ORIGINAL ARTICLE

Ultrasound Imaging of Renal Length in Normal Thai Children

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Background: Ultrasonography rapidly measures the sizes of visceral organs, such as the kidneys, without exposing the patient to ionizing radiation. Various disorders alter kidney size, requiring the availability of a reliable reference for measuring kidney length of children for clinical evaluation.

Objective: To determine normal renal lengths of healthy Thai children and to generate normal renal-length growth pattern according to gender, age, body weight, height, body mass index, and body surface area.

Materials and Methods: Ultrasonography examinations of 726 full-term neonates through children younger than 14 years of age were conducted between 2016 and 2020. The data were divided by age group. Retrospective data were gathered from computerized archives and patients' records.

Results: The present study was an analysis of 726 subjects that revealed that their left kidneys were longer than their right ($p<0.001$). Height significantly correlated with kidney length (right kidney: $R^2=0.866$, $p<0.001$; left kidney: $R^2=0.862$, $p<0.001$). Kidney length varied as a function of gender, as bilateral kidneys were longer in boys versus girls, and the differences in kidney length significantly differed.

Conclusion: The normal size of kidneys of each age group and correlation maps developed in the present study should aid radiologists and clinician to identify diseases of children that cause changes in kidney size.

Keywords: Renal length; Renal size; Ultrasound; Kidney

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Ultrasonography, which is routinely used to evaluate a child's visceral organs, rapidly determines kidney size without exposure to ionizing radiation. Kidney size is an important parameter in the clinical evaluation of renal growth and anomalies. Kidney length is affected by an individual's general characteristics such as age, height, weight, body mass index (BMI), and body surface area (BSA)[1-3]. Kidney size is affected by conditions such as infection and cancer[3,4]. Thus, a valid reference for kidney length in children is important for clinical assessment.

To the authors' knowledge, published studies[1-11] reporting the normal dimensions of the kidney do not include the population of Thailand. Measurements of kidney volume are time-consuming and inconvenient, and kidney length correlates better with other body parameters[8-10]. To the authors' knowledge from the previous studies in the other countries, the longitudinal dimensions of the kidney correlate better with height than the BSAs of children aged five days to 16 days[3], and there is a strong correlation between kidney length and age[4]. Further, a study of 712 healthy school-age children found that body weight is the strongest predictor of kidney length[9]. These investigations did not detect a statistically significant difference in kidney length between boys and girls[3,9], despite the strong association between kidney length and age, as well as other body measurements such as weight and height[12-18].

Here the authors determined the typical sonographic growth patterns of kidney length in children living in Thailand and their associations with age and physical characteristics. This is the first study, to the authors' knowledge, of the newborn and pediatric population of Thailand. This information should help predict changes in renal size and facilitate the early detection of aberrant ultrasound findings in renal disease such as chronic glomerulonephritis or obstructive uropathy[19,20], which require further

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investigation and treatment.

Materials and Methods

Institutional Review Board Faculty of Medicine Vajira Hospital approved the present retrospective analysis (COA 013/2564). Informed consent was not required because of the retrospective design of the present study. The authors conducted ultrasonographic kidney studies on children ranging in age from full-term newborns to 14 years between January 2016 and December 2020 at Vajira Hospital, Bangkok, Thailand. The present study only included healthy children and term newborns. Age, weight, and height were recorded on the day of the ultrasonography examination. Only children with weight-for-age and height-for-age percentiles between the fifth and ninety-fifth percentiles, according to the Health Services Council of Thailand's Growth Charts for Thai Children and Adolescents[21], were included in the present study. Patients with abnormal growth curves were excluded from the study.

Grayscale 2D-ultrasonography images were stored in the hospital's picture archiving and communication system after both sides of the kidneys were evaluated. The lengths of the kidneys and the heights of the children were measured to the nearest centimeter (0.1 cm), and weights were measured to the nearest kilogram (0.1 kg). Recruitment criteria were as follows, healthy full-term newborns to 14 years, no acute or chronic disease that may lead to renal disease, and no personal or family history of renal disease. The authors only included patients with normal kidneys who underwent screening or routine abdominal ultrasonography or complaint of abdominal pain from other cause or unrelated health problems. All retrospective sonographic examinations were performed by radiologists who followed a standard protocol.

