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Normal Pediatric Kidney Dimensions on Multidetector CT: Defining Standards for Pakistani Children

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ABSTRACT

Kidney size in children is a key marker for detecting congenital abnormalities and conditions that may develop later. In South Asia, CT-based normative data are limited. **Objectives:** To establish CT-derived reference ranges for renal size in Pakistani children and examine their relationship with somatic measurements. **Methods:** This retrospective study examined 15 years of data (2010–2024) from Aga Khan University Hospital, Karachi, focusing on CT scans conducted with GE 128-slice or Toshiba 640-slice scanners. The study included children aged one week to 16–17 years, categorized by age, and utilized both descriptive and inferential statistics. **Results:** Kidney size in children is a key marker for detecting congenital abnormalities and conditions that may develop later in life. The right kidney volume rises from about 19 cm^3 in infants to 146 cm^3 in late adolescence, while the left kidney grows from approximately 21 cm^3 to 146 cm^3. There is a strong correlation between renal size and factors like age, height, weight, and body surface area (p<0.001). No significant differences were observed between sexes, and multiple regression analysis confirmed these associations with significant models for both kidneys. **Conclusions:** This study provides the first CT-based reference ranges for renal dimensions in Pakistani children. Renal volume rises consistently with age and strongly correlates with somatic factors, offering valuable benchmarks for clinical assessment.

INTRODUCTION

The understanding of the size of abdominal organs is clinically and diagnostically significant, as changes often indicate underlying pathology. Any deviation in organ dimensions signals the manifestation or progression of disease[1]. The size of organs may be impacted by external factors such as environmental variations, diet, water intake, and high-altitude levels[2]. Childhood is vital period for assessing growth, making renal volumetry critical for diagnosing kidney disease early[1]. Initial normative kidney size data were published 60 years ago, indicating a correlation between anthropometric characteristics and kidney dimensions in children[3]. It is reported that the left kidney tends to be longer and heavier than the right, and renal weight is generally greater in male than in female[4]. Measuring kidney dimensions is crucial for diagnosing renal conditions like acute kidney disease, marked by increased kidney length, and renal hypoplasia[5]. Prompt measurement of kidney volume relative to body surface area (BSA) aids in the early detection and monitoring of chronic kidney disease[6]. Common imaging modalities for assessing renal conditions include CT scan, MRI, and ultrasonography[7]. CT scan and MRI are superior to

ultrasonography for evaluating kidney volumes and dimensions [6]. CT scan is favored for its quick acquisition time, while MRI offers better tissue contrast but comes at a higher cost and demands careful technical management [8].

Accurate renal size estimation is vital for diagnosing and monitoring pediatric renal disorders. In Pakistan, there are no CT-based standard data for children, leading clinicians to rely on reference standards from other populations or ultrasound-based nomograms. These do not consider local variations, potentially resulting in diagnostic errors. Development of population-specific CT reference values is necessary, as renal dimensions are affected by somatic variables. This study aims to establish CT-derived reference ranges for renal volumetry and to assess how age, height, and weight influence these measurements, to enhance clinical decision making in pediatric nephrology, and to provide a foundation for future regional studies.

METHODS

A retrospective cross-sectional study was conducted in the Department of Radiology at Aga Khan University Hospital, Karachi, Pakistan, involving reviewing pediatric CT scans from January 2010 to December 2024 via the hospital's PACS to identify cases where the kidney was visualized. This study was conducted from March 2025 to April 2025. Approximately 7000 pediatric CT scans were screened, selecting children aged 0-18 who met specific criteria. Demographic data such as age, sex, height, and weight were extracted from medical records, ensuring height and weight were recorded within one month of the scan. Participants were divided into age groups from 0-1 week to 16-17 years for targeted comparisons. No formal sample size calculation was performed; all eligible CT scans meeting the selection criteria (totaling 935 patients) were included to maximize data quality and representativeness. Children included in the study underwent contrast or non-contrast CT imaging for reasons not related to renal or urinary pathology, with only high-quality scans showing normal kidney morphology being included. The exclusion criteria consisted of various renal and systemic conditions affecting kidney size and function, as well as incomplete data. Kidney dimensions were measured from CT images using calipers, with length assessed between poles and diameters noted at the hilum. Renal volume was calculated with the formula: Length × Width × Transverse Diameter × 0.52. Illustration of kidney measurement techniques is shown, with the upper axial section depicting transverse and anteroposterior (AP) dimensions at the renal hilum, while the lower images show the maximum pole-to-pole length of the left kidney and the right kidney measured on sagittal section due to its shorter appearance on the coronal view (Figure 1).

