Relationship Among Total Kidney Volume, Renal Function and Age

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Abbreviations and Acronyms

BMI = body mass index

BSA = body surface area

CG = Cockcroft-Gault

CT = computerized tomography

GFR = glomerular filtration rate

MDRD = modification of diet in renal disease

MRI = magnetic resonance imaging

US = ultrasound

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Purpose: We measured kidney volume using software and investigated the relationship between kidney volume and renal function.

Materials and Methods: Age, gender, height, body weight, body mass index, body surface area and serum creatinine were recorded for 539 normal individuals. A tissue segmentation tool program was used to measure kidney volume from computerized tomography images. The glomerular filtration rate was calculated using the Cockcroft-Gault equation and an abbreviated modification of diet in renal disease equation. We looked for correlations of renal parenchymal volume with age and anthropometric measurements. We also tested for a correlation between kidney volume and renal function using the glomerular filtration rate according to the Cockcroft-Gault and modification of diet in renal disease equations.

Results: Mean kidney volume in all participants was 261.3 ± 58.1 ml. Mean volume in men was approximately 14 ml greater than in women (266.1 vs 251.8 ml, $p = 0.004$). Kidney volume correlated significantly with height ($r = 0.344$, $p < 0.001$), body weight ($r = 0.343$, $p < 0.001$), body mass index ($r = 0.177$, $p < 0.001$), body surface area ($r = 0.371$, $p < 0.001$) and age ($r = -0.418$, $p < 0.001$). Kidney volume also correlated with the glomerular filtration rate according to the Cockcroft-Gault and modification of diet in renal disease equations ($p < 0.001$, $r = 0.615$ and $p < 0.001$, $r = 0.432$, respectively). Kidney volume and the glomerular filtration rate decreased in parallel with increasing age.

Conclusions: Kidney volume correlates well with renal function and anthropometric measurements. Knowledge of these relationships will be valuable in clinical urology and nephrology.

Key Words: kidney, organ size, anthropometry, glomerular filtration rate, age factors

KIDNEY volume is an important parameter in the evaluation and followup of patients with end stage renal disease, a kidney transplant, polycystic kidney disease, renal artery stenosis and vesicoureteral reflux.[1–4] Changes in kidney volume may indicate disease presence or progression. Also, clinical therapeutic plans are often influenced by kidney volume measurements. Thus, accurate, reproducible methods to assess kidney volume and a reliable reference source of normal values are important.

When using US to measure kidney size, kidney volume is calculated by applying the dimensions of the 3 orthogonal axes to the ellipsoid formula. This method assumes that the kidney is an ellipsoid and fails to account for variations in kidney shape. As a result, errors may occur in volume calculation. Several groups reported that

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measuring kidney size using US is inaccurate and has poor reproducibility.[5–7] There remains much debate about the suitability of this approach.

Several groups attempted to more accurately measure kidney volume using techniques such as MRI and CT. Techniques using 3-dimensional image reconstruction with CT, which were developed to directly measure kidney volume and CT estimated volume, compare well to anatomical measurements in living kidney donors.[8,9] Also, a significant correlation was found between MRI estimated kidney volume and kidney weight in healthy donors.[10]

Recently there have been several reports of the relationship between CT estimated kidney volume and renal function. However, those studies involved a few individuals, limited representation of some age groups or specific disease subgroups, or were limited to a single gender.[11] We investigated the relationship of kidney volume with renal function and age in a large cohort of men and women with no history of renal disease, representing a broad range of ages.

MATERIALS AND METHODS

Patients

Patients were selected from an institutional review board approved database of patients from January 2009 to July 2010. A search was done for patients who underwent enhanced abdominal or abdominopelvic CT to evaluate localized abdominal pain or a diagnosis of malignancy, or as a regular evaluation. Patients diagnosed with hydronephrosis, multiple renal cysts, renal artery stenosis or renal malformation and those with a history of renal surgery were excluded from study. This resulted in the identification of 539 patients for study inclusion.

