

Length and Volume of Morphologically Normal Kidneys in Korean Children: Ultrasound Measurement and Estimation Using Body Size

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Objective: To evaluate the relationship between anthropometric measurements and renal length and volume measured with ultrasound in Korean children who have morphologically normal kidneys, and to create simple equations to estimate the renal sizes using the anthropometric measurements.

Materials and Methods: We examined 794 Korean children under 18 years of age including a total of 394 boys and 400 girls without renal problems. The maximum renal length (L) (cm), orthogonal anterior-posterior diameter (D) (cm) and width (W) (cm) of each kidney were measured on ultrasound. Kidney volume was calculated as $0.523 \times L \times D \times W$ (cm³). Anthropometric indices including height (cm), weight (kg) and body mass index (m²/kg) were collected through a medical record review. We used linear regression analysis to create simple equations to estimate the renal length and the volume with those anthropometric indices that were mostly correlated with the US-measured renal sizes.

Results: Renal length showed the strongest significant correlation with patient height (R^2 , 0.874 and 0.875 for the right and left kidneys, respectively, $p < 0.001$). Renal volume showed the strongest significant correlation with patient weight (R^2 , 0.842 and 0.854 for the right and left kidneys, respectively, $p < 0.001$). The following equations were developed to describe these relationships with an estimated 95% range of renal length and volume (R^2 , 0.826-0.884, $p < 0.001$): renal length = $2.383 + 0.045 \times \text{Height} (\pm 1.135)$ and = $2.374 + 0.047 \times \text{Height} (\pm 1.173)$ for the right and left kidneys, respectively; and renal volume = $7.941 + 1.246 \times \text{Weight} (\pm 15.920)$ and = $7.303 + 1.532 \times \text{Weight} (\pm 18.704)$ for the right and left kidneys, respectively.

Conclusion: Scatter plots between height and renal length and between weight and renal volume have been established from Korean children and simple equations between them have been developed for use in clinical practice.

Index terms: *Kidney; Organ size; Body size; Ultrasonography; Child*

INTRODUCTION

Childhood is an important period of growth for many

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organ systems. Among various growth parameters, kidney size is an important parameter used for the clinical evaluation of renal growth and renal abnormalities, including atrophy, hypoplasia, and hypertrophy in children. Therefore, having a reliable reference for kidney size in children is valuable.

Several studies suggest that kidney length and volume are strongly correlated with a patient's height, weight and body mass index (BMI) (1, 2). The prevalence of obesity has increased within children globally over the past decade, and this issue has raised concerns for health of the pediatric population. Recent studies in Korea have also reported that the prevalence of obesity among children increased from

5.8% in 1997 to 9.7% in 2005 according to the definition of obesity as being at or above the 95th percentile of the gender-specific BMI for age in the 2007 Korean National Growth Charts or a BMI of 25 or higher (3, 4). Therefore, it is important to establish an up-to-date reference for kidney size in the pediatric population with consideration of the recent increase in average height, weight, and BMI.

There are several methods for measuring renal sizes, including abdominal CT and MRI. However, these approaches have disadvantages such as radiation exposures and high costs. In comparison, ultrasonography (US) is a safe and simple method for evaluating renal length and volume. However, previous studies have only shown the normal range of renal size through a graph, which is somewhat difficult to apply clinically (5, 6). The purpose of this study was to evaluate the relationship of height, weight and BMI with renal length and volume measured with US in Korean children who have morphologically normal kidneys. In addition, we attempted to develop simple equations to estimate the renal sizes using the anthropometric measurements.

MATERIALS AND METHODS

The institutional review board of our hospital approved this retrospective study and informed consent was waived. We reviewed US images of pediatric patients under 18 years of age who were referred to our health system from November 2009 to August 2010 for routine care or follow-up examinations. Patients underwent neither preparations nor sedations for the US examinations.

Ultrasonography was performed using an iU22 ultrasound unit (Philips Ultrasound, Bothell, WA, USA) with a 5-8 or 1-5 MHz convex transducer by two pediatric radiologists with 27 and 9 years of experience for pediatric US, respectively. Renal length (L) (cm) and width (W) (cm) were routinely measured during abdominal US in our institution. The orthogonal anterior-posterior diameter (cm) of each kidney was measured retrospectively by one pediatric radiologist with 9 years of experience for pediatric US. These data were obtained in the sagittal and axial planes passing through the renal hilum with patients in the supine or slightly left or right lateral decubitus positions. Kidney volume was calculated in cubic centimeters using the equation for an ellipsoid: volume (cm³) = mean length (L) x mean width (W) x mean depth (D) x 0.523.