Figure 1: Kidney Measurement Techniques Showing Transverse, Anteroposterior, and Pole-To-Pole Dimensions on Axial and Sagittal Views

Scans utilized Toshiba Aquilion 640-slice and GE Revolution 128-slice CT systems, adhering to standard abdominal protocols and the ALARA principle to minimize radiation while ensuring image quality. Measurements were evaluated on the PACS viewer with consistent settings for accuracy. The study protocol was 2025-10558-34325. Data analysis was performed using SPSS version 25.0, including normality checks via the Shapiro-Wilk test. Descriptive statistics outlined kidney size and volume, while categorical variables like gender and age group were expressed as frequencies and percentages. A simple percentile calculation was done. Independent sample t-tests or one-way ANOVA were used to assess differences in kidney size. Pearson correlation analyzed associations between continuous variables (age and BSA), and linear regression identified predictors of kidney size, setting statistical significance at $p < 0.001$.

RESULTS

The mean age of the study population was 6.97 years (standard deviation ± 4.79). Male predominance was noted at 546 (58.34%). The sample's mean weight, height, BMI, and BSA were found to be 23.32 kg, 112.82 cm, 15.98 kg/m^2, and 0.83, respectively. Kidney dimensions increased significantly with age ($p < 0.001$), with the cranio-caudal diameter ranging from 46.23 mm in infants to 110.60 mm in teenagers. Other diameters also showed growth, but no significant gender differences in kidney dimensions were observed (Table 1).

Table 1: Dimensions of the Right Kidney by Age and Gender

Variables	Right Kidney Cranio-Caudal (mm)	Percentile		Right Kidney Transverse (mm)	Percentile		Right Kidney Anteroposterior (mm)	Percentile	
	Mean ± SD	5	95	Mean ± SD	5	95	Mean ± SD	5	95
0–1 Week (n=14)	46.23 ± 13.92	34.60	83.80	26.18 ± 7.44	19.00	48.40	24.35 ± 7.56	17.00	47.70
1 Week–4 Months (n=53)	47.31 ± 6.31	36.10	58.50	26.50 ± 4.82	18.80	34.00	23.84 ± 3.76	17.40	30.00
4–8 Months (n=30)	54.55 ± 8.53	41.10	67.00	27.40 ± 4.19	20.50	33.40	26.92 ± 4.33	20.50	33.00
8–12 Months (n=55)	59.11 ± 7.53	47.90	71.00	31.50 ± 5.18	24.00	40.20	27.74 ± 3.63	21.00	34.00
1–2 Years (n=82)	65.83 ± 7.30	53.50	76.80	33.60 ± 7.52	25.00	42.20	30.53 ± 4.41	25.00	38.00
2–3 Years (n=58)	72.72 ± 7.03	61.00	83.40	36.68 ± 5.43	28.50	45.50	33.40 ± 4.29	27.50	41.00
3–4 Years (n=46)	75.86 ± 8.01	63.00	89.70	38.01 ± 4.07	31.10	42.30	34.17 ± 4.42	27.70	41.00
4–5 Years (n=49)	76.04 ± 10.62	59.00	91.00	37.94 ± 6.50	26.00	47.20	35.30 ± 6.22	23.00	45.10
5–6 Years (n=59)	80.84 ± 9.13	65.30	95.00	39.91 ± 6.71	29.00	50.80	37.71 ± 4.98	29.20	47.90
6–7 Years (n=62)	83.68 ± 11.64	68.00	107.00	41.45 ± 6.75	32.00	54.90	38.42 ± 6.08	30.20	51.30
7–8 Years (n=49)	85.27 ± 9.44	70.00	102.00	41.66 ± 6.40	33.30	51.90	39.00 ± 5.71	30.70	49.00
8–9 Years (n=49)	89.52 ± 10.60	75.40	108.00	44.08 ± 7.26	35.00	58.80	41.13 ± 6.61	32.30	54.00
9–10 Years (n=50)	88.67 ± 7.35	75.20	100.00	44.54 ± 5.92	36.00	54.20	41.01 ± 5.48	32.10	49.00
10–11 Years (n=60)	93.59 ± 8.45	82.50	110.00	45.77 ± 5.93	36.35	55.80	41.25 ± 4.92	34.02	49.80
11–12 Years (n=49)	93.20 ± 8.93	82.00	106.00	47.34 ± 5.73	38.00	57.00	39.98 ± 5.98	32.00	53.60
12–13 Years (n=67)	99.09 ± 10.30	81.00	113.00	49.27 ± 7.20	38.00	60.40	44.01 ± 6.50	35.40	55.00
13–14 Years (n=77)	101.58 ± 9.75	87.00	120.50	51.20 ± 6.32	39.90	61.40	46.14 ± 6.56	35.90	57.40
14–15 Years (n=19)	102.15 ± 8.33	88.00	115.00	47.22 ± 5.23	37.80	55.40	47.29 ± 5.05	41.00	58.00
15–16 Years (n=05)	110.60 ± 7.64	105.00	123.00	52.30 ± 4.71	47.00	59.40	48.82 ± 5.80	40.00	56.00
16–17 Years (n=02)	94.50 ± 2.12	93.00	96.00	43.50 ± 9.19	37.00	50.00	43.50 ± 9.19	37.00	50.00
Male	80.24 ± 18.33	47.50	109.00	40.01 ± 9.19	25.00	56.30	36.84 ± 8.53	23.00	51.50
Female	80.52 ± 18.50	46.30	108.00	40.81 ± 9.96	24.40	56.10	36.72 ± 8.26	23.60	50.00