Clinical data on age, gender, height, body weight, BMI, BSA, hypertension and diabetes mellitus were recorded at physical examination or obtained from hospital records. Serum creatinine was determined and GFR was calculated with the CG equation,[12] taking BSA into account, and with the abbreviated MDRD equation.[13] The equations used were CG-GFR in ml/min/1.73 m^2 = GFR $\times$ 1.73 m^2/BSA, GFR = (140 $-$ age) $\times$ (weight in kg) $\times$ (0.85 if female)/72 $\times$ Cr and MDRD-GFR in ml/min/1.73 m^2 = $186.3 \times Cr^{-1.154} \times age^{-0.203}$ ($\times$ 0.742 if female), where Cr represents serum creatinine.

Kidney Volume Measurement

CT was done with a 16 multidetector CT scanner (Siemens, Erlangen, Germany) using the standard clinical abdominopelvic imaging protocol. CT images of the renal parenchyma with a 5 mm slice thickness were used. Functioning renal parenchyma was defined as normally enhanced areas on CT images. Kidney volume was measured with the tissue segmentation tool program Rapidia (Infinitt, Seoul, Republic of Korea). The approach to segmentation was based on the threshold value from the selected region of interest.

Venous phase images were obtained with an 80-second delay after contrast agent injection. On venous images the renal parenchyma showed a mean of 220 to 250 HU. In this study normal renal parenchyma was defined as having a density of greater than 150 HU. All values below this threshold were considered to reflect no difference in total parenchymal volume. However, the collecting system did not show values exceeding 150 HU in most cases in the venous phase. For example, in some cases the collecting system showed 120 HU. Thus, we chose a threshold of greater than 150 HU to avoid including nonparenchymal tissues.

In the middle of the kidney (its maximal diameter) we made a new float image around the kidney (fig. 1). We also simply scrolled up and down to cover the entire kidney. The program automatically calculated normal renal parenchymal volume by replacing image pixels with the corresponding value in an identified region of interest (fig. 2).

The volume of each kidney was measured by 3 urologists blinded to patient characteristics. Each urologist measured kidney volume twice. We compared the correlation of the 2 volumes for each urologist using the intraclass correlation coefficient. We then compared the data among the urologists using the interclass correlation coefficient. The 3 sets of results were compared using the interclass or intraclass correlation coefficient. For analysis the kidney volume of each patient was calculated as the mean of the 3 results.

Statistical Analysis

Data are shown as the mean $\pm$ SD. The 3 sets of results were compared among the 3 observers to assess measurement reliability. Pearson's correlation coefficients (r) were calculated to evaluate correlations between kidney volume and patient characteristics. Linear regression analysis was used to assess the relationship between kidney volume and renal function using CG and MDRD GFRs. All p values are 2-tailed with $p < 0.05$ considered statistically significant. Statistical analysis was done using SPSS® for Windows®, version 17.0.

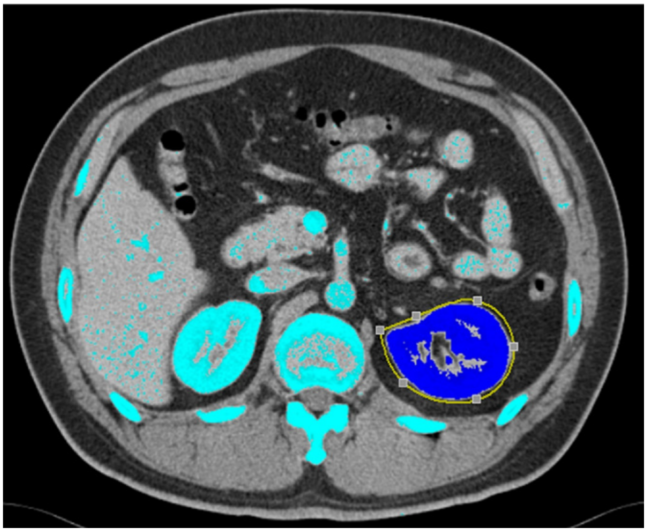

Figure 1. CT shows kidney volume calculated based on normally functioning tissue (dark blue areas). Nonenhanced areas were excluded using software.

