A comparative study of methods of estimating kidney length in kidney transplantation donors

Kiw-Yong Kang1, Young Joon Lee2, Soon Chul Park3, Chul Woo Yang1, Yong-Soo Kim1, In Sung Moon3, Yong Bok Koh3, Byung Kee Bang1 and Bum Soon Choi1

1Department of Internal Medicine, 2Department of Radiology and 3Department of Surgery, College of Medicine, The Catholic University of Korea, South Korea

Abstract

Background. Knowledge of kidney size is important for clinical assessment of renal disease. However, there are few studies on methods of assessing kidney size. The purpose of this study was to determine the usefulness of body index and radiological measurements for prediction of kidney size.

Methods. One hundred and twenty five donors were enrolled. The sizes of donor kidneys obtained after nephrectomies for kidney transplantations were documented and the correlation coefficient between kidney length and body index was calculated. Kidney length was estimated from the distance between the first and third lumbar vertebrae (L1-3), intravenous pyelograms (IVPs), abdominal ultrasonography (US), and abdominal computed tomography (CT).

Results. Normal adult kidneys were 11.08 ± 0.96 cm long, 6.25 ± 0.67 cm wide, 4.73 ± 0.65 cm thick and weighed 196.3 ± 41.0 g. Correlation coefficients between kidney length and body height, body weight, body surface area and total body water content were 0.29, 0.31, 0.26, and 0.32, respectively. The difference between actual and predicted kidney lengths was −0.6 cm for L1-3, +1.2 cm for IVPs, −0.7 cm for abdominal US, −0.8 cm for transverse CT section, and −0.5 cm for coronal CT section.

Conclusions. Abdominal coronal CT section predicted kidney length more accurately than other radiological methods, but all radiological methods were associated with prediction errors. As kidney length was correlated with body index, it is suggested that body index is the most useful and simplest method of estimating kidney size as an adjunct to treatment decisions concerning renal disease.

Keywords: actual kidney size; body index; radiological methods

Introduction

Kidney length and volume are important parameters for clinical assessment of patients with diabetes or renal artery stenosis and for assessment of kidney transplant candidates [1,2]. Estimates of kidney length and volume help to differentiate between chronic and acute renal failure, to decide whether to take renal biopsies and to predict post-transplantational renal allograft function. However, there is a paucity of data on kidney sizes of normal individuals and few comparative studies have been done on radiological methods for estimating kidney size.

There are some studies about the distance of the first lumbar vertebra (L1) to the third (L3) or fourth lumbar vertebra (L4), intravenous pyelograms (IVPs), ultrasound sonography (US), computed tomography (CT) and magnetic resonance imaging (MRI) as modalities for estimating kidney size and function. These reports concern the usefulness of some of these indices for predicting kidney size and function. Currently, US or CT is usually used to determine kidney size but it has been reported that it underestimates kidney size. Although a standardized range of US estimates of normal kidney sizes has been published [3], it remains to be established whether US estimates are accurate.

Living donors underwent simple abdominal X-ray analysis, IVPs, US and CT scanning for preoperative evaluation at our centre and the sizes of donor kidneys were measured after donor nephrectomy. We determined the actual kidney sizes of normal adults, the correlation coefficients between kidney length and the body indexes (height, weight, body surface area, total body water content) and whether radiological measurements are of use for prediction of kidney length.
Materials and methods

Our retrospective study consisted of 125 living voluntary kidney donors (46 males and 79 females). Donors with histories of diabetes, hypertension, or other known medical problems were excluded. Body surface area (BSA) and total body water (TBW) were calculated using the following formulae:

\[
\text{BSA (m}^2\text{)} = \left(\frac{\text{height (cm)} \times \text{weight (kg)}}{3600}\right)^{1/2}
\]

\[
\text{TBW of males (litres)} = 2.447 + 0.3362 \times \text{weight (kg)} + 0.1074 \times \text{height (cm)} - 0.09516 \times \text{age (years)}
\]

\[
\text{TBW of females (litres)} = -2.097 + 0.2466 \times \text{weight (kg)} + 0.1069 \times \text{height (cm)}
\]

Glomerular filtration rate (ml/min) was measured by creatinine clearance (Ccr) and technetium-99m diethyleneetriaminepentaacetic acid (99mTc DTPA) renal scintigraphy: Ccr was measured by using the standard formula (urine creatinine concentration × urinary volume/plasma creatinine concentration).

The sizes of kidneys from the left side were measured after donor nephrectomy. After removal, the kidneys were clamped before anastomosis, and length, width, thickness and weight were measured using sterilized vernier callipers and excluding as much perirenal fat as possible. The blades of the callipers were positioned to touch the outmost points of the upper and lower poles of the kidney lightly and a single reading accurate to 1 mm was taken. There are two non-invasive methods for estimating kidney volume: the stepped-section method, which has been clinically tested on pregnant women [4] and infants [5], and the ellipsoid method [kidney volume = length × width × thickness × (π/6)]. We used the ellipsoid method to estimate kidney volume from the dimensions of the kidneys.

