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Original Article

Normative Data of Ulnar Length in Pediatric Indian Population

M.R. Thatte[1] Pawan Agarwal[2] Anil Bhat[3] P. Umar Farooq Baba[4] Bipin Ghanghurde[5] Mithun Pai[2] Harsh R. Shah[1] Onkar Kulkarni[5] Anand Dugad[5] Mansi Saraf[6] Rajesh B.[6] Raheeb Ahmad Shah[4] Jagmoah Singh Dhakar[7] Dhananjaya Sharma[6]

[1] Department of Plastic Surgery, Bombay Hospital, Mumbai, Maharashtra, India
[2] Department of Plastic Surgery, Netaji Subhash Chandra Bose Medical College, Jabalpur, Madhya Pradesh, India
[3] Department of Hand Surgery, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, Karnataka, India
[4] Department of Plastic Surgery, Sher-I-Kashmir Institute of Medical Sciences, Srinagar, Jammu and Kashmir, India
[5] Department of Plastic Surgery, Wadia Children's Hospital, Mumbai, Maharashtra, India
[6] Department of Surgery, Netaji Subhash Chandra Bose Government Medical College, Jabalpur, Madhya Pradesh, India
[7] Department of Community Medicine, Netaji Subhash Chandra Bose Government Medical College, Jabalpur, Madhya Pradesh, India

Address for correspondence Pawan Agarwal, MCh, FRCS, 292/293, Napier Town, Jabalpur, Madhya Pradesh 482003, India (e-mail: drpawanagarwal@yahoo.com).

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Abstract

Objective The aim of this study is to create clinical normative data for ulnar length in the pediatric population and to demonstrate the usefulness of such data.

Materials and Methods A nationally representative sample of healthy children aged 1 day to 18 years from five centers across India was collected. The percutaneous length of the ulna was measured by using a certified calibrated measuring tape across all centers. Other variables such as geographical domicile, dominance of the hand, age, body mass index (BMI), and sex of the child were also recorded.

Results In total, 1,300 children (883 males and 417 females) with age ranging from 1 day to 18 years were included in the study. Gradual lengthening of the ulna was seen in both male and female children with increasing age without a significant difference; however, at 8, 9, and 14 years, there was significant lengthening of the ulna in males compared with females although the difference was statistically insignificant at 17 years. Apropos BMI at 16 years of age, a longer ulna was observed in obese children. Later on, at 18 years, the difference in ulnar length was insignificant. South Indian children had a significantly longer ulna up to the age of 11 years, but after the age of 11 years there was no difference in ulnar length in all zones. The length of the ulna was not affected by hand dominance. There was good inter-observer agreement and reliability between different centres. Age, zone, and gender, had statistically significant effect on the length of ulna but BMI and hand dominance was not significant.

Keywords
- normative data
- ulnar length
- pediatric
- Indian population

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Conclusion This multicentric study provides normative data on the percutaneous length of the ulna in the Indian pediatric population. Gradual lengthening of the ulna was seen in all children with increasing age. The length of the ulna was significantly more in male, obese, and in South Indian children. However, except for age, other factors become insignificant at maturity.

Introduction

The length of the ulna has been commonly used for measurement of the growth of the forearm.[1,2] Normative data on ulnar length allow an estimation of the effect of congenital, traumatic, neoplastic, or metabolic abnormalities on the forearm growth and function.[3] The measurements would also help in developing age- and population-specific orthopaedic implants, intraoperative decision-making, and studying and validating the functional outcomes of the forearm bones both before and after surgical reconstruction. The length of the ulna can also be used as a surrogate marker to calculate the height and predict pulmonary function in children.[4,5] Therefore, knowledge of the normal dimensions of the ulna is vital for anatomists, hand surgeons, forensic scientists, and anthropological archeologists. There are multiple studies analyzing the ulnar length; however, almost all of them have been done in adults, dry bone, or in cadavers and/or have been done in the western population.[6,7] There are no Indian normative data of ulnar length measurement in the pediatric age groups; therefore, the aim of this study is to establish a normal database of the length of the ulna in different age groups and gender belonging to a sample of the pediatric population in India.

Materials and Methods

This is an observational, prospective, multicentric study conducted over a period of 10 months from January to October 2022 in the Department of Plastic, Hand and Reconstructive Surgery at five centers (Mumbai, Chennai, Manipal, Jabalpur, and Srinagar) across India. A total of 1,300 normal children and 2,600 ulnae were sampled for this study. All departments involved took ethical committee permissions from their respective hospitals. Informed consent from parents/legal guardians and children's assent where appropriate was taken for measurement.

All children, aged 1 day to 18 years, attending the hand surgery, plastic surgery, and pediatric medicine outpatient department were sampled. The children were apparently healthy and without physical deformity. Siblings coming along with a patient were also recruited after adequate consent of the parents/assent of the child. Equal representation of the sexes was attempted across all age groups. Children with developmental disorders affecting the musculoskeletal development, systemic malignancies, past history of bony injuries, arthritic changes of any etiology, infection, or bone or soft-tissue disease were excluded.

The sample size was calculated using the level of precision (sampling error-*d*) to be 5% (0.05) with a 95% confidence level, and the *Z* score (at 5%) was 1.96. The degree of variability (*P*) was taken as 0.5 considering the Indian populations to be highly heterogeneous and diverse. According to the formula, the sample size was 384 ulnae per center. The proposed sample size was taken as 400 ulnae in 200 participants per center.

