0	23.10±1.82	0.498	0.621
WR (gm)	20.0	52.5	40.35±9.51	20	50	37.89±10.20	1.282	0.208
L-SP (mm)	2.33	16.94	11.06±2.61	6.83	14.48	10.69±2.14	0.921	0.363
APL-UN (mm)	9.37	19.30	14.03±1.97	12.26	17.77	14.61±1.54	-1.314	0.197
H-UN (mm)	4.41	14.80	7.57±2.09	4.35	11.94	7.97±2.05	0.630	0.533
D-UN (mm)	0.31	3.68	1.65±0.68	.87	3.16	1.71±0.57	-0.262	0.795
TW-DR (mm)	22.62	34.53	27.53±3	13.17	32.35	26.82±4.14	1.026	0.312
OW-DR (mm)	23.87	35.63	29.33±3.04	21.94	34.71	28.97±3.18	0.616	0.542
APD-DR (mm)	12.14	22.77	18.15±2.30	13.24	26.33	18.46±2.45	-0.692	0.493
DTD-SP (mm)	15.61	26.09	20.53±2.36	16.87	25.97	20.83±2.47	-0.388	0.700
DTD-UN (mm)	10.89	21.20	16.28±2.54	10.99	21.44	16.29±2.54	-0.272	0.787
APL-SF (mm)	8.50	16.50	11.61±1.44	9.36	15.28	11.92±1.43	-0.492	0.626
TL-SF (mm)	9.88	21.22	14.97± 2.29	11.11	18.81	15.38±2.01	-0.624	0.537
APL-LF (mm)	11.61	19.98	15.73±2.07	13.32	19.61	16.23±1.69	-0.804	0.427
TL-LF (mm)	7.04	16.83	10.15±1.64	8.00	13.36	10.26±1.39	0.256	0.800
RI (degree)	15	30	23.82±3.96	12	42	25.28±6.11	-1.319	0.196
PT (degree)	6	24	11.14±3.49	5	18	10.64±2.78	0.838	0.408

[Table/Fig-6]: Various morphometric parameters of both right and left side of radius with t-value and p-value.

Upon comparison between the values from both sides of the radius, no significant difference was found in any of the parameters (p-value >0.05) [Table/Fig-6]. In 35 (43.8%) radii, four grooves were present on the dorsal surface of the distal radius, 34 (42.5%) radii had three grooves, and 11 (13.8%) grooves had only two grooves. Out of a total of 262 observed grooves (in 80 radii), 50 (19.09%) were vertical and 212 (80.9%) were oblique.

From lateral to medial, first groove (for the tendons of abductor pollicis longus and extensor pollicis brevis) was oblique in 47 (58.8%) of radii, vertical in 8 (10%) and absent in 25 (31.3%) of radii. Second groove (for the tendons of tendons of extensor carpi radialis longus and brevis) was oblique in 55 (68.8%) cases of cases, vertical in 17 (21.3%) cases and absent in 8 (10%) radii. Groove 3 (for the tendon of extensor pollicis longus), which lies medial to the dorsal tubercle and is deep and oblique due to the direction change of the tendon from the medial to lateral side, was oblique in 70 (87.5%) radii and vertical in 10 (12.5%) radii. Groove 4 (for the tendons of extensor indicis and extensor digitorum) was oblique in 40 (50%) cases of cases, vertical in 15 (31.3%) cases and absent in 31.3% (25) of radii. For distal end arthroplasty, the knowledge of the number and orientation of grooves is important for repositioning the extensor tendon.

Highly positive correlation was found between OW-DR and TW-DR, suggesting that an increase in the transverse width of the distal end of the radius is associated with an increase in the values of oblique width, as well. Moderate correlation was found between various parameters [Table/Fig-7].

Correlated parameters		r-value	p-value	Correlation
OW-DR	TW-DR	0.74	**0.01**	Highly positive
	DTD-SP	0.7	**0.01**	Moderately positive
	DTD-UN	0.66	**0.01**	Moderate
	TL-SF	0.67	**0.01**	Moderate
	APD-DR	0.6	**0.01**	Moderate
	RL	0.57	**0.01**	Moderate
TW-DR	DTD-SP	0.54	**0.01**	Moderate
	DTD-UN	0.55	**0.01**	Moderate
	TL-SF	0.57	**0.01**	Moderate
	RL	0.57	**0.01**	Moderate
APD-DR	DTD-SP	0.53	**0.01**	Moderate
	TL-SF	0.54	**0.01**	Moderate
DTD-SP	RL	0.51	**0.01**	Moderate
	TL-SF	0.58	**0.01**	Moderate
	APL-LF	0.57	**0.01**	Moderate
DTD-UN	RL	0.52	**0.01**	Moderate
	TL-SF	0.59	**0.01**	Moderate
	APL-LF	0.65	**0.01**	Moderate