All donors underwent simple abdominal X-rays, IVPs and US examinations and 113 also underwent spiral CT of the kidneys. The distances between the upper surfaces of the first lumbar vertebra and the lower surfaces of the third lumbar vertebra (L1–3) of patients without scoliosis were estimated from abdominal X-rays. IVP estimates of kidney lengths were done by measuring the distances between the outermost points on the upper and lower renal poles on the film image. Films were only used if kidney shadows could be adequately visualized. Bipolar length was used for all individuals. Abdominal US examinations were performed by radiologists using SEQUOIA 512 Acuson ultrasound equipment (Mountainview, CA, USA) and a curvilinear 3.5 MHz transducer. Kidney length was defined as the maximum longitudinal length. The electronic callipers of the ultrasound machine had an accuracy of 1 mm. The maximum length of the kidney was measured in the sagittal plane and the width and thickness of the kidney was measured in the transverse plane. Spiral kidney CT was performed using a Somatom Volume Zoom scanner (Siemens, Fuerth, Germany). Zones that included both kidneys in one image were selected for CT evaluation. After localization of the zone, the subject was asked to hold his/her breath, during which scanning was performed. The measurements were performed with 7 mm collimation and images were reconstructed. Renal length was measured in transverse and coronal sections. For transverse sections, CT length was calculated using the following formula: CT length = n × 7 mm, where n is the number of CT cuts through kidney (beginning with the first cut of the upper pole and ending with the last cut of the lower pole). The width and the thickness of the kidneys were measured at the largest transverse sections. For coronal sections, renal length was defined as the maximum longitudinal length.

Correlations between direct measurements of the kidneys upon removal and body indices were calculated as well as correlations between direct measurements of the kidneys and corresponding estimates derived from L1–3, IVP, US, transverse section CT and coronal section CT.

The data are expressed as means ± SD. Kidney length was analysed separately for men and women. The primary data collection was collated using Excel software (Microsoft, Redmond, WA, USA) and statistical analyses were performed using the independent sample t-test, simple correlations and multiple regressions (SPSS software version 9.0, SPSS Inc., Chicago, IL, USA). Statistical significance was assumed at P < 0.05.

Results

The 125 live kidney donors were between 20 and 65 years of age. The mean age of donors was 37 years; 37 were males and 39 were females. Their weight ranged from 41 kg to 108 kg (mean = 63 kg) and their height ranged from 150 cm to 187 cm (mean = 166 cm). BSA ranged from 1.4 to 2.3 (mean = 1.7) and mean TBW was 35.6 ± 6.9 l. The characteristics of the subjects are shown in Table 1.

The kidneys were 11.08 ± 0.96 cm long, 6.25 ± 0.67 cm wide and 4.73 ± 0.65 cm in thick. The mean weight of kidneys was 196.3 ± 41.0 g and the mean volume was 158.7 ± 62.9 cm³. Male kidneys exceeded the dimensions of female kidneys by 0.2 ± 0.04 cm in length, 0.2 ± 0.01 cm in width and 0.2 ± 0.40 cm in thickness (Table 2).

The correlation coefficients between actual kidney length and height, weight, BSA and TBW were 0.29, 0.31, 0.26 and 0.32 respectively (P < 0.05; Table 3). The relationship between actual kidney length and body index, body height and body weight estimated from multiple regression was: kidney length (cm) = 7.968 + 0.01163 × body height (cm) + 0.01795 × body weight (kg) (R² = 0.294, F = 5.065, P = 0.008). Glomerular
filtration rate is also correlated with actual kidney length (Table 3).

Estimates of the lengths of the right and left kidneys derived from X-rays, IVPs, US and CT are shown in Table 4. Radiological estimates of the length of the left kidney were greater than those of the right kidney ($P < 0.05$). The difference between the actual and estimated lengths varied between radiological methods. The means of paired differences between actual and estimated sizes were $0.6 \pm 0.8$ cm for L1–3, $1.2 \pm 0.9$ cm for IVPs, $0.7 \pm 0.8$ cm for abdominal US, $0.8 \pm 0.9$ cm for transverse sections of abdominal CT scans and $-0.5 \pm 0.8$ cm for coronal sections of abdominal CT scans.

Scatter diagrams of estimated vs actual length are presented in Figures 1–5. Estimates of kidney length for L1–3, IVPs, abdominal US and abdominal CT (transverse and coronal sections) were significantly correlated with actual kidney length ($P < 0.05$).

