

Normal renal size by body-surface-area renal volume using ultrasound in a population aged 0-18 years from Aguascalientes state, Mexico

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ABSTRACT

Introduction: No standardized measurements of normal renal size exist in the Mexican pediatric population. The aims of this study were to (1) determine renal volume by ultrasound (US) adjusted for body surface area to define normal renal size and (2) develop normality tables for body-surface-area renal volume (BSARV) for the population aged 0-18 years in the state of Aguascalientes, Mexico. **Methods:** A prospective, cross-sectional study was conducted in a healthy population aged 0 to 18 years in the state of Aguascalientes, Mexico. The assessment was performed with renal US in grayscale. Age, height, sex, weight, and body surface area were recorded. The ultrasonographic parameters in both kidneys were length, volume, relative volume, and BSARV. Mean, standard deviation and 1 to 95 percentiles were calculated. **Results:** We included 1076 participants, 519 women, and 557 men. All had morphologically normal kidneys. There was a direct relationship between kidney length and age and height; the higher the age and height, the greater the kidney length. Normal kidney size according to the BSARV was 41.4 mL/m² to 70.6 mL/m² (10th and 90th percentiles, respectively) for the right kidney and 45.2 mL/m² to 73.8 mL/m² (10th and 90th percentiles, respectively) for the left kidney in both sexes, regardless of age and height. We defined normality charts of BSARV of the right and left kidney (percentiles 1 to 99) for the population aged 0-18 years. **Conclusion:** BSARV was the most accurate ultrasonographic parameter for kidney size in the Mexican population aged 0 to 18 years in one region of the country. BSARV is a simple and practical method for determining kidney size to assess normal kidney growth and development.

Keywords: Ultrasound. Body surface area. Renal volume. Body-surface-area related renal volume.

INTRODUCTION

Kidney growth and development begins in fetal life and continues to adulthood. Ultrasound (US) is the imaging modality of choice for determining renal size because it does not expose patients to radiation and is affordable^{1,2}. Several studies have used ultrasonography to determine renal size in the pediatric population¹⁻⁸. The commonly evaluated ultrasonographic parameters of renal size are length and volume^{2,4}. These measurements

have been associated with age, height, sex, weight, and ethnicity². The anthropometric parameters commonly associated with renal volume are age and height⁵. Normal value tables for renal size have been defined based on these measurements^{2,4,5,9}. However, their use can be impractical and complex for radiologists because they require time and specific measurements such as height percentile charts¹. Therefore, assessment of renal size is often omitted, and only morphologic findings of the renal parenchyma are reported¹.

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Received for publication: 02-05-2023

Accepted for publication: 09-06-2023

DOI: 10.24875/JMEXFRI.M23000055

Available online: 05-10-2023

J Mex Fed Radiol Imaging. 2023;2(3):163-171

www.JMeXFRI.com

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Normal renal size is a critical parameter in the pediatric population because any kidney damage, whether acute or chronic, manifests as an increase or decrease in renal size¹. Therefore, establishing normal values in healthy children is useful for detecting abnormalities. The renal parenchyma volume reflects the nephron mass. Renal function, measured by the glomerular filtration rate, depends on the area of the renal parenchyma^{1,2,4-6,9,10}. Measuring renal volume provides a more accurate estimation of renal function than a one-dimensional measure of renal length. The body-surface-area-related renal volume (BSARV) has been described as the most accurate parameter for renal size in different world populations^{1,4,11,12}. In Mexico, standardized normal renal size measurements by US have not been defined in the pediatric population. The aims of this study were to (1) determine normal renal size with BSARV by US and (2) develop BSARV normality tables for the population aged 0 to 18 years in the state of Aguascalientes, Mexico.

MATERIAL AND METHODS

This cross-sectional study was conducted from December 2021 to November 2022. Healthy participants aged 0 to 18 years living in the Mexican cities of Aguascalientes, Calvillo, and Rincon de Romos in the state of Aguascalientes, Mexico, were included. Participants with a history of congenital obstructive kidney disease, infectious or autoimmune kidney disease, renal transplantation, or a known alteration in renal development were excluded. Participants with morphologic abnormalities detected incidentally during the ultrasonographic assessment were eliminated. The parents or guardians of the participants signed the informed consent form. The Ethics and Research Committees of the Centenario Hospital Miguel Hidalgo, Secretaria de Salud in Aguascalientes, Mexico, approved the study.

Study development and variables

Newborns were recruited from the Hospital de la Mujer in Aguascalientes, Mexico. Participants aged 1 to 3 years were contacted through a DIF center in Calvillo and the San Damian Hemodialysis Clinic. Participants aged 4 to 18 were contacted in schools in Aguascalientes, Calvillo, and Rincon de Romos.