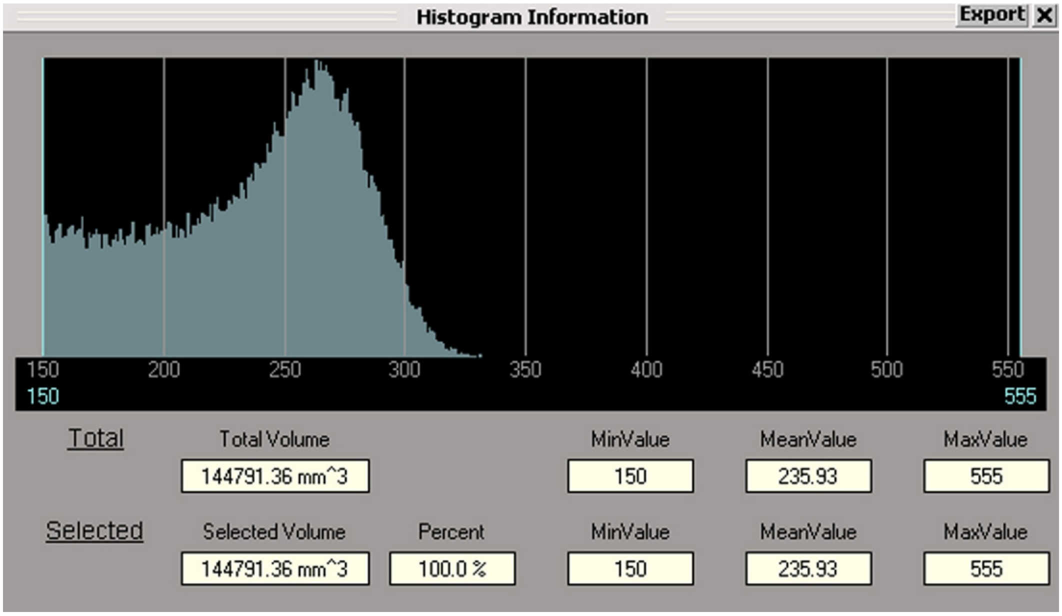

Figure 2. Histogram shows sum of all kidney volumes

RESULTS

Table 1 lists detailed demographic information on the 539 study participants, including 356 men (66.0%) and 183 women (34.0%). Overall mean age was 51.5 ± 18.1 years (range 17 to 86) and the average for men was somewhat higher than for women (55.0 ± 16.9 years, range 17 to 86 vs 44.8 ± 18.6, range 17 to 78). Mean patient height was 164.4 ± 8.3 cm (range 140.0 to 185.0), mean body weight was 64.5 ± 11.6 kg (39.0 to 112.0), mean BMI was 23.8 ± 3.3 kg/m^2 (16.2 to 35.6) and mean BSA was 1.70 ± 0.17 m^2 (1.23 to 2.30).

Compared to women men were older, taller and heavier (each $p < 0.001$), and had higher BMI ($p = 0.001$) and greater BSA ($p < 0.001$). Mean preoperative serum creatinine was 1.05 ± 0.24 mg/dl (range 0.6 to 1.9). Mean CG GFR was 75.0 ± 26.4 ml per minute/1.73 m^2 (range 20.37 to 190.12) and mean MDRD GFR was 77.7 ± 19.3 ml per minute/1.73 m^2 (range 29.56 to 156.37). Mean total kidney volume was 261.3 ± 58.1 ml (range 71.88 to 474.63). The interclass correlation coefficient was 0.995 (95% CI 0.991 to 0.998) and the intraclass correlation coefficient was 0.996 (95% CI 0.992 to 0.999). Mean kidney volume on the right and left sides was 130.8 ± 32.1 and 130.4 ± 34.6 ml, respectively. Kidney volume in men was approximately 14 ml larger than in women (266.1 vs 251.8 ml, $p = 0.004$, respectively). Of the patients 49 (9.1%) had diabetes mellitus, including 33 men (9.3%) and 16 women (8.7%) ($p = 0.841$), and 136 (25.2%) had hypertension, including 95 men (26.7%) and 41 women (22.4%) ($p = 0.278$).