### Table 1. Characteristics of subjects

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>$37 \pm 1$ (20–65, median 37)</td>
<td>$37 \pm 1$ (20–64, median 36)</td>
<td>$39 \pm 1$ (20–65, median 39)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>$165.5 \pm 8.0$</td>
<td>$170.7 \pm 6.5^*$</td>
<td>$158.3 \pm 3.9$</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>$63.5 \pm 11.3$</td>
<td>$68.8 \pm 10.6^*$</td>
<td>$56.2 \pm 7.5$</td>
</tr>
<tr>
<td>BSA (m$^2$)</td>
<td>$1.71 \pm 0.18$</td>
<td>$1.81 \pm 0.21^*$</td>
<td>$1.57 \pm 0.19$</td>
</tr>
<tr>
<td>TBW (l)</td>
<td>$35.6 \pm 6.9$</td>
<td>$40.6 \pm 4.3^*$</td>
<td>$28.7 \pm 2.1$</td>
</tr>
<tr>
<td>GFR by Ccr (ml/min)</td>
<td>$94.1 \pm 17.3$</td>
<td>$98.0 \pm 18.9^*$</td>
<td>$88.4 \pm 13.9$</td>
</tr>
<tr>
<td>Left kidney GFR by $^{99m}$Tc-DTPA (ml/min)</td>
<td>$55.0 \pm 8.7$</td>
<td>$56.5 \pm 8.6^*$</td>
<td>$52.9 \pm 8.6$</td>
</tr>
</tbody>
</table>

BSA, body surface area; TBW, total body water; GFR, glomerular filtration rate; Ccr, creatinine clearance; $^*P < 0.05$ vs Female.

### Table 2. Actual kidney size according to gender

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (cm)</td>
<td>$11.08 \pm 0.96$</td>
<td>$11.15 \pm 1.02^*$</td>
<td>$10.98 \pm 0.85$</td>
</tr>
<tr>
<td>Width (cm)</td>
<td>$6.25 \pm 0.67$</td>
<td>$6.33 \pm 0.66^*$</td>
<td>$6.12 \pm 0.67$</td>
</tr>
<tr>
<td>Thickness (cm)</td>
<td>$4.73 \pm 0.65$</td>
<td>$4.81 \pm 0.77^*$</td>
<td>$4.61 \pm 0.37$</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>$196.3 \pm 41.0$</td>
<td>$208.2 \pm 41.2^*$</td>
<td>$177.7 \pm 33.2$</td>
</tr>
<tr>
<td>Volume (cm$^3$)</td>
<td>$158.7 \pm 62.9$</td>
<td>$167.0 \pm 64.2^*$</td>
<td>$146.0 \pm 59.2$</td>
</tr>
</tbody>
</table>

$^*P < 0.05$ vs Female.

### Table 3. Correlation coefficients between body indexes, glomerular filtration rate and kidney size

<table>
<thead>
<tr>
<th>Body index</th>
<th>Correlation coefficient</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.29</td>
<td>0.011</td>
</tr>
<tr>
<td>Weight</td>
<td>0.31</td>
<td>0.001</td>
</tr>
<tr>
<td>BSA</td>
<td>0.26</td>
<td>0.002</td>
</tr>
<tr>
<td>TBW</td>
<td>0.32</td>
<td>0.001</td>
</tr>
<tr>
<td>GFR</td>
<td>0.23</td>
<td>0.011</td>
</tr>
<tr>
<td>Ccr</td>
<td>0.24</td>
<td>0.013</td>
</tr>
<tr>
<td>Left kidney GFR by $^{99m}$Tc-DTPA</td>
<td>0.24</td>
<td>0.011</td>
</tr>
</tbody>
</table>

BSA, body surface area; TBW, total body water; GFR, glomerular filtration rate; Ccr, creatinine clearance.

### Table 4. Radiological estimates of kidney size

<table>
<thead>
<tr>
<th>Method</th>
<th>Right length</th>
<th>Left length</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVP (cm)</td>
<td>$11.7 \pm 1.0$</td>
<td>$12.3 \pm 1.0^*$</td>
</tr>
<tr>
<td>US (cm)</td>
<td>$10.2 \pm 1.2$</td>
<td>$10.5 \pm 0.8^*$</td>
</tr>
<tr>
<td>CT1$^b$ (cm)</td>
<td>$10.0 \pm 0.8$</td>
<td>$10.4 \pm 0.9^*$</td>
</tr>
<tr>
<td>CT2$^c$ (cm)</td>
<td>$10.3 \pm 0.7$</td>
<td>$10.7 \pm 0.9^*$</td>
</tr>
</tbody>
</table>

$^b$CT1, $n$ (the number of CT cuts through the kidney) $\times 7$ mm.

$^c$CT2, kidney length measured by CT coronal section; $^*P < 0.05$ vs right kidney.

