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Ultrasonographic renal volume in Chinese children: Results of 1683 cases

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ABSTRACT

Background: At present, little information has been made available in the evaluation of renal volume in pediatric groups of different ages.
Purpose: The purposes of the study are to evaluate the relationship between anthropometric measurements and renal volume measured with three-dimensional ultrasonography in Chinese children who have normal kidneys, and to attempt to develop reliable reference values of renal volume to estimate the renal sizes.
Methods: A total of 1572 Chinese Han children suffering from stomachache, cryptorchidism and neurogenic enuresis with no history of renal disease or pathological abnormalities that might affect measurements, aged 1 month to 12 years (mean, 5.64 years) were examined bilateral kidneys by ultrasonography. The measurements of renal volume were determined using QLAB software in IU22 units (Philips Medical Systems, Holland). Anthropometric indices including sex, age, height and weight were collected for reviewed analysis.
Results: A total of 1683 children were included, and renal volume of 1572 cases (93.4%) was accepted. There was no significant difference between renal volumes of male and female separately in left and right kidneys ($P = 0.844$ and $P = 0.621$, respectively), whereas there was a significant difference between mean left and right renal volumes ($P = 0.000$). Age, height and weight were all significant correlations with renal volume (R^2, 0.885 and 0.913 for the left and right kidneys, respectively, both $P = 0.000$), and age was the strongest correlation with renal volume (r, 0.472 and 0.399 for the left and right kidneys, respectively) among the anthropometric indices. We drew regression equations to estimate renal volume as follows: left renal volume (cm^3) = $0.441 \times$ age + $0.156 \times$ height + $0.398 \times$ weight + 6.677 and right renal volume (cm^3) = $0.256 \times$ age + $0.195 \times$ height + $0.632 \times$ weight + 1.788, and developed reference values of renal volume separately for the left and right kidneys in different age groups.
Conclusions: Regression equations have been developed, which define the renal volume from three-dimensional ultrasonography and may assist pediatricians in monitoring renal growth and detecting of unsuspected bilateral increases or decreases in renal size.

Kidney diseases are common in children. Measuring renal size is very important in many pediatric clinical situations: during treatment of acute or chronic renal failure, in recurrent urinary tract infections, in the follow-up after unilateral nephrectomy, in vesicoureteral reflux, and in abnormal development of kidneys such as hydronephrosis, polycystic kidneys, and so on. Given that some treatment decisions are based on serial measurements of renal size, which provide information about disease progression, stability or regression, or about the onset of complications, an accurate and noninvasive method is needed that preferably does not use ionizing radiation or contrast material [1].

Nephron is the basic unit of the structure and function of the kidney. Several studies have shown that total nephron (glomerular) number varies widely in normal human kidneys, and low nephron number has significant clinical implications, as it has been associated with hypertension, proteinuria, and chronic kidney disease [2,3]. However most of the variation in nephron number is present at birth and is therefore developmentally determined. The renal volume accurately represents the renal size, and has been regarded as a potential indicator of renal function [4–9]. Three-dimensional ultrasonography has a rapid scanning and volume postprocessing ability, which provides a new screening modality for the precise measurement of renal volume in children and provides more accurate information for clinicians. While three-dimensional ultrasonography has become a well-established method in the evaluation of renal volume [4,10–13], little information has been made available in the evaluation of renal volume in pediatric groups of different ages, however. In addition, the diagnostic criteria of enlargement or diminishment of kidneys in children are rather vague in China. The purpose of this study was to evaluate the relationship of anthropometric indices including sex, age, height and weight with renal volume determined by three-dimensional ultrasonography in Chinese children who have morphologically normal kidneys without evidence of kidney disease, and to estimate renal volume using the anthropometric indices.

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1. Materials and methods

1.1. Patients

Between December 2008 and February 2015, 1683 Chinese Han children were prospectively examined because of stomachache, cryptorchidism and enuresis by ultrasound in the ultrasonography department of Shengjing Hospital of China Medical University. The following inclusion criteria for enrollment were used: (1) age 1 month to 12 years; (2) no history of renal or other diseases such as cardiovascular diseases and diabetes, and (3) no diseases of urinary system as confirmed by other examinations. All cases were healthy full-term children with normal birth weight. A total of 1683 healthy children were enrolled in this study, which was approved by the institutional ethical board of the hospital, and the informed consent was obtained from all guardians of the children.

Sex, age (in months), weight (kg) and height (cm) of each patient were recorded at the time of physical examination.

1.2. Instruments

Ultrasonography was performed using an IU22 unit (Philips Medical Systems, Holland) with a 2-6 MHz 3D convex array probe.