Exclusion criteria included any congenital renal anomaly

or renal disease that affects US renal size measurement, such as renal agenesis or the horseshoe kidney. Patients with abnormal ultrasound imaging of the kidney, such as cortical scarring, increased echogenicity, pelvic dilatation, renal cysts and other abnormal findings in the urinary bladder or urinary tract, were also excluded. Patients with hematuria or proteinuria within 6 months after US examination or pyuria within 1 month before and after US study in urinalysis were also excluded. If the patient had a systemic disease such as a hematologic, oncologic or endocrine disease that could affect height, weight, BMI and abdominal organ growth, they were also excluded. The most common indication of the US examinations in the enrolled group was the evaluation of fever except from the urinary tract infection. Routine health screening was the second largest cause. Abdominal pain unrelated to renal problems and evaluation of benign mass such as hepatic cyst or hemangioma were followed as reasons for US examinations.

Age, gender, height and weight were collected by reviewing the medical records for each patient. Height (cm) and weight (kg) were measured on the day of US study. BMI was calculated as weight (kg)/height (m²). Obesity was defined as BMI with age which was more than 95 percentiles or 25 kg/m² according to a previous study (7). Statistical analyses were performed using the Statistical Analysis System version 9.2 (SAS Institute Inc., Cary, NC, USA). Paired *t* test was used to compare the length and volume of bilateral kidneys. Simple and multiple linear regression analyses were applied to evaluate the relationship between the anthropometric parameters and the renal length or volume. We also used the linear regression analysis to create simple equations to estimate the renal length and volume with anthropometric indices that were correlated to the US-measured renal sizes. Results were considered statistically significant if the *p*-value was < 0.05 for all data analyses.

RESULTS

A total of 794 Korean children, 394 boys and 400 girls, were included in this study. Ages ranged from 0 to 18 years with a mean of 4.6 ± 4.6 years. The average height of the enrolled group was 100.5 ± 33.8 cm (range: 43-182) and the average weight was 19.4 ± 15.0 kg (range: 2.4-89). The average BMI was calculated as 16.7 ± 2.5 kg/m² (range: 6.1-27.3). The overall percentage of obesity in the study population was 3.7% (29/794), and in school-age children aged 8-18 years, it increased to 7.5% (14/186). The left

kidney was significantly larger than the right kidney in terms of both renal length (mean 7.06 vs. 6.89 cm; $p < 0.001$) and volume (mean 37.07 vs. 32.15 cm³, $p < 0.001$).

Tables 1-4 shows the relationship between each parameter and renal size on univariate and multivariate analyses. The lengths of both the right ($R^2 = 0.874$) and the left ($R^2 = 0.875$) kidneys showed the strongest correlation with patient height in the univariate analysis (Table 1). On the multivariate analysis, only height indicated significantly

strong correlations of the univariate analysis with renal length, whereas weight and BMI showed inconsistent and/or weaker correlations (Table 2). The volume of both the left ($R^2 = 0.854$) and the right ($R^2 = 0.842$) kidneys showed the strongest correlation with patient's weight in the univariate analysis (Table 3). Both height and weight showed significant correlations with renal volume in the multivariate analysis, whereas BMI did not (Table 4).

Given the small, if any, effect of BMI on the renal

Table 1. Univariate Analysis of Relation between Renal Length and Age, Weight, Height or Body Mass Index (BMI) in Boys and Girls

Variable	Right Renal Length						Left Renal Length					
	All (n = 794)		Boys (n = 394)		Girls (n = 400)		All (n = 794)		Boys (n = 394)		Girls (n = 400)	
	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2
Age	0.317	0.821	0.323	0.810	0.311	0.833	0.328	0.816	0.340	0.821	0.317	0.811
Weight	0.096	0.791	0.107	0.814	0.088	0.783	0.100	0.792	0.112	0.823	0.091	0.778
Height	0.045	0.874	0.046	0.864	0.044	0.884	0.047	0.875	0.048	0.877	0.045	0.875
BMI	0.247	0.130	0.245	0.119	0.234	0.145	0.253	0.137	0.261	0.124	0.250	0.155

Note.— All betas were significant as p -value < 0.001 .