The average left kidney diameters increase significantly with age, from 26.77 mm in neonates to 52.76 mm in late childhood/adolescence (15-16 years), with all measured diameters showing growth (p<0.001). No significant gender differences were observed in these measurements (Table 2).

Table 2: Dimensions of the Left Kidney by Age and Gender

Age group / Gender	Left Kidney Cranio-Caudal (mm)	Percentile		Left Kidney Transverse (mm)	Percentile		Left Kidney Anteroposterior (mm)	Percentile	
	Mean ± SD	5	95	Mean ± SD	5	95	Mean ± SD	5	95
0–1 Week	47.74 ± 17.68	36.00	94.50	26.77 ± 9.20	18.00	55.00	23.81 ± 6.02	17.80	40.00
1 Week–4 Months	47.82 ± 6.96	37.40	61.90	25.28 ± 4.44	18.00	32.00	24.91 ± 3.58	19.90	32.00
4–8 Months	53.98 ± 7.42	43.90	65.40	28.79 ± 4.32	21.70	36.00	27.02 ± 5.10	20.00	34.00
8–12 Months	60.27 ± 7.23	51.00	73.60	29.95 ± 4.86	23.00	39.20	28.60 ± 3.99	22.30	35.50
1–2 Years	67.14 ± 7.92	55.00	81.00	33.02 ± 4.76	25.00	40.20	31.13 ± 3.93	25.00	40.00
2–3 Years	73.69 ± 8.13	62.00	89.00	36.67 ± 5.48	28.00	47.80	33.88 ± 4.45	27.70	41.20
3–4 Years	78.15 ± 8.50	64.70	95.70	37.42 ± 4.66	30.00	46.70	35.35 ± 3.59	30.30	40.70
4–5 Years	78.09 ± 11.08	59.00	94.60	38.06 ± 5.74	32.00	48.30	34.73 ± 5.79	26.00	43.60
5–6 Years	81.74 ± 11.30	63.80	101.00	40.38 ± 6.38	30.00	51.80	37.63 ± 4.87	28.50	45.30
6–7 Years	85.08 ± 11.33	71.30	105.00	41.77 ± 6.14	33.00	52.20	39.38 ± 4.82	33.00	47.90
7–8 Years	84.69 ± 11.02	67.80	101.00	42.51 ± 6.82	30.20	53.00	39.39 ± 4.48	31.80	48.40
8–9 Years	89.70 ± 11.13	73.00	112.00	43.48 ± 8.07	32.10	59.00	41.37 ± 6.75	32.30	55.00
9–10 Years	90.08 ± 8.42	77.00	108.00	44.38 ± 5.86	36.00	55.10	42.22 ± 5.25	33.40	50.30
10–11 Years	94.55 ± 9.01	79.20	110.00	44.99 ± 5.94	36.80	55.75	42.47 ± 5.24	34.00	52.45
11–12 Years	94.40 ± 10.12	83.20	114.00	46.02 ± 6.25	37.00	57.00	43.33 ± 4.52	37.20	51.30
12–13 Years	100.89 ± 10.72	82.00	116.00	49.03 ± 6.39	38.00	59.00	44.22 ± 5.39	36.60	53.00
13–14 Years	101.76 ± 9.16	87.00	117.00	49.82 ± 6.80	38.00	61.70	46.26 ± 5.21	38.00	56.00
14–15 Years	104.02 ± 10.43	85.00	120.00	46.69 ± 5.30	40.00	58.00	47.08 ± 3.80	37.60	53.70
15–16 Years	106.76 ± 9.24	99.80	122.00	52.76 ± 5.64	47.00	61.80	49.54 ± 7.35	42.50	58.00
16–17 Years	92.00 ± 2.83	90.00	94.00	41.00 ± 1.41	40.00	42.00	45.50 ± 6.36	41.00	50.00