[Table/Fig-7]: Pearson's correlation between different measured parameters. The r-value of 0.9 to 0.99 strongly positive correlation, 0.7 to 0.9 is highly positive and 0.5 to 0.7 is moderately positive correlation; The p-value in bold font indicates statistically significant values

DISCUSSION

Morphometric values of the lower end of the radius vary among different races. Most orthopaedic surgeons in our country rely on reference data based on Western studies for treatment related to injuries of the lower end of the radius or the distal radioulnar joint. Chan CY et al., stated that ulnar variance is statistically variable in the Chinese and Malaysian populations [15].

In the present study, no statistically significant difference was found between the lengths of the radius on both sides (p-value=0.621). Similar mean values for the length of the radius were reported by Kadel M and Thapa TP, in Nepalese, Van Riet RP et al., in Belgians, Captier G et al., in the French, Avnioğlu S et al., in Turks, and in many Indian studies [Table/Fig-8] [10,12,13,16-20].

In the present study, the mean values of the weight of the radius were 40.35±9.51 grams on the right side and 37.89±10.20 grams on the left side. No statistical difference was observed. Mittal A et al., in Indians and Captier G et al., in the French reported almost similar values for the weight of the radius [Table/Fig-8] [10,18].

In the present study, the mean values of TW-DR, OW-DR and APD-DR on the right and left sides showed no statistically significant difference. Similar values were reported by Gupta C et al., and Prithishkumar IJ et al., in Indian studies and, Kadel M and Thapa TP. in Nepalese dry radius bones [12,13,16]. Captier G et al., in the French reported higher values for TW-DR [18]. Avnioğlu S et al., in Turkey reported higher values for TW and APD-DR [Table/Fig-8] [19].

The mean value of the styloid process length on the right side was 11.06±2.61 mm, and on the left side, it was 10.69±2.14 mm. Almost similar values for L-SP were reported by Mittal A et al., in

Morphometric parameters	Kadel M and Thapa TP, 2021, Nepal [16], N=76	Gupta C et al., 2015, India [12], N=50 (R=23, L=27)	Van Riet RP et al., 2004, Belgium [17], (N=25)	Mittal A et al., 2019, India [10], N=100 (R=50, L=50)	Captier G et al., 2002, France [18], N=76	Prithishkumar IJ et al., 2012, India [13], N=132 (R=69, L=63)	Avnioğlu S et al., 2020, Turkey [19], N=28 (R=12, L=16)	Kumar P and Sharma A, 2021, India [20], (N=50)	Present study, India, N=80 (R=44, L=36)
LR	23.06±1.36 (R)	23.98±1.6 (R)	23.54±1.7	241±15.3 (R)	22.9±15.5	24.29±17.4 (R)	232 (R)	23.172±1.9	23.41±2.14 (R)
	23.08±1.24 (L)	23.12±2.11 (L)		238±15.1 (L)		24.4±16.4 (L)	228.93 (L)		23.10±1.82 (L)
WR	-	-	-	35±9.3 (R)	40.81±15.3	-	-	-	40.35±9.51 (R)
				35±11 (L)					37.89±10.20 (L)
TW-DR	28.74±2.25 (R)	26.4±2.2 (R)	-	-	31.9±3.7	26.3±2.4 (R)	32.65 (R)	-	27.53±3 (R)
	28.18±2.89 (L)	25.5±2.7 (L)				26.7±2.2 (L)	32.88 (L)		26.82±4.14 (L)
OW-DR	29.18±2.56 (R)	28.3±2.1 (R)	-	-	-	26.7±2.3 (R)	-	-	29.33±3.04 (R)
	27.24±2.47 (L)	27.8±2.3 (L)				27.2±2.2 (L)			28.97±3.18 (L)
APD-DR	18.86±1.58 (R)	18.9±2.1 (R)	-	-	22.7±3.5	17.5±1.7 (R)	-	-	18.15±2.30 (R)
	18.82±1.3 (L)	18.4±2.2 (L)				17.8±1.6 (L)			18.46±2.45 (L)
APL-UN	-	-	-	16.7±1.9 (R)	-	-	14.32 (R)	-	14.03±1.97 (R)
				16.2±2.1 (L)			14.83 (L)		14.61±1.54 (L)
H-UN	-	-	-	6.6±1.3 (R)	-	-	-	-	7.57±2.09 (R)
				6.8±1.2 (L)					7.97±2.05 (L)
D-UN	-	-	-	1.82±.39 (R)	-	-	2.02 (R)	-	1.65±0.68 (R)
				1.71±.52 (L)			1.73 (L)		1.71±0.57 (L)