Table 2. Multivariate Analysis of Relation between Renal Length and Age, Weight, Height, Body Mass Index (BMI) or Gender

Variable	Right Renal Length						Left Renal Length					
	All (n = 794)		Boys (n = 394)		Girls (n = 400)		All (n = 794)		Boys (n = 394)		Girls (n = 400)	
	β	P	β	P	β	P	β	P	β	P	β	P
Age	0.025	0.190	- 0.007	0.810	0.040	0.100	0.006	0.760	0.000	0.980	- 0.004	0.870
Weight	- 0.014	0.040	0.006	0.640	- 0.020	0.010	- 0.017	0.010	- 0.004	0.770	- 0.018	0.030
Height	0.046	< 0.001	0.044	< 0.001	0.045	< 0.001	0.051	< 0.001	0.048	< 0.001	0.051	< 0.001
BMI	0.062	< 0.001	0.043	0.054	0.065	< 0.001	0.078	< 0.001	0.063	0.005	0.079	< 0.001
Gender	- 0.003	0.930					- 0.014	0.730				
R^2	0.880		0.870		0.890		0.880		0.880		0.880	

Table 3. Univariate Analysis of Relation between Renal Volume and Age, Weight, Height or Body Mass Index (BMI) in Boys and girls

Variable	Right Renal Volume						Left Renal Volume					
	All (n = 794)		Boys (n = 394)		Girls (n = 400)		All (n = 794)		Boys (n = 394)		Girls (n = 400)	
	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2	β	R^2
Age	3.952	0.813	3.898	0.784	4.025	0.844	4.875	0.830	4.868	0.831	4.908	0.832
Weight	1.246	0.842	1.324	0.826	1.189	0.862	1.532	0.854	1.632	0.853	1.458	0.859
Height	0.550	0.835	0.546	0.811	0.556	0.859	0.673	0.838	0.673	0.838	0.675	0.839
BMI	3.552	0.185	3.448	0.157	3.661	0.214	4.377	0.188	4.164	0.155	4.579	0.222

Note.— All betas were significant as p -value < 0.001 .

Table 4. Multivariate Analysis of Relation between Renal Volume and Age, Weight, Height, Body Mass Index (BMI) or Gender

Variable	Right Renal Volume						Left Renal Volume					
	All (n = 794)		Boys (n = 394)		Girls (n = 400)		All (n = 794)		Boys (n = 394)		Girls (n = 400)	
	β	P	β	P	β	P	β	P	β	P	β	P
Age	0.149	0.550	- 0.296	0.460	0.410	0.190	0.720	0.010	0.740	0.090	0.550	0.170
Weight	0.585	< 0.001	0.173	< 0.001	0.492	< 0.001	0.752	< 0.001	0.891	< 0.001	0.738	< 0.001
Height	0.281	< 0.001	0.251	< 0.001	0.278	< 0.001	0.260	< 0.001	0.223	0.001	0.272	< 0.001
BMI	0.232	0.190	- 0.032	0.920	0.310	0.150	0.200	0.340	- 0.022	0.950	0.273	0.330
Gender	0.638	0.240					0.780	0.220				
R^2	0.870		0.840		0.890		0.870		0.870		0.880	

sizes and robustness of height and weight as standalone independent variables, we developed simple univariate equations to estimate kidney length and volume using height and weight, respectively, as shown below including the estimated 95% confidence limit (R^2 0.826-0.884, $p < 0.001$) (Figs. 1, 2).