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Male	81.01 ± 18.85	49.00	109.00	39.80 ± 9.26	24.00	55.00	37.48 ± 8.05	24.00	50.50
Female	81.82 ± 18.51	46.00	110.00	40.16 ± 9.38	24.50	55.50	37.43 ± 8.25	23.30	50.40

As age increases, kidney volume grows, with the left kidney ranging from 20.74 ± 27.22 cm^3 to 145.58 ± 32.55 cm^3 and the right kidney from 19.26 ± 24.33 cm^3 in infants to 146.32 ± 20.81 cm^3 in teenagers. No significant sex differences were noted (left: p=0.741; right: p=0.684), but kidney volumes varied significantly across age groups (p<0.001) (Table 3).

**Table 3:** Measurements of Kidney Volume by Gender and Age

Age group / Gender	Right Kidney Volume (mL)	Percentile		Left Kidney Volume (mL)	Percentile	
	Mean ± SD	5	95	Mean ± SD	P-5	P-95
0–1 Week	19.26 ± 24.33	6.68	100.60	20.74 ± 27.22	6.74	108.11
1 Week–4 Months	16.18 ± 6.76	7.78	30.92	16.35 ± 7.19	8.44	26.09
4–8 Months	21.83 ± 8.38	10.30	34.87	22.72 ± 8.55	10.06	35.94
8–12 Months	27.33 ± 8.40	16.36	43.03	27.66 ± 9.69	13.60	48.78
1–2 Years	35.73 ± 12.23	21.73	56.86	36.71 ± 11.68	21.16	59.31
2–3 Years	46.99 ± 13.25	29.33	73.32	48.53 ± 14.95	29.18	84.90
3–4 Years	51.74 ± 12.97	35.76	70.84	54.49 ± 14.42	34.72	86.88
4–5 Years	55.05 ± 20.81	15.86	101.34	56.03 ± 21.82	23.84	89.73
5–6 Years	65.07 ± 22.43	31.05	97.22	66.54 ± 23.29	30.95	115.11
6–7 Years	71.56 ± 27.81	43.71	138.88	75.13 ± 27.43	46.33	125.04
7–8 Years	73.54 ± 23.46	40.23	121.06	76.02 ± 25.55	38.03	119.34
8–9 Years	87.41 ± 35.42	48.54	168.31	87.77 ± 38.13	48.71	172.46
9–10 Years	85.15 ± 22.37	53.85	136.42	88.58 ± 22.73	60.96	137.14
10–11 Years	92.57 ± 21.52	58.14	130.92	95.37 ± 25.45	57.45	144.30
11–12 Years	92.52 ± 23.37	61.05	128.36	98.82 ± 24.70	66.98	145.63
12–13 Years	113.09 ± 33.10	70.96	155.01	115.70 ± 33.35	67.88	171.43
13–14 Years	126.15 ± 33.01	76.64	186.74	123.25 ± 30.28	76.66	177.35
14–15 Years	118.42 ± 19.21	86.49	159.34	119.62 ± 24.73	82.10	175.83
15–16 Years	146.32 ± 20.81	130.97	182.67	145.58 ± 32.55	114.96	195.27
16–17 Years	90.91 ± 2.04	89.47	92.35	89.22 ± 12.81	80.16	98.28
Male	68.96 ± 40.64	14.74	145.63	70.67 ± 41.43	15.25	145.49
Female	70.04 ± 39.44	14.26	142.13	71.56 ± 39.51	15.20	138.58