[Table/Fig-8]: Morphometric parameters- LR, WR, Width of distal end radius and Ulnar Notch, reported by different authors [10,12,13,16-20].

Indian radius bones, Captier G et al., in the French, Gupta C et al., and Prithishkumar IJ et al., in Indian radius bones, while Kadel M and Thapa TP, in Nepalese reported similar values for the right side and higher values for the left side, with the difference between both sides being statistically significant [Table/Fig-9] [10,12,13,16,18].

In the present study, the mean angle of the Radial Inclination (RI) measured on the right side was 23.82±3.96° and on the left side was 25.28±6.11°. Werner FW et al., reported higher values for RI, whereas Kadel M and Thapa TP, in Nepalese, Gartland JJ Jr and Werley CW, in Philadelphia, and Gupta C et al., Prithishkumar IJ et al., and, Kumar P and Sharma A in India reported almost similar values [Table/Fig-9] [12,13,16,20-22].

The mean angle of the Palmar Tilt (PT) reported by the present study on the right radius was 11.14±3.49°, and on the left side, it was 10.64±2.78°. Almost similar values were reported by Kadel M and Thapa TP, in Nepalese, Gartland JJ Jr and Werley CW, in Philadelphia, and Prithishkumar IJ et al., in India; however, Werner FW et al., reported lower values for PT [Table/Fig-9] [13,16,21,22].

Radiological studies done by Nalbant A et al., in Turkey, Bhat MA et al., in India, Hadi SA and Wijiono W, in Indonesia, Mishra PK et al., in India, and Chan CY et al., in Malaysia reported almost similar values for the Length of the Styloid Process (L-SP), RI, and PT as reported by the present study [Table/Fig-10] [14,15,23-25].

Morphometric parameters	Side of bone	Kadel M and Thapa TP, 2021, Nepal [16], N=76	Gupta C et al., 2015, India [12], N=50 (R=23, L=27)	Gartland JJ Jr and Werley CW, 1951, Philadelphia [22], N=60	Mittal A et al., 2019, India [10], N=100 (R=50, L=50)	Captier G et al., 2002, France [18], N=76	Prithishkumar IJ et al., 2012, India [13], N=132 (R=69, L=63)	Werner FW et al., 1992, United States [21], N=58	Kumar P and Sharma A 2021, India [20] N=50	Present study, N=80 (R=44, L=36)
Styloid process length (mm)	Total	10.9±1.7		-		12.8±3.3		-	-	11.07±2.61
	Right	10.26±1.73	10±1.3		12.2±1.6	-	10.8±1.5			11.06±2.61
	Left	18.86±1.58	9.7±1.4		12.5±1.8	-	11±1.4			10.69±2.14
	p-value	0.008	-		-	-	0.44			0.36
Radial inclination (degree)	Total	23.62±3.1	-	23°	-	-		30	15.56±2.33	23.8±3.96
	Right	24.46±2.7	24.5	-			22.1±2.9	-	-	23.82±3.96
	Left	22.76±3.28	25.6	-			21.8±2.5	-	-	25.28±6.11
	p-value	0.071	-	-			0.54	-	-	0.20
Palmar tilt (degree)	Total	9.27±3.16	-	11°	-	-		6	-	11.14±3.49
	Right	9.61±3		-			9.1±2.0	-		11.14±3.49
	Left	8.9±3.4		-			8.2±2.9	-		10.64±2.78
	p-value	0.474		-			0.05	-		0.41

[Table/Fig-9]: Morphometric values of length of styloid process, Radial Inclination (RI) and Palmar Tilt (PT) reported by various studies in dry human radius [10,12,13,16,18,20-22].