Renal length (cm):

Boys: right = $2.270 + 0.046 \times \text{Height}$ (± 1.200), left = $2.203 + 0.048 \times \text{Height}$ (± 1.192)

Girls: right = $2.485 + 0.044 \times \text{Height}$ (± 1.072), left = $2.528 + 0.045 \times \text{Height}$ (± 1.152)

All groups: right = $2.383 + 0.045 \times \text{Height}$ (± 1.135), left = $2.374 + 0.047 \times \text{Height}$ (± 1.173)

Renal volume (cm^3):

Boys: right = $6.408 + 1.324 \times \text{Weight}$ (± 16.649), left =

$5.349 + 1.632 \times \text{Weight}$ (± 18.555)

Girls: right = $9.037 + 1.189 \times \text{Weight}$ (± 15.047), left = $8.692 + 1.458 \times \text{Weight}$ (± 18.657)

All groups: right = $7.941 + 1.246 \times \text{Weight}$ (± 15.920), left = $7.303 + 1.532 \times \text{Weight}$ (± 18.704)

DISCUSSION

There are many reports about US renal sizes and volumes and their relationships with body size (1, 2, 8, 9). To our knowledge, this study is one of the largest studies performed which evaluates the relationship between renal size and anthropometric indices. There were discrepancies in sizes between the left and the right kidney. In our study, the left kidney was significantly larger than the right

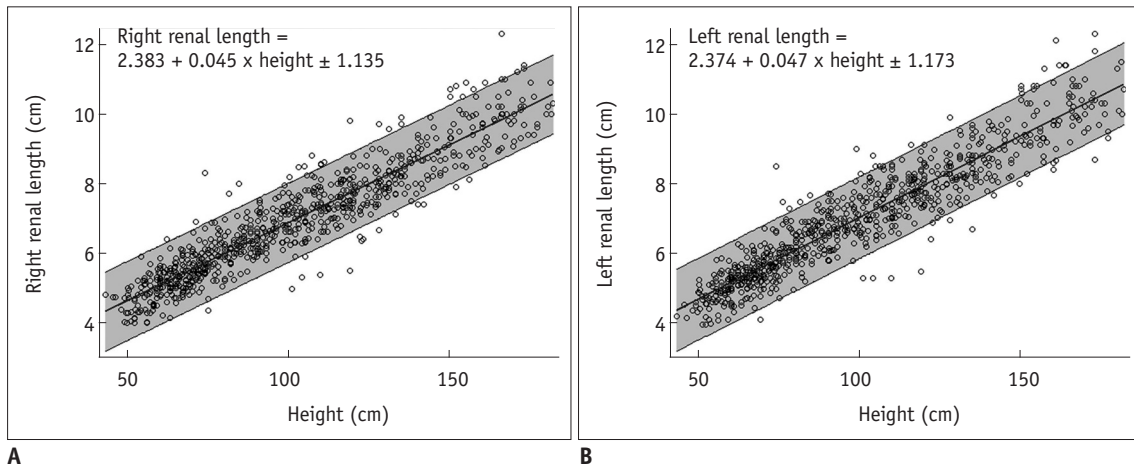


Fig. 1. Scatterplots and linear regression lines of height and renal length.

Graphs with simple equations for relationship between patient height and length of (A) right and (B) left kidneys including range for estimated 95% confidence limit.

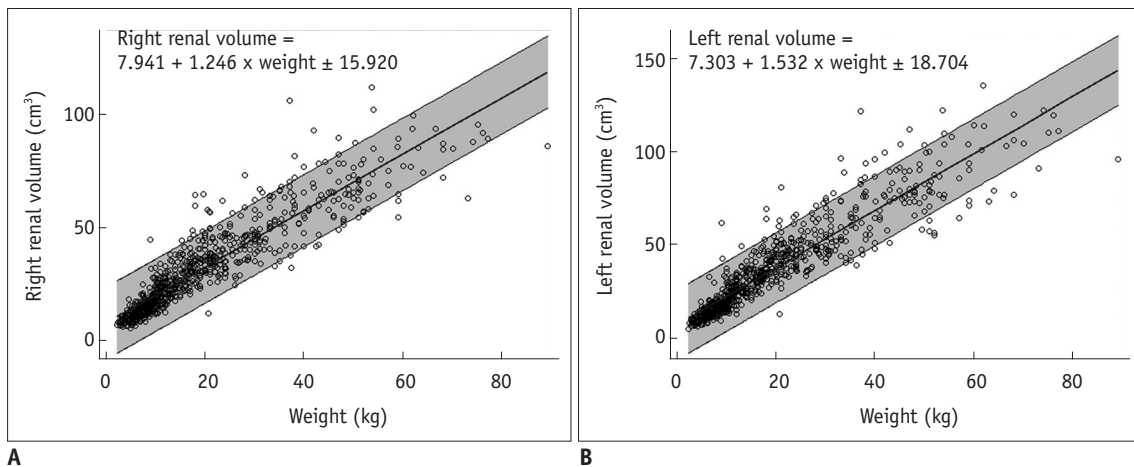


Fig. 2. Scatterplots and linear regression lines of weight and renal volume.