Age, height, sex, weight, and body surface area were recorded electronically. Ultrasonographic assessment parameters were renal length, renal volume, relative renal volume of the left and right kidney, and BSARV.

Definitions

Renal volume (RV): was calculated using the ellipsoid formula¹:

$$\text{Renal volume} = 0.523 (\text{length} * \text{depth} * \text{width}),$$

which measures longitudinal axis (length), anteroposterior axis (depth) in the longitudinal plane, and the transverse axis (width) at the level of the renal hilum.

Relative renal volume: includes the left or right kidney volume divided by the total renal volume respectively.

Body surface area (BSA): is the estimated surface area of the human body calculated using the Dubois formula¹³:

$$\text{BSA (m}^2\text{)} = 0.007184 * \text{body weight (kg)}^{0.425} * \text{body height (cm)}^{0.725}$$

Body-surface-area renal volume (BSARV): is the renal volume adjusted to the body surface area, obtained by dividing the renal volume by the body surface area.

$$\text{BSARV} = \frac{\text{Renal volume (mL)}}{\text{Body surface area (m}^2\text{)}}$$

US imaging and analysis protocol

Renal US was performed in real-time using two *SonoScope* model E2V (Sonoscape medical board, Shenzhen, China) portable ultrasound machines with 3C-A convex transducers. Renal measurements were performed using the standard technique in the three maximal dimensions (Figure 1). The maximum longitudinal and anteroposterior diameters were determined in the longitudinal plane, and the transverse diameter of each kidney in the axial plane. Most of the ultrasound images were obtained from a dorsal approach in the prone position and others from a ventral approach in the supine position.

US examinations were performed by two second-year radiology residents, one third-year radiology resident, and one radiologist (HCG) with 18 years of experience.

Statistical analysis

Continuous variables with normal distribution are reported as means and standard deviations. Non-parametric distributed continuous variables are described as means and interquartile ranges (IQR), and qualitative variables as absolute and relative frequencies. Multiple linear regression was performed to assess the