Significant positive correlations (p<0.001) were observed between kidney volumes and all somatic variables. Age, weight, height, and BSA all showed strong associations with kidney volume, with correlation coefficients ranging from r = 0.82 for the right kidney to r=0.81 for the left kidney. Both right (r=0.383) and left (r=0.381) kidney volumes demonstrated a moderate relationship with BMI (Figure 2).

Kidney volumes and BSA showed a substantial positive association, according to separate analyses for males and females. There was a similar linear relationship between renal volume and BSA in both genders, with a substantial relation (e.g., r=0.825, p<0.001) (Figure 3).
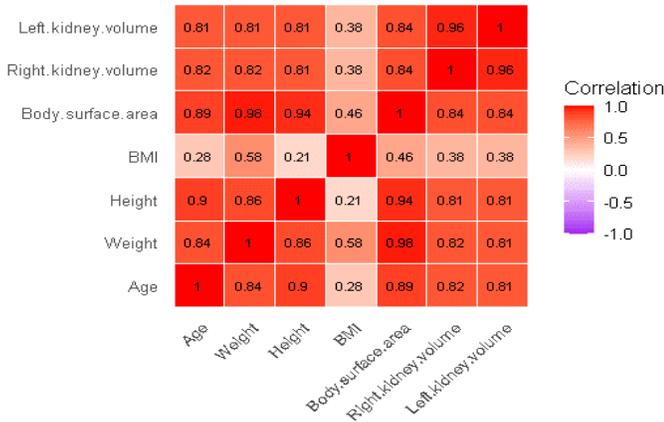
Figure 2: Kidney Volumes and Anthropometric Characteristics are Correlated
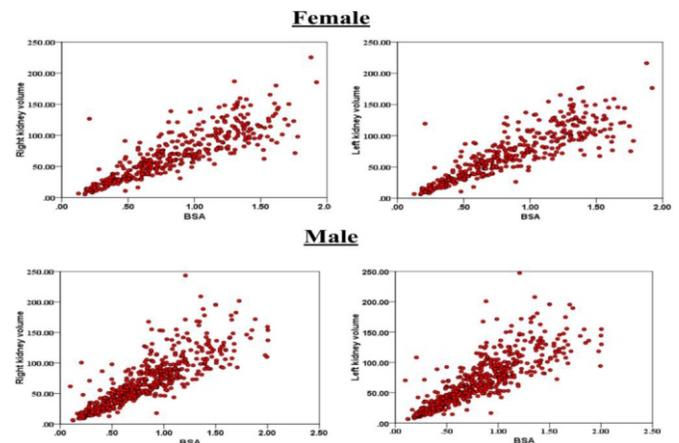
Figure 3: Gender Specific Relationship Between Kidney Volumes and Body Surface Area

Age is the main predictor of right kidney volume (β=0.313,

p<0.001), with left renal volume also increasing with age, BMI, and BSA. The regression models accounted for approximately 74% of the variation in right kidney volume and 73% in left kidney volume, indicating a robust model fit (Table 4).