Percutaneous length of the ulna was measured using a certified calibrated measuring tape (Cescorf anthropometric tape manufactured by NutriActiva, LLC, Bloomington, MN, United States), which was supplied to all units, and all the principal investigators and co-investigators of the partner center were trained on the methodology through online meetings. The percutaneous length of the ulna was measured with the elbow flexed and palm placed over the opposite shoulder and marking the tips of the olecranon and styloid processes of the ulna. The distance between the proximal and distal landmarks was measured using a measuring tape. Length was measured independently on both the right and left sides (►**Figs. 1** and **2**). All measurements were taken between 11 a.m. and 3 p.m. to eliminate diurnal variations. Each measurement was taken by two observers separately in centimeters and an average of two readings was taken to avoid any errors in measurement. An officially certified and calibrated measuring tape was used by all associated centers. Apart from the percutaneous length of the ulna, geographical domicile, vis-à-vis, part of India (north, central, west, and south zones), dominance of the hand with the age and sex of the child, height, and weight were also recorded. The body mass index (BMI) was calculated and the child was categorized as normal (BMI of 18.5–24.9), overweight (BMI of 25–29.9), or obese (BMI $\geq$30). In addition, the mother tongue

Fig. 1 Measurement of the percutaneous length of the right ulna with a calibrated measuring tape.

Fig. 2 Measurement of the percutaneous length of the left ulna with a calibrated measuring tape.

was noted from a population diversity point of view in the Indian context.

The data were analyzed using IBM-SPSS version 23.0 and expressed in sample mean and standard deviation. A *p*-value less than 0.05 was considered statistically significant. The statistical methods used were nonparametric tests Mann–Whitney *U* test and Kruskal–Wallis one way analysis of variance for more than two variables. Intra- and interobserver comparisons were done using intraclass correlation coefficient (ICC) test. An ICC value between 0.75 and 0.90 was considered as good intraclass reliability. Any bias was eliminated by using two independent measurements by different examiners and multiple regression analysis with a variance inflation factor (VIF).

Results

A total of 1,300 children (2,600 ulnae) were included in the study. The demographic data, such as gender, age, BMI, hand dominance, and geographical domicile, are shown in ►**Table 1** (►**Fig. 3**).

Gradual lengthening of the ulna was seen in all children with increasing age with a significant difference; till 7, 10 and between 13–14 years. After 14 years though the ulna length continues to grow but did not achieve statistical significance. ($p = 0.816$ and 0.956; ►**Table 2** and ►**Fig. 4**).

The gradual lengthening of the ulna was seen in both male and female children with increasing age without significant difference; however, at the age of 8, 9, and 14 years, there was significant lengthening of the ulna in males compared with females although the difference was statistically insignificant at 17 years ($p = 0.218$; ►**Table 3**; ►**Fig. 4**).

The mean length of the ulna in different age groups according to the geographical zone is shown in ►**Table 4**. South Indian children had a statistically significantly larger length of the ulna up to 11 years of age; however, such difference was not seen after 11 years of age ($p = 1.00$ and 0.317; ►**Table 4**; ►**Fig. 4**).

The mean length of the ulna, vis-à-vis, BMI in different age groups is shown in ►**Table 5**. The mean length of the ulna increases in normal, overweight, or obese children similarly up to 15 years of age; however, a significantly longer ulna was seen in obese children at the age of 16 years ($p = 0.029$; ►**Table 5**; ►**Fig. 4**). Nevertheless, the proportion of obese children was only 5%. Later on, at the age of 18 years, the difference in ulnar length was insignificant ($p = 0.48$).

The mean length of the ulna according to hand dominance in different age groups is shown in ►**Table 6**. It also shows that the length of the ulna was not affected by hand dominance ($p = 0.796$; ►**Table 6**; ►**Fig. 4**). The measurement of ICC showed excellent to good inter-observer agreement reliability (Inter-class correlation coefficient for right (0.85, 95% CI–0.66–0.99, p– > 0.05) and left (0.70, 95% CI 0.47–0.99, p– > 0.05) and reliability between different centres (Intra –class correlation coefficient for right (0.91, 95% CI–0.90–0.92, p– > 0.05) and left (0.80, 95% CI 0.77–0.82, p– > 0.05) respectively.

On multiple regression analysis, the geographical zone, gender, and age were statistically significant, but BMI and hand dominance were not significant for both upper limbs (►**Table 7**; ►**Fig. 5**).

The ulnar length-to-height ratio of the children was assessed and out of 2,100 ulnae ($n = 1{,}050$), 2,032 ulnae ($n = 1{,}016$) fell between 0.1 and 0.2. The remaining 34 patients had a ratio of less than 0.10 and greater than 0.20 (►**Table 8**).

Discussion

Our multicentric study provides normative data on the percutaneous length of the ulna in the Indian pediatric population across different ages, genders, BMI, and geographical zones. To our knowledge, this is the first study to report normative data on ulnar length in the pediatric Indian population. Such data are essential for describing the natural history of disease, developing standards of care, establishing illness classifications, and evaluating the clinical significance of therapeutic interventions.[8–10]

There are no widely accepted objective assessment tools for estimation after surgical reconstruction of congenital and traumatic forearm abnormalities. Normative data of the forearm act as the gold standard reference for evaluating the clinical outcome of therapeutic interventions, comparison of treatment, and follow-up with that of normative individuals matched for their age, gender, and different congenital and traumatic anomalies of the hand and forearm.[9,11,12] Randomized clinical trials (RCTs) can also establish the statistical significance of treatment efficacy and effectiveness of outcomes at "beyond-chance" levels. However, conducting RCT for surgical treatment may not be feasible or ethical.[13]

The utility of normative data for ulnar length would be in congenital radial dysplasia and fractures involving the physis of the distal forearm. Radial longitudinal deficiency (RLD) or radial club hand account for 25 to 33% of all upper limb deficiencies, with an incidence that varies from 1 in 30,000 to 100,000 live births in different studies. The prevalence has