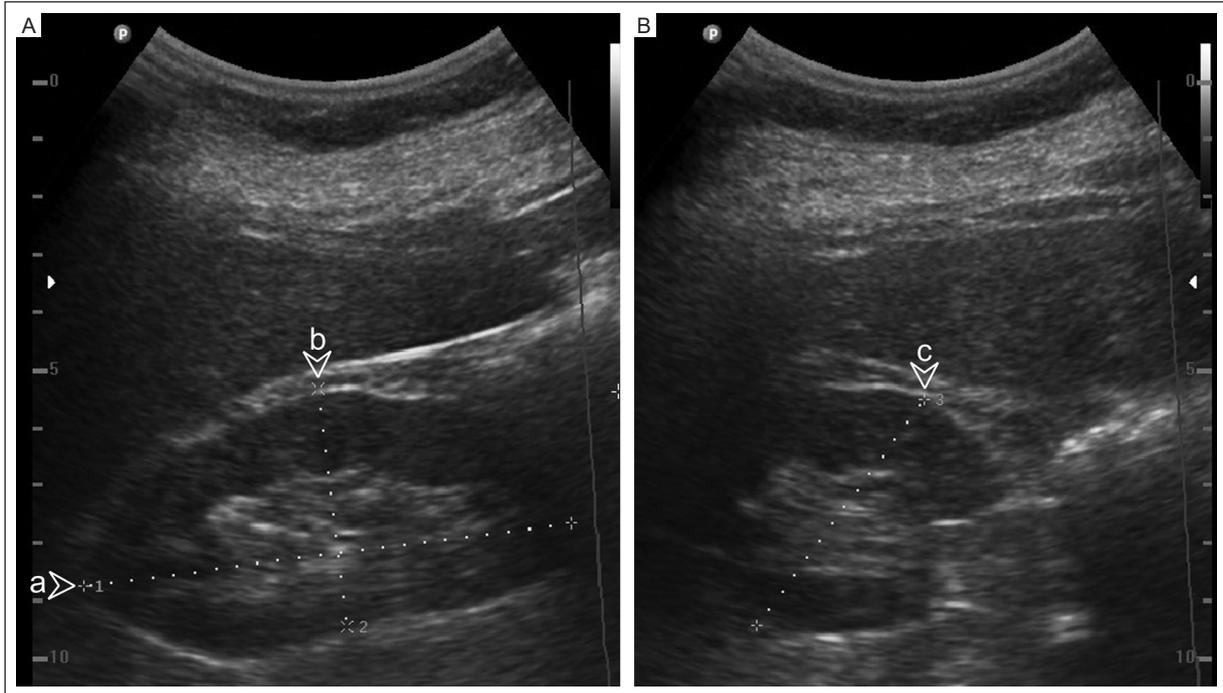


Figure 1. Standard renal US technique. **A:** the longitudinal axis (line a) and the anteroposterior axis (line b) are obtained in the longitudinal plane. The renal cortex and medulla should be visible at both ends. Calipers are placed at the ends of each renal pole and the region of greatest volume in its anteroposterior diameter. **B:** the transverse axis (line c) is determined in an axial plane at the level of the renal hilum with calipers placed at the ends of each side.

US: Ultrasound.

relationship between renal length, age, and height, with a β value reported with a 95% confidence interval. BSARV was compared by age group using the Mann-Whitney U test. BSARV was evaluated with respect to a normal distribution with the Kolmogorov-Smirnov test. Normal value tables were developed with the 1, 5, 10, 25, 50, 50, 75, 90, 95, and 99 percentiles of renal length in relation to age and height, renal volume in relation to age, and BSARV in relation to age. A p -value < 0.05 was considered significant. Statistical analysis was performed using STATA version 12 software (Stata Corp, College Station, TX, USA).

RESULTS

A total of 1083 US examinations were performed in a healthy population aged 0 to 18 years. Seven participants were eliminated because of incidental ultrasonographic findings: two cases because of pyelocaliceal ectasia, three due to renal agenesis, and two due to renal hypoplasia. The study included 1076 participants, 519 women, and 557 men. All were from the state of Aguascalientes: 542 from Aguascalientes city, 402 from Calvillo, and

132 from Rincon de Romos. The mean height of the participants was 141 ± 32 cm (IQR 109 to 161), and the mean weight was 80.7 ± 36.5 kg (IQR 19 to 56).

Relationship of renal length to age and height

Figure 2 shows the distribution curves of renal length-age and renal length-height for both kidneys. A direct relationship was found between renal length, age, and height; the greater the age or height, the greater the renal length. Renal length normality tables of the right and left kidney (percentiles 1, 5, 10, 25, 50, 50, 75, 90, 95, and 99) in relation to age and height in the population aged 0-18 years are shown in Supplementary Tables 1, 2, 3, and 4.

The relationship of age and height with renal length was analyzed with multiple linear regression (Table 1). Coefficient β -values less than 1 ($p < 0.01$) were obtained for both variables. We found a poor correlation between age, height, and renal length of both kidneys.

Relationship of renal volume to age

The renal volume of both kidneys in relation to age is shown in Figure 3. A direct relationship was found