Table 4: Analysis of Multiple Linear Regression for Variables Related to the Volumes of the Right and Left Kidneys

Model	Age (β, 95% CI, p)	Gender (β, 95% CI, p)	Weight (β, 95% CI, p)	Height (β,95% CI, p)	BMI (β, 95% CI, p)	BSA (β, 95% CI, p)	Constant (B, 95% CI, p)	R^2 / Adj. R^2
Right Kidney	0.313 (1.92–3.34, <0.001)	0.031 (0.23–5.20, 0.073)	0.118 (1.06–1.66, 0.670)	0.005 (0.51–0.50, 0.983)	0.064 (0.05–1.15, 0.074)	0.650 (29.42–158.26, 0.178)	1.659 (21.75–18.44, 0.871)	0.738 / 0.736
Left Kidney	0.283 (1.67–3.13, <0.001)	0.029 (0.37–5.21, 0.089)	0.508 (0.12–2.68, 0.073)	0.117 (0.39–0.66, 0.605)	0.087 (0.14–1.37, 0.017)	1.156 (19.27–212.32, 0.019)	5.640 (−26.30–15.02, 0.592)	0.729 / 0.727

DISCUSSION

This study utilized CT scans to analyze kidney sizes and volumes in pediatric patients. It was established that kidney dimensions increase with age, with the most rapid growth occurring from infancy to early childhood, followed by a slower growth rate through childhood and teenage years. This growth is closely linked to overall body development during early years, highlighting this period as critical for kidney maturation [9, 10]. Current findings revealed that kidneys showed a consistent increase in size over a span that extended from 0–1 week to around 16–17 years. This pattern was most commonly seen between the ages of 0–2 years and the age of 2–7 years [11]. This initial development and growth indicate that newborns' organs are rapidly developing during this phase, parallel to the whole body. On the other hand, the period between 8 and 13 years showed a comparatively slower rate of increase, which can be explained by puberty, during which hormones influence renal tissue growth as well as renal blood flow [12, 13]. Similar age-related growth patterns have been noticed in both Asian and European which indicate that an increase in kidney growth is associated with the overall growth of the body [14, 15]. Current study findings showed that age is strongly related to the kidney volume more than BSA and BMI. But some published studies are in disagreement with our finding, like Obrycki *et al.* indicate that the BSA is strongly related (r=0.94) with the kidney size [16]. In another study from China, Qin *et al.* found that renal volume is associated with both height and BSA, with a strong correlation (r=0.89) [17]. The finding that age is the strongest predictor in our study might indicate that unique growth patterns depend on the nutritional intake and overall biological development among study participants in this part of the world. Male and female in any age group did not significantly differ in kidney size. This is comparable to the findings of Rongviriyapanich *et al.* and Mohtasib *et al.* who observed no variation before later adolescence [10, 18]. Liu *et al.* noticed that male adolescents tended to have slightly larger kidneys. However, this difference largely disappeared after adjustment for height and BSA [19]. This further indicates that gender alone is not a reliable predictor of kidney size once body dimensions are taken into account. Moreover, our findings are consistent with

those reported by Rongviriyapanich *et al.* and Obrycki *et al.* An increase in the renal size is directly associated with the child's age, with only minimal gender differences [10, 20]. This indicates that body size is a reliable predictor for use in local clinical settings. The high R^2 values (around 0.73–0.74) in our regression models indicate that most of the variation in renal volume is attributed to body growth and development. Overall, these findings provide new and valuable data by offering CT-based kidney sizes and volume values specifically tailored to this part of the world. The detailed age-based breakdown enhances the practical utility of these findings for radiologists and pediatric nephrologists and can assist in the early identification of small kidneys, abnormal development, or chronic diseases. However, limitations of the study are that it is a single-center study and the sample size is relatively small, which can limit generalizability. More extensive multicenter research in larger and more heterogeneous groups of patients is required to confirm such reference ranges and to improve further pediatric renal volumetry norms in this group.

CONCLUSIONS

The current study presents uniform data on kidney size and volume in the Pakistani pediatric population, showing a strong correlation with body growth and minimal differences between genders. These insights and prediction models may assist physicians in making accurate diagnoses in pediatric nephrology and radiology, enabling earlier detection of kidney issues and tailored follow-up care.

Authors' Contribution

Conceptualization: MY, WAM
Methodology: MY, WAM, MM, FUI, AR, BZ, MS, MA, AH, MK
Formal analysis: AH, MK
Writing and Drafting: MY, WAM, MMA,
Review and Editing: MY, WAM, MM, FUI, AR, BZ, MS, MA, AH, MK

All authors approved the final manuscript and take responsibility for the integrity of the work.

Conflicts of Interest

All the authors declare no conflict of interest.

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