1.3. Ultrasound examination

The bladder of each subject was emptied before examination. To establish the accuracy of the measurement technique, the ultrasound examinations were performed by one ultrasonographer with training in using 3D applications in service and more than 5 years of work experience.

Ultrasound scans were acquired with patients lying in the left and right lateral decubitus positions. A longitudinal image of the kidney was obtained with a 2- to 6-MHz 3D transducer during a single breath-hold period which allowed the visualization of renal sections to be reconstructed. For younger children unable to breath hold, we improved the scanning speed by rotating the button of speed. Children were eliminated from this study when clear images were not obtained for any reason, such as intense crying, movement and so on.

The series of 3D data were acquired and analyzed using QLAB software on the ultrasound machine with reconstructed images in the three spatial planes. Appropriate stacks of each kidney were used to determine the volume, using the stacked contour volume software of the IU22 ultrasound machine. The outline of the kidney was drawn, shown in the Y plane to obtain the perimeter trace and the area of each slice of each kidney was calculated, then the volume was determined by the ultrasound machine automatically.

1.4. Statistical analysis

We compared the renal volumes between left and right kidneys by paired sample *t* tests, and between boys and girls by Student's test. Multiple linear regression analysis was used to evaluate the association between the renal volume and the age, height, and weight. Age-specific reference ranges for renal volume were reported by mean ± standard deviation (SD). All data were stored and analyzed with SPSS ver. 16.0 (SPSS Inc., Chicago, IL, USA), with values of $P < 0.05$ considered significant. A month was used as a unit for statistical analysis (one year = 12 months).

2. Results

2.1. Distributions of age in subjects and measurement of renal volume with three-dimension ultrasonography

Of the 1683 children undergoing ultrasound, renal volumes were clearly determined in 1572 (794 boys and 778 girls), while 111 children were eliminated from the study because of hydronephrosis, abnormal renal function and unclear images of severe crying children. The total detection rate was 93.4%. Distributions of age in subjects, recorded as months and years, are shown in Tables 1 and 2, respectively. An example of measurement of renal volume with three-dimensional ultrasonography is shown in Fig. 1. The mean height and weight were 109.53 ± 30.97 cm and 20.76 ± 12.20 kg, respectively.

Paired sample *t* test showed that there was a significant difference between mean left and right renal volumes (61.68 mL and 53.39 mL, $t = 30.023$, $P = 6.68 * 10^{-157}$). Student's *t* test showed that there was no significant difference between the renal volumes of male and female ($t = 0.197$ and 0.495 for the left and right kidneys, respectively, with $P = 0.844$ and $P = 0.621$, respectively). Consequently, data on renal volumes of male and female were combined for analysis.

2.2. Relations between renal volume and age, height and weight

Using multiple linear regression analysis, we found that there was a significant correlation between renal volume and age, height and weight (all $P < 0.05$), and age was the strongest correlation with renal volume (r, 0.472 and 0.399 for the left and right kidneys, respectively) among the anthropometric indices, as shown in Tables 3 and 4.

We developed regression equations to estimate renal volume using age, height and weight, respectively, in left and right kidneys as follows: left renal volume (cm^3) = 0.441 × age + 0.156 × height + 0.398 × weight + 6.677 and right renal volume (cm^3) = 0.256 × age + 0.195 × height +0.632 × weight + 1.788.

2.3. All values in different age groups fit the normal distribution

Therefore, mean ± SD ($\bar{x} \pm s$) was used to assess the reference ranges with age of the renal volumes. Mean ± SD of the renal volumes for children according to age group is shown in Tables 5 and 6.

3. Discussion

Knowledge of normal renal size is essential not only to follow up children with renal disease but also to know whether the kidneys are growing appropriately. In addition, renal volume estimated also correlates with renal function [14,15]. In some early renal diseases, there are obviously changes in renal volume but not in renal structure. There are intimate relationships between renal volumes and kidney diseases, such as congenital kidney malformations, polycystic kidney, acute or chronic urinary tract infections and renal insufficiency and so on. Congenital kidney diseases that result in chronic renal failure, most commonly kidney malformations and polycystic kidneys, are more common in children than in adults. Childhood is an important period of growth for many organ systems, including the kidney. It is therefore necessary to establish precise normal reference values of renal volume in healthy children correlated with anthropometric indices, in order to determine kidney growth and development. Regular monitoring of kidney growth provides clinicians with one of the best indicators of the underlying pathological condition in kidney disorders, enabling indirect evaluation of renal function.

At present, there are many imaging examination modalities available for determining renal volume, including abdominal computed

Table 1
Distribution of age in months in subjects of ≤1 year of age in children.

Age group (months)	Male (case no.)	Female (case no.)	Total (case no.)
1–3	54	50	104
3–6	50	60	110
6–12	53	55	108