Tables 2 and 3 show changes in kidney volume in relation to age, gender and anthropometric measurements. Kidney volume decreased with increasing age ($r = -0.418$, $p < 0.001$). To clarify this relationship patients were divided into age groups by decade. Renal volume was greatest for men in the third decade of life (mean 307.1 ± 60.4 ml, range 194.31 to 474.63). Volume decreased at the rate of approximately 3 to 4 ml per decade until age 40 years, by approximately 20 ml from ages 50 to 59 and by approximately 30 ml from ages 60 to 79. In women renal volume was greatest during adolescence (mean 278.0 ± 34.4 ml, range 226.81 to 352.01). Volume decreased at the rate of approximately 5 to 10 ml each decade until age 60 years and thereafter by approximately 30 to 40 ml each decade.

Kidney volume also correlated significantly with height ($r = 0.344$, $p < 0.001$), weight ($r = 0.343$, $p < 0.001$), BMI ($r = 0.177$, $p < 0.001$) and BSA ($r = 0.371$,

Table 1. *Patient characteristics*

	Mean ± SD Men	Mean ± SD Women	p Value
Ht (cm)	168.2 ± 6.3	157.0 ± 6.4	<0.001*
Wt (kg)	68.4 ± 10.9	56.7 ± 8.7	<0.001*
BMI (kg/m^2)	24.1 ± 3.1	23.0 ± 3.8	0.001*
BSA (m^2)	1.78 ± 0.15	1.56 ± 0.12	<0.001*
Preop creatinine (mg/dl)	1.13 ± 0.22	0.88 ± 0.19	<0.001*
GFR (ml/min/1.73 m^2):			
CG	75.0 ± 26.8	75.1 ± 25.8	0.964
MDRD	76.3 ± 18.3	80.2 ± 21.1	0.035*
Kidney vol (ml):	266.1 ± 60.7	251.8 ± 51.7	0.004*
Rt	133.4 ± 32.9	125.8 ± 30.2	0.008*
Lt	132.7 ± 35.9	126.0 ± 31.5	0.027*

* Statistically significant.

Table 2. *Kidney volume change by gender and age*

Age	No. Men (%)	Mean ± SD Kidney Vol (ml)	No. Women (%)	Mean ± SD Kidney Vol (ml)	p Value
20 or Less	16 (4.5)	290.3 ± 35.9	21 (11.5)	278.0 ± 34.4	0.299
21-30	27 (7.6)	307.1 ± 60.4	40 (21.8)	273.9 ± 47.9	0.015*
31-40	36 (10.1)	303.1 ± 56.8	19 (10.4)	259.6 ± 40.7	0.005*
41–50	43 (12.1)	300.5 ± 58.1	22 (12.0)	261.5 ± 59.1	0.013*
51–60	59 (16.6)	278.9 ± 58.4	31 (17.0)	254.9 ± 36.6	0.041*
61–70	113 (31.7)	249.6 ± 51.6	38 (20.7)	223.7 ± 48.5	0.007*
71 or Greater	62 (17.4)	214.3 ± 35.8	12 (6.6)	182.8 ± 40.1	0.008*

* Statistically significant.

p <0.001). In women kidney volume tended to decrease with increasing BMI but this was not statistically significant (p = 0.736). There was no significant relationship between kidney volume and hypertension or diabetes mellitus.

There was a significant correlation between kidney volume and CG GFR (r = 0.615, p <0.001). A significant but less pronounced correlation was also found for kidney volume and MDRD GFR (r = 0.432, p <0.001). Figure 3 shows the correlation between renal volume and CG GFR (overall, men and women r = 0.615, 0.631 and 0.594, respectively). We analyzed renal volume and CG GFR changes depending on age in each gender. Figure 4 shows that kidney volume and CG GFR decreased in parallel with age.