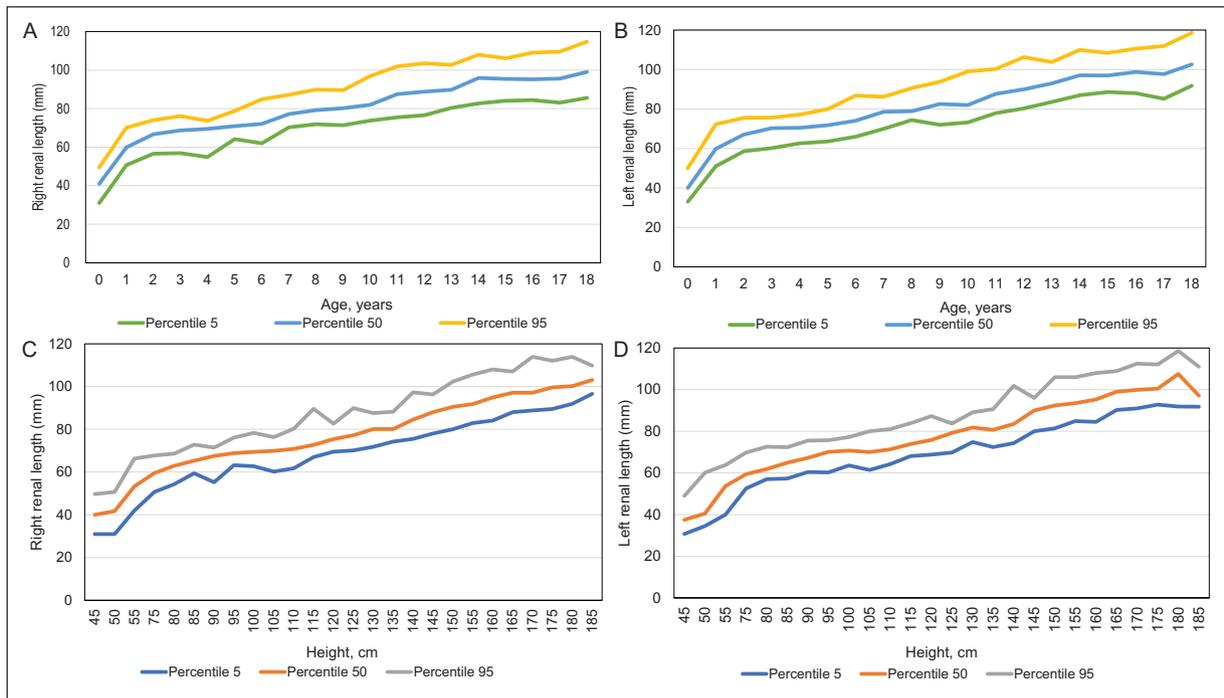


Figure 2. Renal length and age and height are directly related in a population aged 0-18 years from Aguascalientes state, Mexico. **A:** right renal length-age relationship. **B:** left renal length-age relationship. **C:** right renal length-height relationship. **D:** left renal length-height relationship.

Table 1. Renal length β Coefficient by age and height in a population aged 0-18 years Aguascalientes State, Mexico

Parameters	Right kidney			Left kidney		
	β coefficient	95% CI	p-value	β coefficient	95% CI	p-value
Age	0.6587	0.4369 - 0.8804	< 0.01	0.5372	0.3303 - 0.7441	< 0.01
Height	0.3539	0.3205 - 0.3873	< 0.01	0.3824	0.3512 - 0.4135	< 0.01

CI: confidence interval.

between renal volume and age; the older the age, the greater the renal volume. Renal volume normality tables for the right and left kidneys (percentiles 1, 5, 10, 25, 50, 50, 75, 90, 95, and 99) of the population aged 0-18 years are shown in Supplementary Tables 5 and 6.

Relative renal volume

The relative renal volume of the right and left kidneys was estimated. Renal volume was symmetrical, with comparable values for both kidneys (Table 2). All percentiles from 1 to 99 had a less than 10% difference in relative volume between both kidneys.

Body-surface-area renal volume (BSARV)

BSARV histograms showed a symmetrical distribution of right and left kidneys in the population aged 0 to 18 years (Figure 4). The mean BSARV of the right kidney was 55.1 ± 12.1 mL/m² and 58.0 ± 11.4 mL/m² for the left kidney. BSARV was stratified into percentiles 1 to 99 (Table 3). The normal range of the BSARV of the right kidney was 41.4 mL/m² (10th percentile) to 70.6 mL/m² (90th percentile), with a mean of 53.54 mL/m². The normal range of the left kidney was 45.2 mL/m² (10th percentile) to 73.8 mL/m² (90th percentile), with a mean of 56.6 mL/m².

Table 2. Relative renal volumes of both kidneys in a population aged 0-18 years from Aguascalientes state, Mexico

Parameters	Percentiles								
	1	5	10	25	50	75	90	95	99
Right kidney relative renal volume	0.36	0.41	0.43	0.45	0.48	0.51	0.52	0.55	0.60
Left kidney relative renal volume	0.40	0.44	0.46	0.48	0.51	0.54	0.56	0.58	0.63

Table 3. BSARV of both kidneys in a population aged 0-18 years from Aguascalientes state, Mexico

Parameters	Percentiles								
	1	5	10	25	50	75	90	95	99
Right kidney, mL/m ²	32.8	38.6	41.4	46.8	53.4	62.01	70.6	77.5	91.5
Left kidney, mL/m ²	33.9	41.8	45.2	50.5	56.6	64.4	73.8	79.9	95.4

BSARV: body-surface-area renal volume.

Table 4. Right kidney BSARV in a population aged 0-18 years from Aguascalientes State, Mexico