Table 1 Showing frequency distribution of population

Age (y)	Age (*N*)	Gender		BMI			Hand dominance			Zone			
		Male	Female	Normal	Over weight	Obese	Right	Left	Ambidextrous	Central	North	West	South
		N (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)	*N* (%)
1	303 (23.3)	208 (68.6)	95 (31.4)	275 (98.2)	2 (0.7)	3 (1.1)	116 (96.7)	0	4 (3.3)	106 (35.0)	19 (6.3)	140 (46.2)	38 (12.5)
2	163 (12.5)	116 (71.2)	47 (28.8)	144 (99.3)	1 (0.7)	0	104 (80.6)	5 (3.9)	20 (15.5)	78 (47.9)	18 (11.0)	47 (28.8)	20 (12.3)
3	158 (12.5)	110 (69.6)	48 (30.4)	136	0	0	128 (87.7)	4 (2.7)	14 (9.6)	77 (48.7)	22 (13.9)	42 (26.6)	17 (10.8)
4	94 (7.2)	62 (66.0)	32 (34.0)	79 (97.5)	0	2 (2.5)	83 (89.2)	6 (6.5)	4 (4.3)	31 (33.0)	13 (13.8)	36 (38.3)	14 (14.9)
5	113 (8.7)	80 (70.8)	33 (29.2)	99 (99.0)	0	1 (1.0)	105 (93.8)	1 (0.9)	6 (5.4)	55 (48.7)	13 (11.5)	30 (26.5)	15 (13.3)
6	74 (5.7)	54 (73.0)	20 (27.0)	51 (98.1)	1 (1.9)	0	72 (97.3)	1 (1.4)	1 (1.4)	21 (28.4)	22 (29.7)	17 (23.0)	14 (18.9)
7	56 (4.3)	35 (62.5)	21 (37.5)	37	0	0	54 (98.2)	1 (1.8)	0	8 (14.3)	19 (33.9)	20 (35.7)	9 (16.1)
8	34 (2.6)	25 (73.5)	9 (26.5)	27	0	0	33 (97.1)	0	1 (2.9)	3 (8.8)	7 (20.6)	13 (38.2)	11 (32.4)
9	56 (4.3)	33 (58.9)	23 (41.1)	41	0	0	55	0	0	5 (8.9)	15 (26.8)	28 (50.0)	8 (143)
10	48 (3.7)	26 (54.2)	22 (45.8)	33 (97.1)	1 (2.9)	0	45 (93.8)	3 (6.3)	0	11 (22.9)	14 (29.2)	14 (29.2)	9 (18.8)
11	28 (2.2)	15 (53.6)	13 (46.4)	17	0	0	27 (96.4)	1 (3.6)	0	0	11 (39.3)	8 (28.6)	9 (32.1)
12	42 (3.2)	29 (69.0)	13 (31.0)	22 (91.7)	1 (4.2)	1 (4.2)	41 (97.6)	1 (2.4)	0	0	18 (42.9)	10 (23.8)	14 (33.3)
13	37 (2.8)	22 (59.5)	15 (40.5)	25 (92.6)	2 (7.4)	0	36 (97.3)	1 (2.7)	0	3 (8.1)	10 (27.0)	19 (51.4)	5 (13.5)
14	33 (2.5)	23 (69.6)	10 (30.3)	15 (93.8)	0	1 (6.3)	33	0	0	2 (6.1)	17 (51.5)	9 (27.3)	5 (15.2)
15	19 (1.5)	14 (73.7)	5 (26.3)	7 (87.5)	0	1 (12.5)	19	0	0	0	11 (57.9)	6 (31.6)	2 (10.5)
16	24 (1.8)	18 (75.0)	6 (25.0)	11 (78.6)	0	3 (21.4)	24	0	0	0	10 (41.7)	6 (25.0)	8 (33.3)
17	10 (0.8)	6 (60.0)	4 (40.0)	4 (80.0)	1 (20.0)	0	10	0	0	0	5 (50.0)	3 (30.0)	2 (20.0)
18	8 (0.5)	8 (100)	0	0	0	2	8	0	0	0	6 (85.7)	2 (14.3)	0

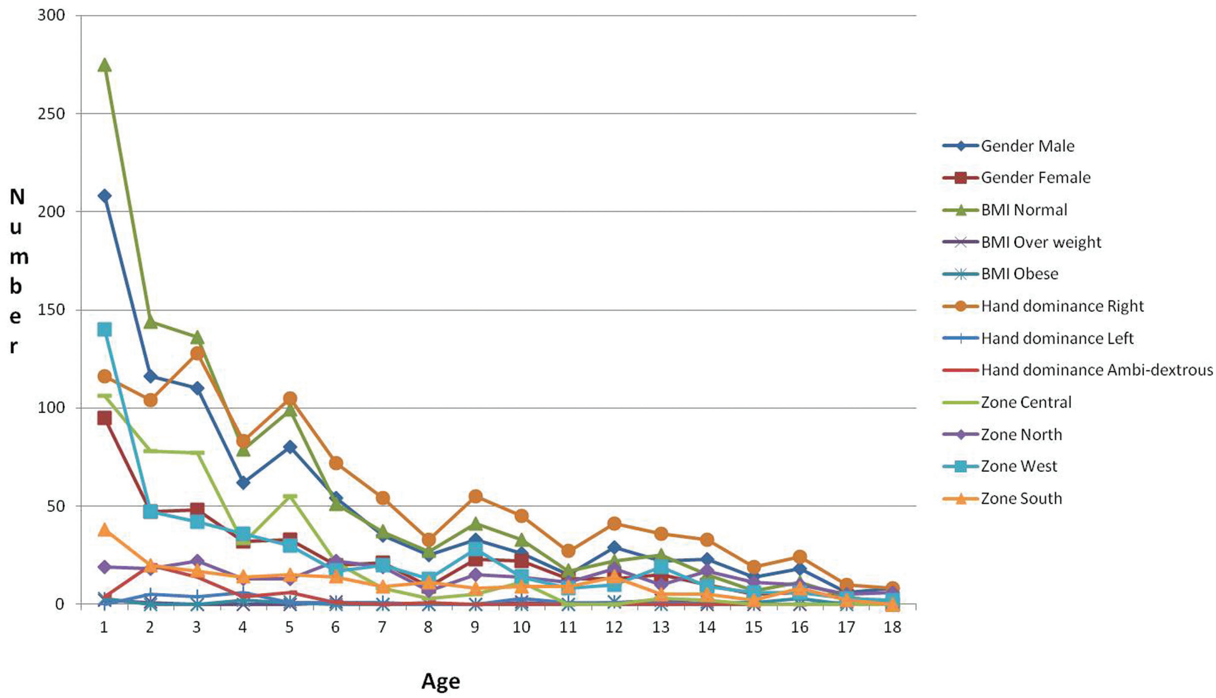

Fig. 3 Distribution frequency of population.