DISCUSSION

With improvements in imaging instrumentation and technology it is now possible to measure renal volume using US, CT or MRI. Critical issues for selecting an imaging method are the accuracy, ease and consistency of measurement. There are reports of intra-observer and interobserver discrepancies among those using US to measure kidney volume while the high costs associated with MRI may preclude its widespread use for patients in the clinical setting.

Recent improvements in 3-dimensional reconstruction programs for CT have allowed clinicians to more easily make preoperative measurements of kidney volume in kidney donors or in patients with kidney disease. However, to our knowledge there is as yet no standard method to measure kidney volume. Researchers have used different systems and programs, such as the voxel count method, the semiautomated method or the automated method. In our study it was easy for urologists to run the program and measure kidney volume without the help of radiologists. Volume measurement calculation for each kidney took less than 1 minute.

We found that mean total kidney volume was 261.3 ± 58.1 ml, a little less than in other studies.[11,14] The difference may be due to various factors, such as differences in age or gender distribution, or in the total number of the patients, the inclusion or exclusion of nonfunctioning renal tissue in measurements and especially differences in the methods used to measure kidney volume. Regardless of approach, the accuracy of each method to evaluate kidney volume is the most important consideration. We noted a high level of interobserver and intraobserver agreement for volume measurements, indicating that observers had no influence on the measurement of kidney volume.

A number of groups have reported factors that influence kidney volume. Our results of the correlation between kidney volume and anthropometric parameters are similar to those in previous studies.[11,15–18] Kidney volume significantly and positively correlated with height, weight, BMI and BSA. This demonstrates that these parameters may be good indicators of total renal volume. We also found that kidney volume in men was 5.6% greater than in women, similar to the results of Johnson et al.[18] Although we anticipated that hypertension and diabetes might influence kidney volume due to their direct effects on vascular tone and glomerular filtration, no such effects were observed.

Kidney volume is a useful parameter when evaluating renal function. Some groups reported a correlation between GFR and kidney volume measured by CT. Shin et al examined 113 healthy young men and reported that total kidney volume correlated significantly with CG GFR (r = 0.43).[17] Others observed a strong correlation between total renal vol-

Table 3. *Total kidney volume and anthropometric characteristics*

	Pearson's r			
	Overall*	Men*	Women	p Value
Age	−0.418	−0.487	−0.444	<0.001*
Ht	0.344	0.356	0.372	<0.001*
Wt	0.343	0.394	0.153	0.040*
BMI	0.177	0.267	−0.025	0.736
BSA	0.371	0.415	0.282	<0.001*
GFR:				
CG	0.615	0.631	0.594	<0.001*
MDRD	0.432	0.443	0.472	<0.001*

* Statistically significant (p <0.001).

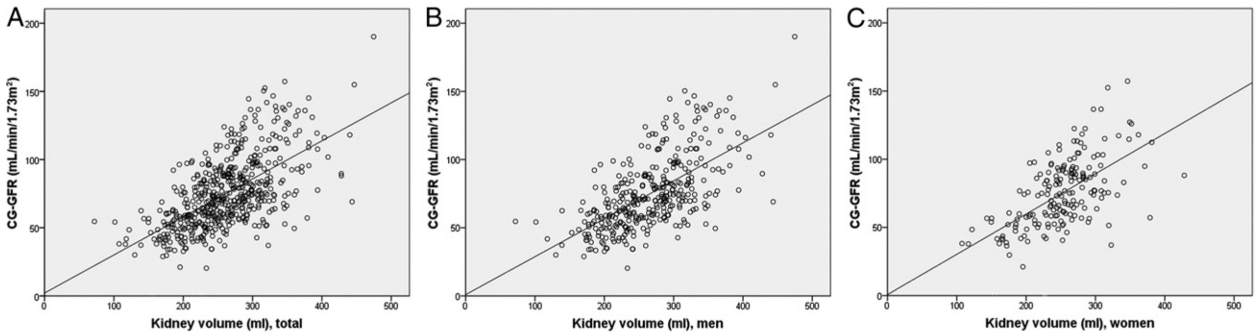

Figure 3. CG GFR by kidney volume in all patients (*A*), men (*B*) and women (*C*) (r = 0.605, 0.626 and 0.574, respectively)