Age, years	n	Mean, mL/m ²	SD	95% CI	Percentiles, mL/m ²								
					1	5	10	25	50	75	90	95	99
0 to < 1	78	52.2	14.4	49.0-55.5	25.4	28.1	33.4	40.2	50.6	59.3	68.1	73.0	110.0
1 to < 2	56	52.7	9.60	50.1-55.3	34.9	38.4	39.8	46.0	51.6	60.0	66.4	70.5	74.70
2 to < 3	53	56.5	10.0	53.7-59.2	36.5	40.5	44.6	49.7	55.3	63.2	70.1	73.1	81.90
3 to < 4	41	52.6	12.1	48.8-56.5	32.6	35.2	39.4	45.7	51.6	58.2	65.0	69.0	100.2
4 to < 5	32	49.3	10.3	45.6-53.1	32.8	33.1	36.1	41.9	49.2	55.7	64.0	67.9	69.00
5 to < 6	63	53.3	10.0	50.8-55.9	35.7	39.7	40.7	46.6	52.4	59.1	67.8	68.9	89.50
6 to < 7	70	54.5	9.70	52.1-56.8	35.4	38.7	41.4	49.5	54.5	69.4	69.3	71.6	76.80
7 to < 8	52	54.6	9.10	52.1-57.2	39.6	42.3	43.3	47.4	54.0	59.6	66.8	70.7	80.50
8 to < 9	34	51.7	10.4	48.1-55.4	34.8	36.6	38.9	44.3	50.5	57.0	70.6	72.1	77.20
9 to < 10	48	49.0	8.10	46.7-51.4	34.3	37.2	39.2	42.9	48.4	53.4	60.2	64.1	72.60
10 to < 11	31	54.3	12.4	49.7-58.9	38.9	42.0	42.4	45.9	52.5	58.8	64.2	66.0	107.5
11 to < 12	42	58.3	17.8	52.7-63.8	33.1	37.1	41.9	46.1	56.9	64.8	78.3	88.2	117.2
12 to < 13	67	59.7	11.7	56.9-62.6	39.5	44.4	45.9	49.5	57.6	69.0	76.7	78.9	91.50
13 to < 14	59	54.7	9.50	52.2-57.2	37.1	40.1	41.8	46.9	55.4	62.3	69.5	70.2	77.90
14 to < 15	106	61.8	13.5	59.2-64.4	39.7	43.2	46.9	50.7	58.4	73.0	81.6	86.7	91.90
15 to < 16	83	56.4	11.2	53.9-58.9	34.9	41.6	43.6	48.6	53.7	64.3	72.1	78.2	82.90
16 to < 17	113	53.3	10.9	51.3-55.4	32.8	38.0	41.4	46.6	50.9	59.9	66.2	74.5	87.10
17 to < 18	35	57.0	16.0	51.5-62.5	33.2	39.6	41.6	43.4	53.8	65.2	80.4	84.4	111.6
18 to < 19	14	57.7	12.1	50.7-64.7	38.8	38.8	41.4	44.7	61.9	66.0	70.0	76.2	76.20

BSARV: body-surface-area renal volume; CI: confidence interval; SD: standard deviation.

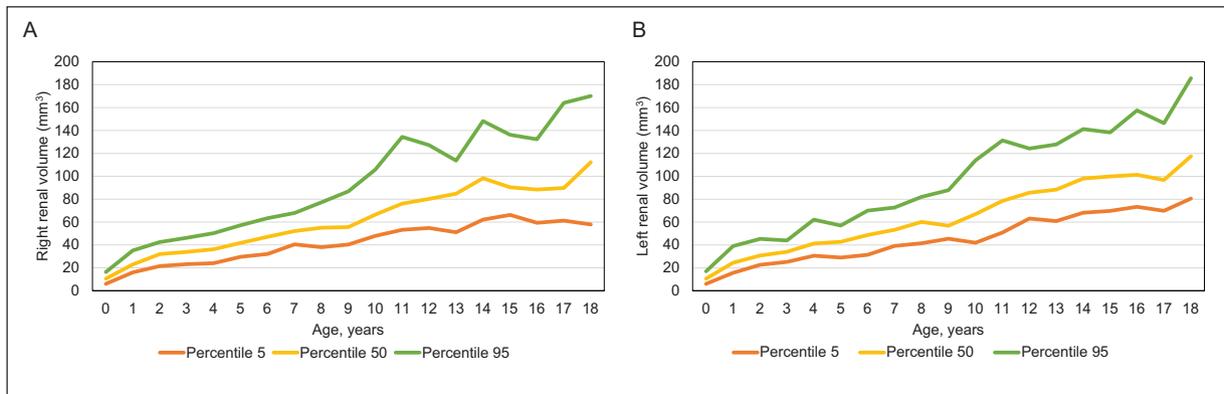


Figure 3. Renal volume-age relationship in a population aged 0-18 years from Aguascalientes state, Mexico. **A:** right kidney, and **B:** left kidney. Volume increases in direct relationship with age.