Table 2 Mean length of the ulna according to the Age

Age (y)	Mean right ulnar length (cm)	Mean left ulnar length (cm)	Right p-Value[a]	Left p-Value[a]
	Mean ± SD	Mean ± SD		
1	9.69 ± 2.68	9.56 ± 1.94	0.000	0.000
2	12.13 ± 2.84	12.15 ± 3.23	0.002	0.005
3	12.91 ± 1.76	12.90 ± 1.68	0.000	0.000
4	14.56 ± 2.27	14.35 ± 1.86	0.021	0.152
5	15.06 ± 2.10	15.04 ± 2.11	0.000	0.000
6	16.88 ± 4.10	16.49 ± 1.40	0.025	0.381
7	17.26 ± 1.56	17.35 ± 1.56	0.001	0.003
8	18.89 ± 2.42	18.95 ± 2.46	0.442	0.572
9	19.19 ± 2.24	19.31 ± 2.27	0.054	0.113
10	19.97 ± 2.48	20.13 ± 2.55	0.000	0.001
11	21.94 ± 1.73	22.04 ± 1.74	0.115	0.345
12	22.52 ± 2.33	22.87 ± 1.71	0.763	0.475
13	22.92 ± 2.34	23.02 ± 2.37	0.007	0.030
14	24.20 ± 1.92	24.42 ± 1.91	0.029	0.031
15	25.74 ± 2.04	25.78 ± 2.06	0.716	0.986
16	25.76 ± 1.90	22.54 ± 2.73	0.861	0.690
17	25.39 ± 2.00	25.69 ± 2.23	0.151	0.211
18	26.91 ± 1.41	27.21 ± 1.38	0.816	0.956

[a]By Mann–Whitney U test.

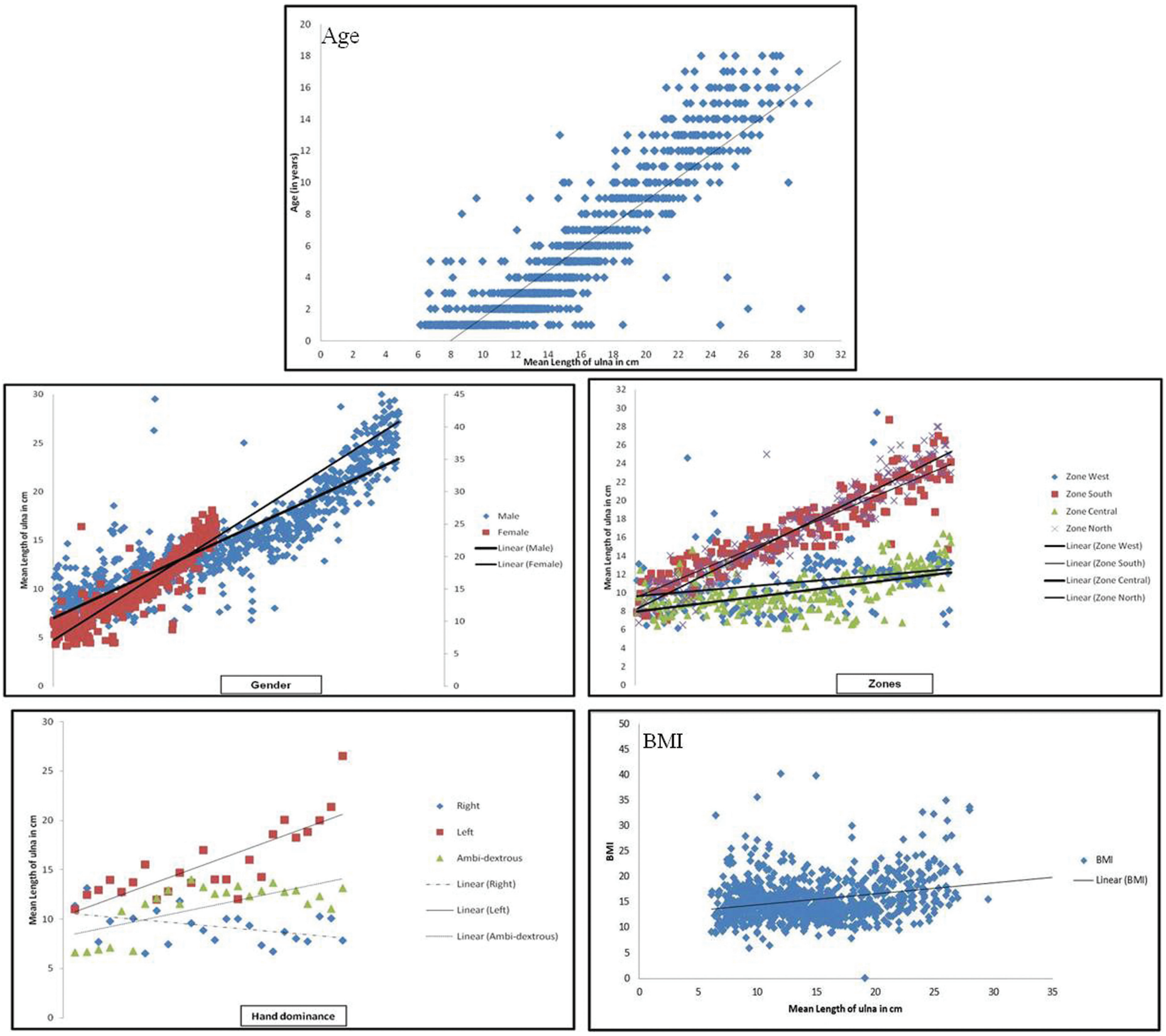

Fig. 4 Correlation of age, gender, geographical zones, body mass index (BMI), and hand dominance with the mean length of the ulna.