Graphs with simple equations for relationship between patient weight and volume of (A) right and (B) left kidneys including range for estimated 95% confidence limit.

kidney. This has also been shown in prior studies (5, 10). However, there are some studies that have demonstrated no significant differences between the left and right kidney size in children (11, 12).

It is well-known that renal size is related to age, height and weight. Many studies have shown that height correlates best with renal length (13, 14). Our study supports these prior results in that the bilateral kidney lengths show the strongest correlation with height. There is also a previous article which concludes that renal volume is closely related with body weight (13), and our results were consistent with this observation as well. In the univariate analysis, renal length shows the highest correlation with patient height and weight. Univariate equations were formulated by using simple linear regressions to estimate renal length and volume through respective body indices. The results of the univariate and multivariate analyses were also considered with the ease of use in clinical practices. Scatterplots were created, and they showed a close linear relationship between height and renal length and also between weight and renal volume.

There are also controversies regarding the correlation between gender and kidney size in children. Some studies suggest that girls have smaller kidneys (15, 16) and other studies indicate no differences in renal size between genders (17, 18). These differences may be due to the low statistical power of a small number of study groups. In our study, we made separate equations for renal size measurements for boys and girls. However, we suggest that the constants used in each equation are not remarkably different. Multivariate analysis also demonstrated that gender was not a significant independent factor on renal length and volume.

Body mass index is one of the widely-used parameters for measuring obesity. There have been several studies that evaluated body surface area and lean body mass as a predictor of renal size in children (14, 16). However, there are far fewer studies about the relationships between BMI and renal length and volume. Pantoja Zuzuárregui et al. (1) suggested that BMI is well-correlated with renal length. Interestingly, we found much weaker correlations between BMI and renal length or volume compared with that of height and weight. This suggests that BMI might not be a significant confounder in estimating the renal sizes. However, considering that the overall percentage of obese children in our study group was low, the effect of BMI might have diluted our study. Therefore, our study results may not

be applicable to a population where obesity rate is higher and the effects of BMI may need to be further investigated.

Several prior articles have suggested nomograms for predicting renal size according to body height and weight (9, 13). Herein, we have proposed a simple equation with an estimated 95% normal range that demonstrates a linear relationship between the renal size and the body parameters for easy practice. We believe that this equation can be easily applied in clinical practices and can enable a quick assessment of normal kidney size in sonographic studies.

There are limitations to our study. First, it was a retrospective study of renal size even though renal length and width measurements were routinely performed by two pediatric radiologists. The second limitation is that we examined renal size only by US, which has indicated a relatively high intra- and inter-observer error with previous studies (19, 20). The difference in US techniques, patient positioning, and cursor placement can affect the reproducibility of measurements on renal length. Therefore, future prospective studies evaluating intra- and inter-observer agreements are necessary. Moreover, Bakker et al. (21) proposed that renal volume acquired by US calculated with ellipsoid formula is not accurate, compared with renal volume acquired by MRI. Although only a small amount of patients were being compared. We think that the US assessment of renal volume is sufficient enough to obtain the normal range and to reveal relationships with body height and weight. Also, due to the need for sedation in CT or MRI, and the radiation exposure associated with CT, we prefer US evaluation in pediatric patients. However, this conclusion needs to be supported with future studies performed on a large number of patients especially in the comparison of renal volume acquired by US and MRI. The third limitation is that there were no evaluations of renal function measurements such as the serum creatinine level or glomerular filtration rate. We only evaluated sonographically normal kidneys and urinalysis for renal length and volume. However, renal function may be impaired in these morphologically normal kidneys. There have been several studies showing that renal function influences renal size (22, 23). Therefore, further study is also needed to analyze this relationship.

In conclusion, scatter plots between height and renal lengths and also between weight and renal volume were established among Korean children and simple equations between them were developed for use in clinical practice.

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