Table 5. BSARV left kidney in a population aged 0-18 years of the Aguascalientes State, Mexico

Age, years	n	Mean, mL/m ²	SD	95% CI	Percentiles, mL/m ²								
					1	5	10	25	50	75	90	95	99
0 to < 1	78	53.8	15.4	50.3-57.3	24.5	29.1	33.1	45.3	51.1	59.2	74.8	78.8	114.9
1 to < 2	56	55.2	11.5	52.1-58.3	33.9	38.5	40.5	46.9	54.1	60.7	69.0	80.1	86.60
2 to < 3	53	58.0	9.60	55.3-60.6	41.1	44.2	46.5	50.6	55.9	64.2	71.9	76.8	79.20
3 to < 4	41	55.1	9.70	52.0-58.1	41.4	42.7	43.7	47.9	54.4	61.7	67.4	68.2	88.40
4 to < 5	32	58.2	10.5	54.4-62.0	39.1	41.8	48.2	52.0	56.7	63.4	70.7	81.0	87.80
5 to < 6	63	54.9	10.2	52.3-57.5	35.4	39.5	43.1	48.1	54.1	60.2	68.1	71.8	87.10
6 to < 7	70	56.6	9.00	54.5-58.8	37.3	39.3	44.3	50.9	56.9	63.2	67.0	71.9	77.10
7 to < 8	52	55.2	8.60	52.8-57.6	41.9	45.4	45.7	49.3	53.0	60.4	65.9	74.8	80.80
8 to < 9	34	55.7	9.60	52.4-59.1	38.7	40.2	45.4	48.0	56.0	60.4	69.4	74.3	78.70
9 to < 10	48	53.6	9.20	50.9-56.3	39.3	41.8	43.1	48.1	51.9	57.9	65.2	74.7	80.50
10 to < 11	31	55.9	10.9	51.8-59.9	37.9	39.0	46.0	48.8	54.0	62.2	73.9	76.2	81.40
11 to < 12	42	58.2	14.0	53.9-62.6	39.0	41.7	43.3	47.0	54.4	65.8	79.1	89.2	92.00
12 to < 13	67	61.8	12.5	58.7-64.9	42.2	48.5	49.3	53.2	59.3	66.3	76.8	86.3	110.3
13 to < 14	59	59.9	9.70	56.4-61.4	39.9	43.8	45.7	53.4	58.0	64.6	69.5	75.5	95.40
14 to < 15	106	62.5	11.2	60.3-64.7	42.8	47.3	49.8	54.8	60.6	69.8	81.3	85.6	92.80
15 to < 16	83	61.1	11.5	58.5-63.6	34.7	41.8	46.5	54.0	60.0	67.2	75.3	79.5	98.30
16 to < 17	113	60.4	11.1	58.3-62.5	40.0	46.1	49.2	52.9	58.5	66.5	75.2	84.8	91.30
17 to < 18	35	59.1	11.0	55.3-62.9	35.3	43.1	48.1	50.8	57.9	65.7	72.1	82.6	88.70
18 to < 19	14	63.5	11.3	57.0-70.0	41.3	41.3	49.4	52.6	66.8	69.9	73.8	83.2	83.20

BSARV: body-surface-area renal volume; CI: confidence Interval; SD: standard deviation.

Figure 5 shows the relationship between BSARV and age (5th, 50th, and 95th percentiles). BSARV did not directly increase with increasing age. It remained in an

average range of 53.54 mL/m² for the right kidney and 56.6 mL/m² for the left kidney, regardless of age. Normality charts of BSARV of the right and left kidney