been reported to be higher in boys, at a ratio of 3:2, and they are bilateral in 38 to 58% of cases.[14,15] Different surgeries have been described for correction of radial club hand such as "centralization" or "radialization" of the wrist.[16,17] A study by Bhat et al showed at long-term follow-up after radialization that the length of the affected ulna was 56% of the length of the normal ulna.[18] Thatte and Mehta found that the mean ulnar length was 69 and 62%, respectively, of the contralateral ulna at 5 years of follow-up in 21 cases of unilateral and bilateral RLD operated by distraction, radialization, and Evan's bilobed flap.[19] Other surgical options include cubitocarpal arthrodesis and transfer of the second metacarpophalangeal joint. However, the results of these surgeries were variable with poor growth of the ulna and issue of the limb length discrepancy at skeletal maturity. The nonsurgically treated group attained 64% of normal ulnar length, whereas the centralization group attained 48 to 58% of normal ulnar length.[11] Therefore, the normative data of the ulnar length are very useful in determining the natural history of RLD and comparison of results of different techniques. This is especially true in a treated cohort with bilateral radial dysplasia where an opposite limb is not available for comparison.

Fractures involving the physis of the distal forearm are very common in children, which may lead to premature physeal arrest in approximately 55% cases and significant growth disturbance. Growth disturbance can occur in the forms of growth arrest or overgrowth.[20,21] Thus, the availability of normative data on ulnar length is important for understanding the natural history and complications that may result from an injury commonly encountered in orthopaedic practice. In cases of unilateral involvement, hand function can be compared with the normal side as the human body is bilaterally symmetrical. However, asymmetries may be found for an individual, making it impractical to compare with the contralateral limb, again emphasizing the utility of the normative data.[22] Another utility of normative data is that normal variants can cause significant anxiety to parents, who present the child for assessment and seek reassurance. Knowing normal variants can avoid unnecessary referrals,

Table 3 Mean length of the ulna according to gender

Age (y)	Mean left ulnar length (cm)		*p*-Value	Mean right ulnar length (cm)		*p*-Value[a]
	Male	Female		Male	Female	
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
1	9.75 ± 2.21	9.58 ± 3.51	0.117	9.7 ± 2.04	9.26 ± 1.66	0.132
2	12.3 ± 3.21	11.72 ± 1.51	0.111	12.32 ± 3.69	11.75 ± 1.55	0.145
3	13.01 ± 1.77	12.69 ± 1.71	0.620	12.97 ± 1.62	12.75 ± 1.8	0.857
4	14.46 ± 1.99	14.77 ± 2.77	0.765	14.39 ± 2.05	14.27 ± 1.42	0.746
5	15 ± 2.38	15.21 ± 1.2	0.693	14.95 ± 2.38	15.27 ± 1.22	0.972
6	16.97 ± 4.74	16.61 ± 1.38	0.630	16.41 ± 1.44	16.71 ± 1.29	0.550
7	17.47 ± 1.52	16.92 ± 1.61	0.253	17.55 ± 1.45	17.02 ± 1.7	0.267
8	19.4 ± 1.69	17.46 ± 3.54	0.049	19.51 ± 1.74	17.38 ± 3.47	0.033
9	19.79 ± 1.95	18.33 ± 2.39	0.005	19.9 ± 1.96	18.45 ± 2.46	0.012
10	20.18 ± 2.48	19.72 ± 2.52	0.828	20.1 ± 3.04	20.16 ± 1.89	0.548
11	21.76 ± 1.64	22.16 ± 1.86	0.363	21.86 ± 1.77	22.25 ± 1.76	0.525
12	22.8 ± 1.9	21.89 ± 3.08	0.536	22.91 ± 1.87	22.8 ± 1.33	0.727
13	23.19 ± 2.25	22.51 ± 2.48	0.511	23.28 ± 2.23	22.63 ± 2.59	0.636
14	24.8 ± 1.75	22.83 ± 1.62	0.014	24.99 ± 1.82	23.12 ± 1.45	0.004
15	26.01 ± 2.2	25.00 ± 1.45	0.343	26.04 ± 2.23	25.06 ± 1.44	0.391
16	26.18 ± 1.78	24.48 ± 1.77	0.	25.87 ± 2.95	24.55 ± 1.82	0.476
17	25.78 ± 2.59	24.8 ± 0.29	0.218	26.06 ± 2.91	25.13 ± 0.25	0.218
18	26.91 ± 1.41	NA	NA	27.21 ± 1.38	NA	NA

Abbreviations: NA, data not available; SD, standard deviation.
[a]Mann–Whitney *U* test.

which resolve spontaneously with normal growth and development without intervention.[23]

The growth of limbs is dependent on the age, sex, and race of the individual. The length of the ulna increases with age, and there is a strong correlation between the length of the ulna and age; however, the extent of lengthening is still unclear.[24] In our study, we found a linear growth of the ulna with increasing age. Asymmetries in the length of the long bones due to hand preference can be attributed to mechanical stress and strain or to genetic or hormonal factors. However, the effect of hand preference is negated because individuals frequently employ both hands to perform many tasks.[25] Our study also found no difference in growth rate in both hands. The final length of the long bones is determined by estrogen as it is responsible for fusion of their epiphyseal growth plates. Hence, earlier maturation may lead to premature termination of long bone growth, resulting in a shorter length of the long bones in female children.[26] Our study also showed that the ulnar length was greater in males; however, the difference was negated at maturity.