With patients in the supine or slightly left or right lateral decubitus position, examinations were performed in sagittal and axial planes passing through the renal hilum to evaluate the longest dimension of each kidney. With distance pole to pole, a standard sonographic measurement of maximum renal length was achieved (Figure 1). A pediatric radiologist retrospectively reviewed these images to ensure that they satisfied the inclusion criteria, and the measurements were corrected if required. IBM SPSS Statistics, version 2.0 was used for statistical analysis, and appropriate descriptive statistical methods were applied. The data were divided by age group for first seven days of birth, every four months in first year, and every 12 months from age 1 to 14 years. The paired-sample t-test was used to assess group differences. Simple and multiple linear regression analyses were used to investigate the relationships between ultrasonography-measured renal length, age, and body characteristics. The Pearson correlation coefficient was used to measure the degree of linear correlation between the two variables. The p-value less than 0.05 indicated statistical significance. Normal ranges and related information were calculated and organized according to age and gender. Growth curves of renal length and upper limits, established according to the ninety-fifth percentile's upper confidence limit, were graphically depicted as a function of age for younger than two years and older than two years.

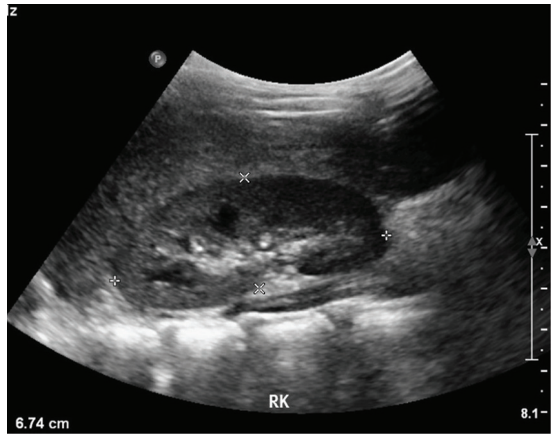

Figure 1. Maximum longitudinal dimension of the kidney through hilum of kidney.

Results

The present study included 393 boys or 54.1% and 333 girls or 45.9%, who underwent 726 standard ultrasonography tests. The ages of the participants ranged from newborn to 15 years, 284 children or 39.1% were younger than two years, and 442 children or 60.9% were older than two years. The left kidney was significantly longer than the right kidney ($p<0.001$). The mean (SD) lengths of left and right kidneys of all children were 7.15 cm (1.96) and 7.06 cm (1.94), respectively. Univariate analysis revealed that the lengths of the right and left kidneys were most closely associated with height ($R^2=0.866$ and 0.862, respectively) versus the other variables (Table 1). Multivariate analysis revealed that age, weight, height, and BMI were significantly associated with renal length, whereas BSA and gender showed weaker correlations (Table 2).

Table 1. Univariate analysis of relationship between renal length and body parameters

Variables	Right renal length						Left renal length					
	All (n=726)		Male (n=393)		Female (n=333)		All (n=726)		Male (n=393)		Female (n=333)	
	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2
Age	0.919	0.845	0.935	0.874	0.895	0.802	0.917	0.840	0.928	0.861	0.899	0.807
Weight	0.875	0.766	0.897	0.805	0.861	0.741	0.869	0.754	0.889	0.790	0.855	0.731
Height	0.931	0.866	0.937	0.879	0.918	0.844	0.928	0.862	0.934	0.873	0.917	0.841
BMI	0.641	0.411	0.717	0.515	0.541	0.293	0.632	0.400	0.707	0.499	0.534	0.285
BSA	0.917	0.841	0.932	0.868	0.899	0.808	0.912	0.831	0.924	0.854	0.895	0.801

β=standardized regression coefficient; BMI=body mass index; BAS=body surface area

All betas were significant (p<0.001)

Table 2. Multivariate analysis (enter method) of relationship between renal length and body parameters

Variables	Right renal length						Left renal length					
	All (n=726)		Male (n=393)		Female (n=333)		All (n=726)		Male (n=393)		Female (n=333)	
	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value
Age	0.404	<0.001	0.453	<0.001	0.384	<0.001	0.419	<0.001	0.428	<0.001	0.445	<0.001
Weight	0.176	0.027	0.098	0.343	0.437	0.001	0.181	0.026	0.055	0.613	0.522	<0.001
Height	0.600	<0.001	0.545	<0.001	0.676	<0.001	0.639	<0.001	0.627	<0.001	0.667	<0.001
BMI	0.149	<0.001	0.153	<0.001	0.163	<0.001	0.151	<0.001	0.151	<0.001	0.173	<0.001
Adjust R^2	0.890		0.907		0.866		0.885		0.896		0.868	