ume and MDRD GFR (r = 0.6 and 0.62, respectively).[11,18] Recently Funahashi et al measured kidney volume in 183 patients before and after unilateral nephrectomy, and found strong correlations between total renal volume and renal function before and after surgery (r = 0.517 and 0.434, respectively).[19] We also noted that kidney volume strongly correlated with CG GFR and to a lesser degree with MDRD GFR (r = 0.615 and 0.432, respectively).

While some groups observed a decrease in total renal volume with age,[20] others did not.[11,18] A potential drawback of the current study is the uneven distribution of patient age. Two-thirds of patients were older than 50 years. We had no data on patients in the first decade of life and limited data on those in the second decade. Nevertheless, we found a significant inverse correlation between renal volume and age (r = −0.418). Total kidney volume attained a maximum between ages 21 and 30 years in men and by age 20 years in women. Thereafter it decreased with age.

Our study supports previous observations of age related changes in glomerular volume in rats and humans.[21] In humans glomerular volume appears to increase approximately 7-fold from infancy to adulthood and then decreases substantially between adulthood and senescence. Renal volume also decreases with age. The age related decrease in GFR in individuals with no specific renal disease was attributable to an involutional process leading to glomerular atrophy.[22] We attempted simultaneous analysis of changes in total renal volume measured by CT, GFR and age. Our results revealed similar changes in total kidney volume and GFR as a function of age in men and women.

CONCLUSIONS

To our knowledge this study provides new insights regarding the radiological measurement of kidney volume and the relationship of kidney volume with GFR and age in individuals with no history of renal disease. Measuring kidney volume with computerized programs is easy and reliable. CT estimated kidney volume correlated well with height, body weight, BMI and BSA. Kidney volume also strongly correlated positively with renal function and correlated inversely with age. Knowledge of these relationships will be valuable in clinical settings.

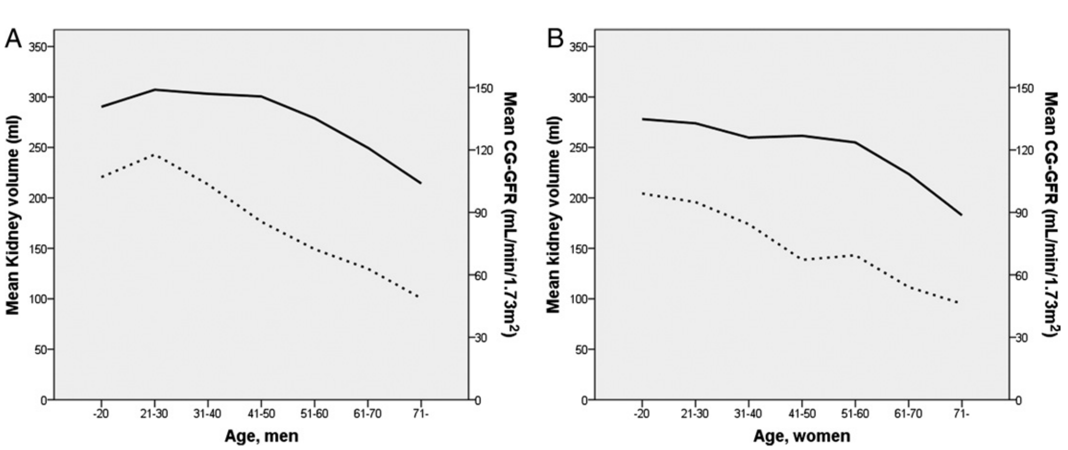

Figure 4. Mean kidney volume (solid line) and mean CG GFR (dotted line) by age group in men (*A*) and women (*B*)

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