Ulnar length can be used as a surrogate marker for estimation of height, gender, and pulmonary function in children. There are many studies that showed definite a correlation between ulnar length and height and gender of the individual.[7,27,28] We have also correlated the ulna length with height of children and data showed that ulna length and height ratio falls between 0.10–0.20 in ~97% children. Therefore ratio between 0.10–0.20, is within the normal range for pediatric age group and we termed this as Indian ratio.

The ulna is a subcutaneous bone that is easily accessible. This makes the ulna a perfect anatomical structure for taking anthropometric measurements in a large population. We used a calibrated measuring tape to estimate the ulnar length. Alternative methods for measurement that can be used include digital sliding calipers, forearm X-ray, xerox copies of the forearm, and segmometer using dual-energy X-ray absorptiometry (DXA). However, a bias was observed with segmometer measurements, which overestimate the DXA measurements. This is likely due to the inclusion of soft tissue when using a segmometer as opposed to a direct bone measurement.[29,30]

The specific limitation of the study is the nonuniform sample size leading to potential bias due to sampling error. The major drawbacks with normative data are difficulty in determining to what extent data from a population could be applied to determine individual normative data.[31] In general, the normative data should be applied with caution in clinical decision-making and should be used with correlated variables, and mainly when the "extreme values" correspond with poor performance or with symptoms.[32] Furthermore, the normative values and ranges should be interpreted in the context of limitations associated with instrument and

Table 4 Mean length of the ulna according to the zone

Age (y)	Mean left ulnar length (cm)				*p*-Value[a]	Mean right ulnar length (cm)				*p*-Value[a]
	Zone					Zone				
	Central	North	West	South		Central	North	West	South	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
1	10.29 ± 3.92	9.79 ± 1.62	9.13 ± 1.55	10.04 ± 1.6	0.006	9.9 ± 2.42	9.86 ± 1.61	9.14 ± 1.57	10.01 ± 1.54	0.005
2	12.3 ± 3.73	11.9 ± 1.76	11.9 ± 1.78	12.23 ± 1.27	0.971	12.31 ± 4.34	12.01 ± 1.83	11.89 ± 1.76	12.3 ± 1.3	0.820
3	12.45 ± 1.78	13.22 ± 1.12	13.21 ± 2.02	13.85 ± 0.84	0.002	12.32 ± 1.7	13.37 ± 1.19	13.36 ± 1.79	13.82 ± 0.71	0.001
4	14.55 ± 3.02	13.75 ± 0.76	14.6 ± 1.38	15.25 ± 3.02	0.083	13.78 ± 1.79	13.92 ± 0.82	14.61 ± 1.43	15.32 ± 3	0.076
5	14.8 ± 2.42	15.39 ± 1.08	14.98 ± 1.38	15.9 ± 2.58	0.106	14.67 ± 2.42	15.68 ± 0.98	15.01 ± 1.31	15.93 ± 2.63	0.084
6	16 ± 1.2	16.27 ± 1.5	18.43 ± 8.18	17.25 ± 1.05	0.065	15.97 ± 1.2	16.41 ± 1.55	16.53 ± 1.5	17.36 ± 0.93	0.036
7	16.97 ± 0.93	17.18 ± 1.32	17.09 ± 2.04	18.06 ± 1.18	0.282	16.9 ± 1	17.33 ± 1.41	17.21 ± 1.93	18.11 ± 1.27	0.259
8	18.22 ± 0.77	18.69 ± 2.08	18.13 ± 3.39	20.09 ± 0.58	0.152	18.22 ± 0.78	18.99 ± 2.23	18.2 ± 3.4	20 ± 0.89	0.268
9	16.99 ± 2.43	19.52 ± 1.25	19.16 ± 2.63	20.06 ± 1.32	0.063	17.11 ± 2.46	19.83 ± 1.28	19.17 ± 2.66	20.19 ± 1.25	0.060
10	18.87 ± 2.01	20.19 ± 3.41	20.47 ± 1.69	20.17 ± 2.32	0.596	18.39 ± 2.64	21.08 ± 2.8	20.48 ± 1.72	20.22 ± 2.44	0.229
11	NA	22.57 ± 1.36	20.64 ± 1.35	22.33 ± 1.94	0.034	NA	22.94 ± 1.43	20.55 ± 1.31	22.28 ± 1.68	0.019
12	NA	22.65 ± 1.97	21.5 ± 3.5	23.07 ± 1.53	0.570	NA	22.88 ± 1.96	22.69 ± 1.75	23 ± 1.41	0.994
13	22.12 ± 0.9	22.62 ± 3.46	22.75 ± 1.83	24.6 ± 1.52	0.130	22.07 ± 0.95	22.91 ± 3.56	22.84 ± 1.9	24.5 ± 1.32	0.179
14	21.28 ± 0.16	24.37 ± 2.03	24.37 ± 1.57	24.5 ± 1.87	0.213	21.42 ± 0.45	24.78 ± 2.06	24.2 ± 1.5	24.8 ± 1.48	0.165
15	NA	25.99 ± 2.57	25.37 ± 1.19	25.5 ± 0.71	0.818	NA	26.17 ± 2.57	25.33 ± 1.13	25 ± 0	0.672
16	NA	26.53 ± 1.84	24.98 ± 1.65	25.38 ± 2	0.324	NA	25.97 ± 3.74	25.06 ± 1.7	25.38 ± 2	0.364
17	NA	26.16 ± 2	25.02 ± 2.34	24 ± 1.41	0.516	NA	26.7 ± 2.22	25.12 ± 2.35	24 ± 1.41	0.353
18	NA	26.72 ± 1.44	28.1 ± 0.0	NA	1.00	NA	27.1 ± 1.48	27.9 ± 0.0	NA	0.317

Abbreviations: BMI, body mass index; NA, data not available; SD, standard deviations.
[a]Kruskal–Wallis test.