β=standardized regression coefficient; BMI=body mass index; BAS=body surface area

Model summary for all patients for right kidney: R square=0.890, adjusted R square=0.889, Durbin-Watson test statistic=1.837; Model summary for male patients for right kidney: R square=0.907, adjusted R square=0.906, Durbin-Watson test statistic=1.889; Model summary for female patients for right kidney: R square=0.866, adjusted R square=0.864, Durbin-Watson test statistic=1.859; Model summary for all patients for left kidney: R square=0.885, adjusted R square=0.884, Durbin-Watson test statistic=1.745; Model summary for male patients for left kidney: R square=0.896, adjusted R square=0.895, Durbin-Watson test statistic=1.817; Model summary for female patients for left kidney: R square=0.868, adjusted R square=0.866, Durbin-Watson test statistic=1.824

There was a significant relationship between gender and kidney length (Figure 2). Boys had longer left and right kidneys (p<0.001, right kidney; p<0.001, left kidney). The curve depicting renal-length curve before and after 24 months showed that kidney length increased rapidly during the first 24 months and slowed thereafter, with p=0.041 for younger than two years, right kidney, p=0.037 for older than two years, right kidney, p=0.027 for younger than two years, left kidney, and p=0.029 for older than two years, left kidney. Kidney lengths by age categories are shown in Table 3 and 4.

Discussion

Differentiating renal problems requires knowledge of the normal limits of kidney size of healthy children. This is particularly important because renal length varies during childhood. For example, children may experience renal-tract abnormalities including reflux nephropathy, renal hypoplasia, obstructive uropathy, and renal agenesis[5,10,21,22]. Studies have established the correlations between renal diameters through ultrasonography and other bodily parameters such as weight, height, BMI, and BSA[2,5,6,8,16,23]. To the best of the authors' knowledge, this is the first study of children, including newborn, living in Thailand to investigate the association between renal size and the parameters of overall body size between the left and right kidneys[3,4,17,24,25]. The authors showed the left kidney was longer than the right kidney, which is consistent with published data[6,7,8,20]. This finding may be explained by the smaller size of the spleen compared to the liver, which allows the kidney to more readily increase in size[19]. Further, the left renal artery is shorter than the right, and increasing blood flow in the left renal artery may result in a larger left kidney[20].

The authors show here a significant difference in renal growth before and after 24 months of age. Consistent with previous studies, renal length rapidly increased until 24 months and then slowed[16,21]. Renal length closely correlated with height, which supports the findings of others[1,5,6,8,12,16]. The strong

Table 3. Longitudinal lengths of both kidneys in children age 24 months or less

Age	n	Site	Mean	SD	Minimum	Maximum	Percentiles	
							5th	95th
1 to 7 days	56	Right	4.31	0.50	3.2	5.8	3.5	5.1
		Left	4.35	0.42	3.4	5.3	3.7	5.1
1 week to 4 months	73	Right	4.66	0.47	3.3	5.8	3.9	5.5
		Left	4.72	0.50	3.4	6.1	4.0	5.7
4 to 8 months	61	Right	5.39	0.48	4.3	6.7	4.6	6.3
		Left	5.48	0.49	4.6	6.8	4.7	6.3
8 to 12 months	43	Right	5.67	0.76	4.5	9.1	4.6	6.9
		Left	5.69	0.50	4.3	7.1	4.5	6.5
12 to 24 months	52	Right	5.89	0.53	4.6	7.0	4.9	6.8
		Left	5.93	0.64	4.4	7.1	4.6	7.0

SD=standard deviation

Table 4. Longitudinal lengths of both kidneys in children age between 2 and 15 years