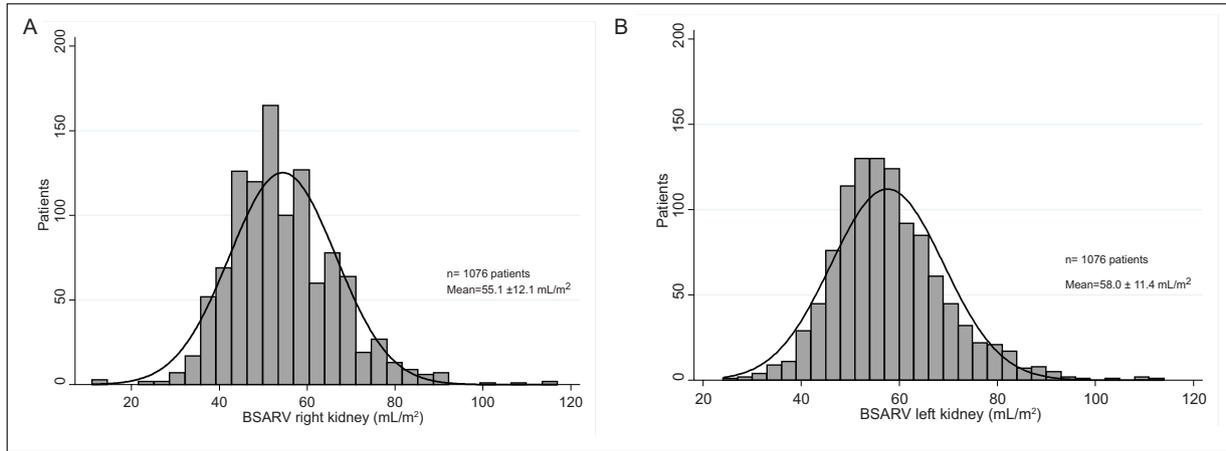


Figure 4. BSARV distribution histograms in a population aged 0-18 years from Aguascalientes state, Mexico. **A:** right kidney, **B:** left kidney showing a symmetrical (Gaussian) distribution independent of age, sex, and height. The mean BSARV of the right kidney is 55.1 ± 12.1 mL/m² and of the left kidney 58.0 ± 11.4 mL/m².

BSARV: body-surface-area renal volume.

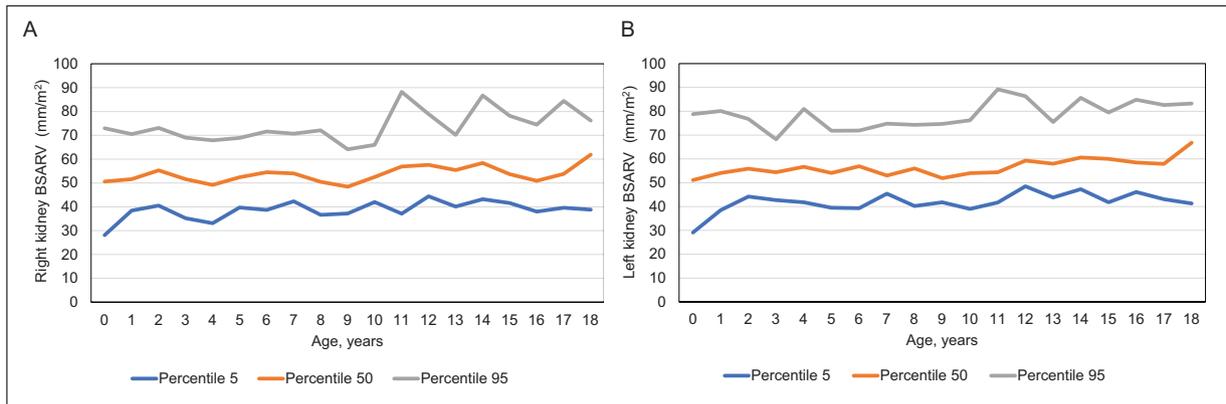


Figure 5. A: in a population aged 0-18 years from Aguascalientes state, Mexico, the normal range of the right kidney BSARV was 41.4 mL/m² (10th percentile) to 70.6 mL/m² (90th percentile) in both sexes, regardless of age and height. **B:** the normal range of the left kidney BSARV was 45.2 mL/m² (10th percentile) to 73.8 mL/m² (90th percentile) in both sexes, regardless of age and height. BSARV does not increase in direct relation to age.

BSARV: body-surface-area renal volume.

(percentiles 1, 5, 10, 25, 50, 50, 75, 90, 95, and 99) of the population aged 0-18 years are shown in Tables 4 and 5.

DISCUSSION

In our study, BSARV was the most accurate ultrasonographic parameter of renal size in both sexes in the Mexican population aged 0 to 18 years from the state of Aguascalientes, Mexico. The normal BSARV values were 41.4 mL/m² to 70.6 mL/m² (10th and 90th percentiles, respectively) for the right kidney and 45.2 mL/m² to 73.8 mL/m² (10th and 90th percentiles, respectively)

for the left kidney, regardless of age and height. This study is the first that reports renal size using standardized BSARV measurements in a region of Mexico. We have developed normality charts of BSARV of the right and left kidney (percentiles 1 to 99) for the population aged 0 to 18 years. Follow-up by individual percentile can be performed, and individual prognosis of renal growth and development can be defined based on these standardized BSARV measurements.