Table 5 Mean length of the ulna according to BMI

Age (y)	Mean left ulnar length (cm)			p-Value[a]	Mean right ulnar length (cm)			p-Value[a]
	BMI				BMI			
	Normal	Overweight	Obese		Normal	Overweight	Obese	
	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	
1	9.7 ± 2.77	9.5 ± 0.71	9.49 ± 2.8	0.994	9.54 ± 1.97	9.5 ± 0.71	9.5 ± 2.78	0.985
2	12.17 ± 2.96	11 ± 0.0	NA	0.304	12.18 ± 3.37	11 ± 0.0	NA	0.333
3	12.86 ± 1.84	NA	NA	NA	12.83 ± 1.74	NA	NA	NA
4	14.71 ± 2.43	NA	14 ± 1.41	0.493	14.42 ± 1.99	NA	14.25 ± 1.06	0.772
5	15 ± 2.2	NA	17 ± 0.0	0.117	14.94 ± 2.21	NA	17 ± 0.0	0.166
6	17.11 ± 4.84	18 ± 0.0	NA	0.271	16.5 ± 1.34	18 ± 0.0	NA	0.243
7	17.3 ± 1.69	NA	NA	NA	17.36 ± 1.65	NA	NA	NA
8	18.94 ± 2.54	NA	NA	NA	18.94 ± 2.55	NA	NA	NA
9	19.07 ± 2.51	NA	NA	NA	19.12 ± 2.53	NA	NA	NA
10	19.93 ± 2.04	18 ± 0.0	NA	0.168	19.79 ± 2.39	18 ± 0.0	NA	0.202
11	21.54 ± 1.85	NA	NA	NA	21.46 ± 1.72	NA	NA	NA
12	22.28 ± 2.67	23.9 ± 0.0	24 ± 0.0	0.386	22.77 ± 1.56	24.05 ± 0.0	24 ± 0.0	0.281
13	22.92 ± 1.78	24.4 ± 2.59	NA	0.354	22.95 ± 1.75	24.47 ± 3.16	NA	0.354
14	23.98 ± 1.9	NA	24.73 ± 0	0.914	23.97 ± 1.74	NA	25.13 ± 0.0	0.329
15	25.29 ± 1.07	NA	26.2 ± 0	0.272	25.15 ± 1	NA	25.97 ± 0.0	0.264
16	24.63 ± 1.49	NA	27.33 ± 1.15	0.029	24.67 ± 1.53	NA	27.33 ± 1.15	0.029
17	24.26 ± 1.98	26 ± 0.0	NA	0.480	24.34 ± 2.03	26 ± 0.0	NA	0.480
18	NA	NA	28.1 ± 0.0	NA	NA	NA	27.9 ± 0.0	NA

Abbreviations: BMI, body mass index; NA, data not available; SD, standard deviation.
[a]Kruskal–Wallis test.

Table 6 Mean length of the ulna according to hand dominance

Age (y)	Mean ulnar length (cm)		p-Value[a]
	Hand dominance		
	Dominant hand: 993 right and 24 left	Nondominant hand: 993 left and 24 right	
	Mean ± SD	Mean ± SD	
1	10.18 ± 2.78	10.34 ± 3.76	0.976
2	12.30 ± 2.67	12.29 ± 3.27	0.903
3	12.89 ± 1.64	12.91 ± 1.70	0.910
4	14.41 ± 1.94	14.53 ± 2.33	0.889
5	15.04 ± 2.14	15.06 ± 2.14	0.969
6	16.99 ± 4.81	16.88 ± 4.12	0.888
7	17.40 ± 1.38	17.36 1.40	0.917
8	19.22 ± 1.64	19.19 ± 1.65	0.903
9	19.42 ± 1.84	19.36 ± 1.84	0.823
10	20.04 ± 2.42	19.76 ± 2.47	0.930
11	21.99 ± 1.72	21.94 ± 1.72	0.737
12	22.69 ± 1.86	22.52 ± 2.32	0.858
13	22.96 ± 2.34	22.88 ± 2.29	0.825
14	24.31 ± 1.89	24.20 ± 1.91	0.817
15	25.76 ± 2.04	25.74 ± 2.04	0.953
16	25.65 ± 2.13	25.75 ± 1.89	0.992
17	25.53 ± 2.11	25.38 ± 2.00	0.733
18	27.06 ± 1.38	26.91 ± 1.41	0.796

[a]Kruskal–Wallis test.

Table 7 Multiple regression association of the right and left hands with zone, gender, hand dominance, age, and BMI

	Model	Unstandardized coefficients		β	*p*-Value	95% CI	Collinearity statistics	
		B4	SE				Tolerance	VIF
Right hand	Zone	0.579	0.083	0.144	0.001	0.416–0.742	0.634	1.577
	Gender	−0.413	0.172	−0.040	0.017	−0.751 to −0.075)	0.983	1.087
	Hand dominance	−0.508	0.171	−0.052	0.003	−0.843 to −0.173)	0.868	1.152
	Age (mo)	0.077	0.002	0.793	0.001	0.073–0.081	0.642	1.558
	BMI (kg/m^2)	−0.001	0.013	−0.001	0.931	−0.026 to 0.024	0.942	1.062
Left hand	Zone	0.573	0.134	0.123	0.001	0.310–0.836	0.634	1.577
	Gender	−0.476	0.278	−0.039	0.087	−1.022 to 0.069	0.983	1.017
	Hand dominance	−0.681	0.275	−0.061	0.014	−1.222 to −0.141)	0.868	1.152
	Age (mo)	0.076	0.003	0.679	0.001	0.070–0.082	0.642	1.558
	BMI (kg/m^2)	−0.014	0.021	−0.016	0.506	−0.054–0.027	0.942	1.062

Abbreviations: BMI, body mass index; CI, confidence interval; SE, standard error; VIF, variance inflation factor.
Note: Multiple regression model of the right ($r = 0.88$) and left hands ($r = 0.75$) with demographic variables was strongly positive on both sides. Acceptable tolerance range is <0.10 and VIF <10.

techniques and limitations associated with using each technique used for collecting normative data. We have used a calibrated measuring tape to avoid this pitfall of measuring instrument. Regardless of the limitations, the clinical norms are useful guidelines for clinical practice. The strength of the study includes power and appropriate sample size, appropriateness of demographic characteristics, and use of appropriate instrument for measurement.