Age (years)	n	Site	Mean	SD	Minimum	Maximum	Percentiles	
							5th	95th
2 to 3	46	Right	6.62	0.71	5.1	8.4	5.5	8.2
		Left	6.75	0.74	5.0	8.3	5.4	7.8
3 to 4	46	Right	6.81	0.50	5.5	7.7	5.9	7.6
		Left	6.90	0.50	5.7	8.3	6.0	7.8
4 to 5	40	Right	7.42	0.83	6.0	9.2	6.1	9.2
		Left	7.55	0.87	6.0	9.5	6.2	9.5
5 to 6	41	Right	7.78	0.90	3.9	9.9	6.4	8.9
		Left	8.05	0.61	7.0	9.5	7.0	9.0
6 to 7	42	Right	8.02	0.75	6.7	9.6	6.7	9.6
		Left	8.15	0.93	6.6	10.8	6.7	10.5
7 to 8	38	Right	8.11	0.55	6.8	9.2	7.1	9.0
		Left	8.18	0.40	7.0	9.0	7.4	8.9
8 to 9	31	Right	8.39	0.79	7.2	10.1	7.3	9.9
		Left	8.49	0.68	7.5	9.8	7.5	9.8
9 to 10	38	Right	9.00	0.65	8.0	10.7	8.1	10.6
		Left	8.97	0.69	7.8	10.7	8.0	10.4
10 to 11	31	Right	9.27	0.63	7.8	10.8	7.9	10.4
		Left	9.36	0.77	7.7	11.2	8.0	10.9
11 to 12	30	Right	9.48	0.61	8.4	10.8	8.4	10.6
		Left	9.48	0.68	8.1	10.5	8.1	10.4
12 to 13	28	Right	9.77	0.70	8.5	11.5	8.7	11.3
		Left	9.87	0.66	8.7	11.3	8.8	11.2
13 to 14	28	Right	9.98	0.68	9.0	12.0	9.1	11.7
		Left	10.14	1.05	8.9	13.8	8.9	13.0

SD=standard deviation

association between kidney length and height may be explained by the increase in height during the first two years of life[1,3]. Nevertheless, in children, the relationship between gender and kidney size is uncertain, mainly because of conflicting data showing that girls have smaller kidneys[18,23] or that renal size does not differ between the genders[3,9,10]. Consistent with the former findings[18,23], here, the authors discovered a significant disparity in kidney length between genders. Thus, boys had bilaterally longer kidneys than girls. This may be explained by boys' higher BSA[24].

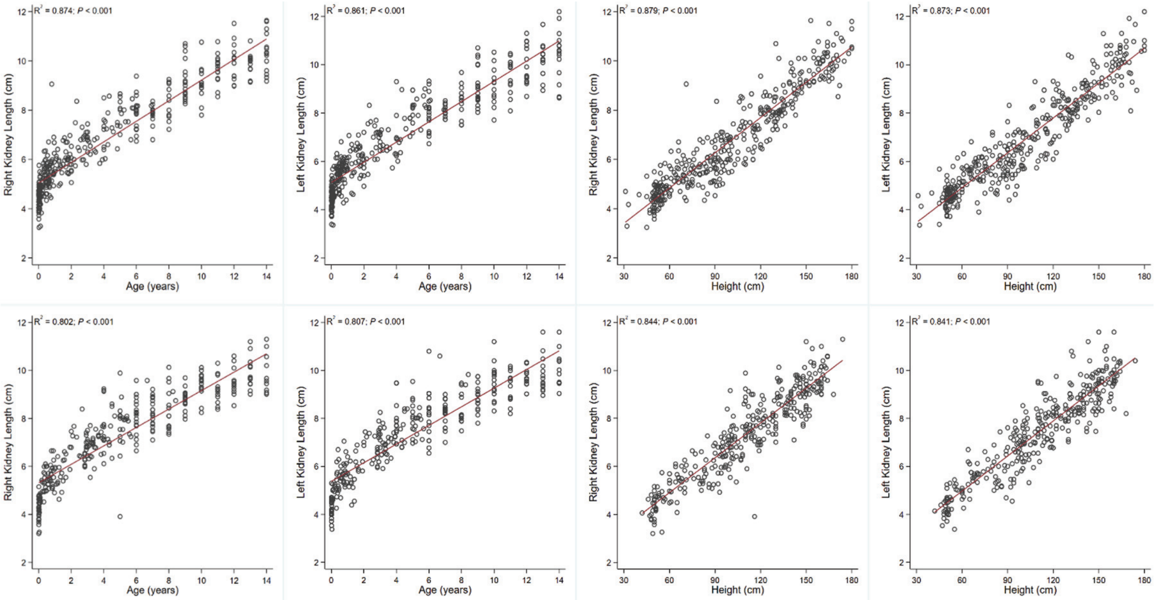

Figure 2. Male (top) vs. female (bottom) renal growth curve by age and height.