Morphometric parameters	Nalbant A et al., 2023, Turkey [23], N=124	Bhat M A et al., 2020, India [24], N=212 (R=139, L=73)	Hadi SA and Wijiono W, 2013, Indonesia [14], N=400	Mishra PK et al., 2016, India [25], N=242 (R=156, L=86)	Chan CY et al., 2008, Malaysian [15], N=77	Present study, N=80 (R=44, L=36)
Styloid process length (mm)	10.55±4.34	12.3±1.6 (R) 11.7±1.62 (L)	11.31±1.66	11.27±3.62(R) 11.36±6.76(L)	-	11.06±2.61 (R) 10.69±2.14 (L)
Radial inclination (degree)	23.35±1.96	26.09±2.9 (R) 25.16±2.8 (L)	23.99±3.75	23.18±7.84(R) 23.42±6.72(L)	25.1±3.42	23.82±3.96 (R) 25.28±6.11 (L)
Palmar tilt (degree)	15.7±2.87	11.86±2.43 (R) 11.07±2.19 (L)	13.76±4.36	10.48±5.16(R) 9.30±5.24(L)	12.6±3.55	11.14±3.49(R) 10.64±2.78 (L)

[Table/Fig-10]: Mean value of styloid process length, Radial Inclination (RI) and Palmar Tilt (PT) reported by various radiological studies [14,15,23-25].

Morphometrics parameters (mm)		Mittal A et al., 2019, India [10], N=100		Ağır I et al., 2014, Turkey [26], N=20	Present study, India N=80	
		Right	Left	Total	Right	Left
Distance of dorsal tubercle	DTD-SP	19.4±2.7	19.8±2.2	13.48	20.53±2.36	20.83±2.47
	DTD-UN	15.9±1.7	16.4±1.7	13.97	16.28±2.54	16.29±2.54
Scaphoid facet	APL-SF	15.5±1.7	15.7±1.9	-	11.61±1.44	11.92±1.43
	TL-SF	16.9±1.7	17.1±1.8	-	14.97±2.29	15.38±2.01
Lunate facet	APL-LF	17.5±1.9	18.1±1.8	-	15.73±2.07	16.23±1.69
	TL-LF	10.8±1.2	10.6±1.2	-	10.15±1.64	10.26±1.39

[Table/Fig-11]: Mean values of morphometric parameters of dorsal tubercle, scaphoid facet and lunate facet by different authors [10,26].

In the present study, the mean values of the DTD-SP and DTD-UN were 20.53±2.36 mm (right side) and 20.83±2.47 mm (left side), respectively. The mean values for the APD-SF and TD-SF on the right side were 11.61±1.44 mm and 14.97±2.29 mm, and on the left side were 11.92±1.43 mm and 15.38±2.01 mm, respectively. The APD of the Lunate Facet (APD-LF) and the Total Length of the Lunate Facet (TL-LF) were 15.73±2.07 mm and 10.15±1.64 mm, respectively, on the right side and 16.23±1.69 mm and 10.26±1.39 mm on the left side. Mittal A et al., in India reported almost similar values and Ağır I et al., in Turkey reported lesser values for DTD-SP and DTD-UN [Table/Fig-11] [10,26].

The correlation between the biomechanics of the radiocarpal joint and the morphometry of the lesser end of the radius has been established. Miyake T et al., conducted a cadaveric study and reported that stress was on the volar region in a neutral position, and when a dorsal tilt was artificially created, stress shifted to the dorsal region. This stress was further increased when the dorsal tilt reached up to 30 degrees [27]. In 1951, Gartland JJ Jr and Werley CW, stated that there is a strong correlation between the dorsal tilt and the clinical outcome of fractures of the lesser end of the radius. They reported that 31.7% of patients had an unsatisfactory outcome [22]. Altissimi M et al., found a higher percentage of unsatisfactory results in the long-term results of conservative treatment when the RI was <5 degrees and the dorsal tilt was >15 degrees [28].

The above studies suggest that it is important to align the morphology of the distal end of the radius during the treatment of fractures to be, as close to normal as, possible. In the current scenario, most surgeons follow treatment protocols based on Western figures, which may not be suitable for the Indian population. Therefore, the data from the present study may assist orthopaedic surgeons treating the Indian population.

Limitation(s)

The present study was single-centric and there was no gender discrimination.

CONCLUSION(S)

In the present study, the differences between the morphometric values on both sides were not statistically significant. The findings of the present study may be helpful to orthopaedic surgeons in deciding the correct size of prostheses or in other corrective surgeries related to the distal end of the radius. This includes the correction of its angulation in the Indian population, as there are variations in the data from the present study compared to data from foreign studies. The data from the present study may also be useful for further cadaveric and radiological parametric studies of the lower end of the radius.

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