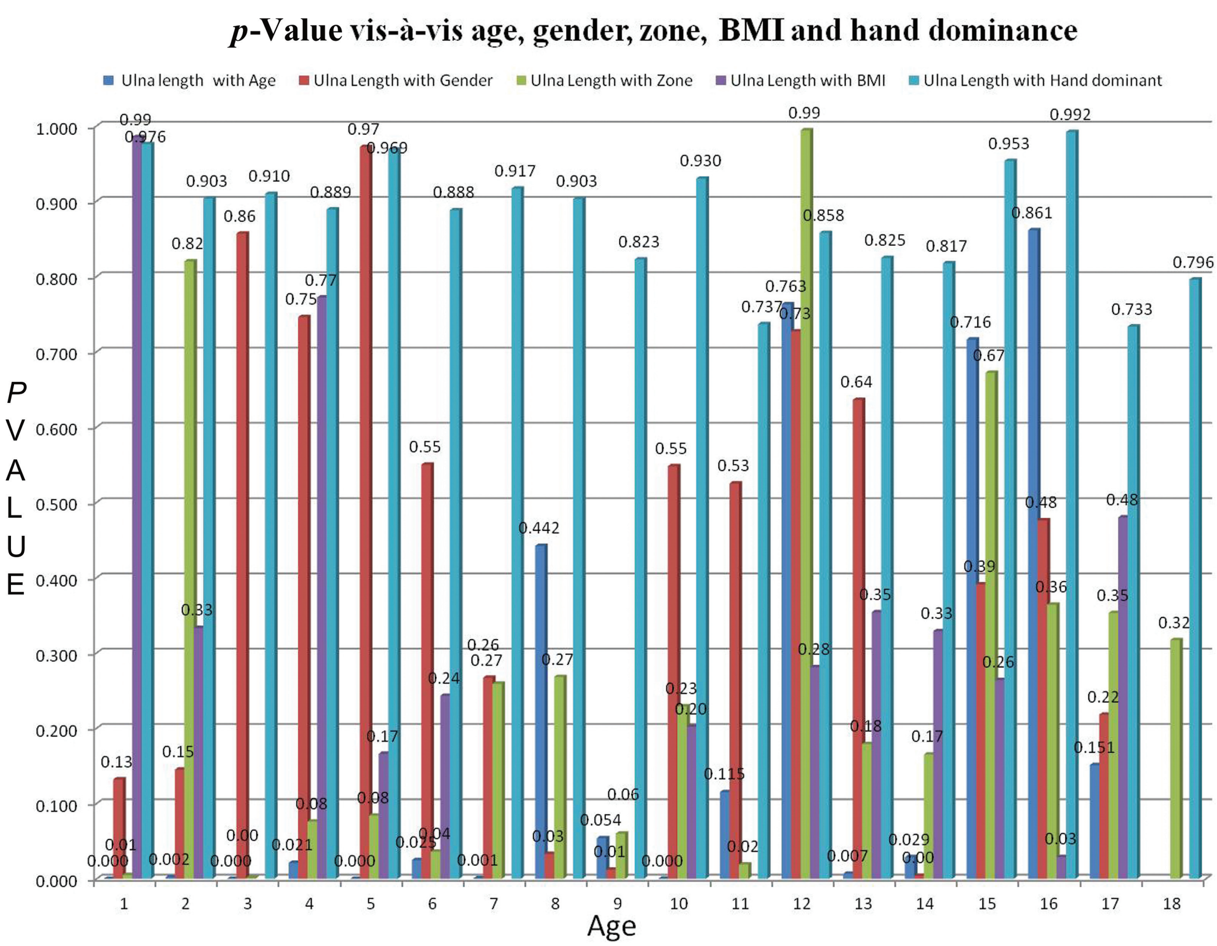

Fig. 5 The *p*-value vis-à-vis age, gender, zone, body mass index (BMI), and hand dominance.

Table 8 Ratio of the ulnar length and height of children (Indian ratio)

Range	Indian ratio			
	Left ulnar length:height		Right ulnar length:height	
	Frequency	%	Frequency	%
0.10–0.20	1,016	96.8	1,016	96.8
<0.10 and >0.20	34	3.2	34	3.2
Total	1,050	100	1,050	100
Mean (SD)	0.156 (0.053)		0.156 (0.053)	

Abbreviation: SD, standard deviation.

Conclusion

This multicentric study provides normative data on percutaneous length of the ulna in the Indian pediatric population. Gradual lengthening of ulna was seen in all children with increasing age however; after 14 years though the ulna length continues to grow further but did not achieve statistical significance. The length of ulna was significantly more in males, obese and in South Indians. However, except for age, other factors become insignificant at maturity. These data may serve as a guide to predict response to treatment and compare different treatment functional outcomes of congenital, traumatic, neoplastic, and metabolic abnormalities affecting the forearm bones.

Authors' Contributions

M.R.T. contributed to conceptualization, data collection, data analysis, and manuscript writing and editing. P.A. and A.B. contributed to data collection, data analysis, and manuscript writing and editing. P.U.F.B., B.G., M.P., H.R.S., O.K., and A.D. contributed to data collection, data analysis, and manuscript writing. M.S., R.B., and R.A.S contributed to data collection and data analysis. J.S.D. contributed to data analysis. D.S. contributed to manuscript writing and editing.

Ethical Approval

This study was approved by the institutional review board. All centers involved in study obtained institutional ethics committee clearance.

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Conflict of Interest

None declared.

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