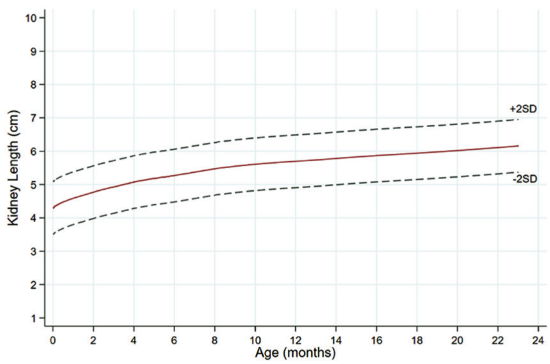

Figure 3. Mean renal length and 2 standard deviations by age in children under 24 months (n=235).

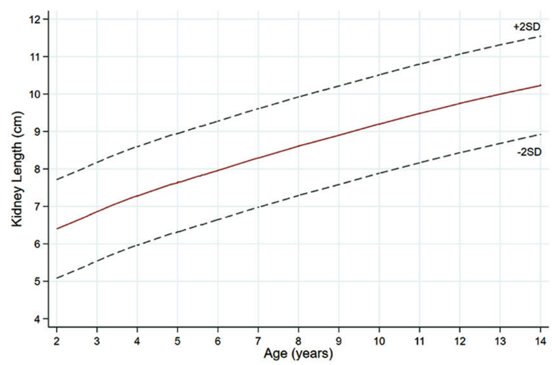

Figure 4. Mean renal length and 2 standard deviations by age in children above 24 months (n=491).

Although differences in renal length between the genders and between the right and left kidney are statistically significant, they are not considered clinically significant[10,24]. In the present study, the authors determined renal lengths of children as a function of age (Figure 2) and found that the difference was small, not statistically different, and not clinically significant. The difference may be related to changes in the degree of respiration affecting the accuracy of the measurements, or changes in the patient's position during the examination, which may influence the filling of the renal collecting system that alters kidney's size[25].

The ultrasonographical measurements of normal renal lengths published by the Children's Hospital, Boston in 1984[8] are widely used as standard reference values worldwide, including by the authors' hospital. The present study database comprising 726 cases is significantly larger than the database cited above comprising 203 cases[8]. Moreover, the present fitted plot of mean length within two standard deviations of the mean is an excellent reference for common scanning settings for children younger than two years (Figure 3) or older than two years (Figure 4).

The retrospective nature of the present study may have certain limitations. The present study was conducted in children including newborn that may cry and not cooperate, which would affect measurement of organs. However, during the ultrasound tests, radiologists frequently measure renal length according to the standard protocol. Further, variations in ultrasonographic techniques, patient's positioning, and cursor placement during measurements may alter the ability to correct renal-length measurements. Thus, a prospective study investigating intra- and interobserver agreement will be required. Although the cases were not randomly selected from different regions of Thailand, the authors' hospital serves as one of Thailand's main referrals, thus the findings may apply to the children of the entire country.

Conclusion

In summary, the authors generated correlation plots of age as a function of kidney length among Thai children. In addition, disparities in size between the right and the left kidneys, as well as between genders were found, requiring separate evaluation of each kidney. Further, the authors analyzed the relationship between age and kidney length, and the associated tables and graphs can be utilized by radiologists to examine disorders that cause changes in renal size.

What is already known on this topic?

A valid reference for kidney length in children is important for clinical assessment. Previous published studies reported the normal dimensions of the kidney in children but did not include the population of Thailand. Body weight is the strongest predictor of kidney length.

What this study adds?

This study shows normal renal lengths of healthy Thai children and generate normal renal-length growth pattern according to gender, age, body weight, height, BMI, and body surface area. The lengths of both kidneys were most closely associated with height. Kidney length increased rapidly during the first 24 months and slowed thereafter.

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Conflicts of interest

The authors declare no conflict of interest.

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