Increased or decreased renal size is the earliest ultrasonographic finding of altered renal function and precedes morphologic changes in the renal parenchyma. Scholbach et al.¹ showed in a renal US study of 624

German children aged 1 month to 16 years that renal volume was a better predictor of glomerular filtration rate than renal length. BSARV was 45 mL/m² to 85 mL/m² (10th and 90th percentiles, respectively) in the right kidney and 45 mL/m² to 86 mL/m² (10th and 90th percentiles, respectively) in the left kidney. BSARV was the best parameter of renal size, regardless of age. The authors determined normality ranges for BSARV for the studied population. BSARV values in the German population were higher than our study in the Mexican population, approximately 3 mL/m² from the 10th percentile and 11 mL/m² from the 90th percentile. This difference could be due to the anthropometric differences of each population, including height, weight, and body surface area. Obycki et al.⁴ conducted a multicenter study that included 1,782 children aged 0 to 19 years from a European Caucasian population. Renal US was performed to assess the relationship between renal volume and height, weight, body mass index, and body surface area. The BSARV was the most significant parameter as a predictor of renal size. The normal range of BSARV between the 10th and 90th percentiles is useful to correctly assess renal size in the Mexican population aged 0-18 years in one region of the country.

Determining the relative renal volume on ultrasound is useful for detecting impairment of renal growth and development. A difference greater than 20% in renal volume between the two kidneys may indicate unilateral renal dysfunction¹. In our study, the difference in relative renal volume among 1 to 99 percentiles were approximately 10% between the left and right kidneys. These values indicate that the size of the two kidneys was comparable.

Renal size has been reported related to height^{2,4-6}. Kim et al.⁵ performed renal ultrasound on 794 Koreans under 18 years; renal size correlated with height, weight, and BMI. Height showed a more significant relationship with renal size. Similar results were reported by Haugstvedt et al.^{1,2}, who assessed 46 children aged 0-16 years with renal US. They found a correlation between renal size, age, height, weight, and body surface area and an adequate correlation with height during the first 11 years. This finding is probably related to rapid growth at this stage of life. Our results showed that renal length increased directly with age and height in the population aged 0-18 years. In our study, normality tables were defined for renal length related to height, age, and body surface area in a region with a high incidence and prevalence of chronic kidney disease¹⁴⁻¹⁵. Normality tables for renal length as a function of age and height in our population show a wide range of values. Their clinical application may be

impractical because it requires comparing many reference values, in contrast to the normal range of BSARV proposed as an ultrasonographic parameter of renal size in the population of both sexes aged 0 to 18.

Our study has several strengths. We included a large sample of male and female participants assessed with renal US. This imaging modality is widely available and affordable to the general population. On the other hand, several limitations were identified. First, only the population of one region of Mexico was included. Therefore, recommendations for using BSARV in clinical practice would be limited to this region, as there may be anthropometric differences due to the ethnic characteristics of the different regions of Mexico. Studies in other regions of Mexico are needed to validate normal renal size based on BSARV. Second, because of the nature of the operator-dependent US, inter and intraobserver variability in the measurement of BSARV needs to be determined. Third, the US renal examinations were performed indistinctly in the prone or supine position, so the accuracy of the measurements could vary with these two positions¹⁶. Fourth, the measurement of renal volume in our study was performed with 2D US, which increases the measurement variability and is also time-consuming^{17,18}. Fifth, calculating the body surface area requires the radiologist or ultrasound technician to have records of the patient's height and weight. Sixth, the patient's BSARV must be calculated, which requires an additional procedure.

CONCLUSION

In our study, BSARV was an accurate parameter for determining renal size by US in the Mexican population aged 0 to 18 years of both sexes. The BSARV normal range is 41.4 mL/m² to 70.6 mL/m² for the right kidney and 45.2 mL/m² to 73.8 mL/m² for the left kidney, regardless of age and size. Normality charts of BSARV of the right and left kidney for the population aged 0 to 18 years were defined. BSARV is an easy-to-remember and practical parameter for determining renal size by ultrasound. In the epidemiological context of the Mexican state of Aguascalientes, Mexico, which has a high incidence and prevalence of chronic kidney disease, it may be beneficial to use BSARV to detect renal size abnormalities in individuals 0-18 years old. The simple observation that a kidney deviates from normal percentiles may be particularly valuable in the follow-up of normal renal growth and development and for early detection of renal pathologies.

Supplementary data

Supplementary data are available at 10.24875/JMEXFRI.M23000055. These data are provided by the corresponding author and published online for the benefit of the reader. The contents of supplementary data are the sole responsibility of the authors.

Acknowledgments

The authors thank Professor Ana M. Contreras-Navarro for her guidance in preparing and writing this scientific paper. This original research in the Radiology Specialty field was an awarded thesis at the Primera Convocatoria Nacional 2023, “Las Mejores Tesis para Publicar en el JMEXFRI.”

Funding

This research received no external funding.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical disclosures

Protection of Individuals. This study complied with the Declaration of Helsinki (1964) and subsequent amendments.

Confidentiality of Data. The authors declare they followed their center’s protocol for sharing patient data.

Right to privacy and informed consent. The parents or guardians of the participants signed the informed consent form.

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