### Discussion

The aims of this study were to define the normal kidney size of adults using living renal transplantation donors, to determine the relationship between kidney length and body indexes and compare with actual
kidney length with kidney lengths predicted by radiological measurements. The mean kidney measurements were 11.08 cm for length, 6.25 cm for width and 4.73 cm for thickness. As a previous study [6] has shown that there is no difference between the sizes of in vitro perfused kidneys and kidneys in situ perfused kidneys were measured in our study.

The mean size of kidneys recorded in this study was greater than that reported in another study [6]. This is probably due to differences in the physical characteristics of the populations studied, as previous reports have shown that renal length differs according to country and race [7–10]. In our study, we evaluated the relationships between actual kidney size and gender, age and body indexes. Males had greater body indexes (height, weight, body surface area and total body water) and kidney sizes, kidney weights and kidney volumes than females. There was a significant relationship between body index and actual kidney length. These findings indicate that physical characteristics are important determinants of kidney size. In an earlier study, weight and BSA were better predictors than estimates using ultrasound or CT, therefore they recommended clinical and radiological consideration should be necessary for exact determination of kidney volume [11]. In another study, kidney length correlated best with body height [12]. In our study, kidney length correlated significantly and positively with weight, height, BSA and TBW ($P < 0.05$). Based on these findings, we calculated the correlation between body index and kidney length. This equation may be of assistance for estimating kidney size during clinical assessment of patients. Glomerular filtration rates measured by Ccr and $^{99m}$Tc DTPA renal scintigraphy
were also correlated with actual kidney size. This is because the BSA is correlated positively with total glomerular volume and also significantly with metabolic rate [13].

We expected actual kidney size might be correlated with age because donor age is known as one of the risk factors of renal graft survival. However, we observed there was no relationship between actual kidney size and age (data not shown, $P=0.909$). It might be because donor age is composed of similar age groups is not kidney size, since kidney weight increases significantly with donor age from 15 to 45 years but it remains stable after 45 years of age [13]. Therefore, further study is needed such as a serial study with different age groups or a study including all age groups to evaluate the relationship between actual kidney size and age.

Several authors have reported estimates of normal kidney length and volume using radiological methods. However, all radiological methods have limitations. X-ray measurements have been made of distances between L1 and L3, third intervertebral space or L4. However, the magnification effect between body and film resulted in overestimation or underestimation of kidney length [14]. In that study, the lengths of 97% of normal adult kidneys were within the ranges defined by the distances between L1 and L3 and L1 and L4. The relationship between kidney length and the height of the first three lumbar vertebrae was statistically significant, but it underestimated the actual length. The relationship between actual renal length and L1–L4 was also significant and it was an overestimate. In our study, L1–L3 underestimated kidney length.

IVPs overestimate kidney size because of magnification effects and the osmotic action of contrast agents [6]. The magnification effect has been shown by previous studies to overestimate kidney length by about 15%. In our study, IVPs overestimated kidney length by 10%. With IVPs, there is also a risk of contrast media-induced nephropathy and exposure to X-rays.

The use of abdominal US for estimation of kidney length appears to be a relatively accurate and safe method [6]. Abdominal US is a simple, non-invasive method of estimating kidney length in vivo and of possible US measurements, kidney length is the easiest to measure. In most clinics, therapeutic decisions are frequently based on US measurements of kidney size. In this study, comparison with actual lengths of kidneys showed that US tends to underestimate kidney size. This result corresponds with that of an earlier study [6]. The tendency of US to underestimate actual kidney size could be caused by the difficulty of locating the plane of maximum bipolar length or by movement during respiration and, as measurement is operator-dependant, there is a possibility that some measurements would not be made parallel to the axes of the kidney [15]. In vivo US examinations are also sometimes limited by inadequate visualization and demarcation of the kidneys because of overlying bowel gas, surrounding tissues or obesity.

In our study, measurement using coronal sections of abdominal CTs was more accurate than other radiological methods. The accuracy of lengthwise measurements was better with coronal CT sections than with transverse CT sections or ultrasound. Recently, abdominal CT has been used to evaluate the anatomy of living kidney donors before donation. Abdominal CT can be used to obtain direct three-dimensional measurements of renal size before transplantation. Abdominal CT permits accurate cross-sectional radiographic visualization of visceral organs. Because the width between slices is known, length and volume can be calculated from number of the slides and the product of the area and the width, respectively. However, some limitations are associated with abdominal CT: in vivo abdominal CT examinations can be hampered by breathing and other movement artefacts and the axis of the CT scan may not be parallel to the axis of kidney. Furthermore, fat within the kidneys is not included in CT estimates of length, resulting in underestimation of kidney length [16,17]. Further investigation is required to quantify interobserver and intraobserver variation in measurements of kidney size using CT. There is also a risk of contrast media-induced nephropathy and exposure to X-rays.

Unilateral or bilateral changes in kidney size are important signs of renal disease. Kidney size can be estimated by measuring renal length, renal volume, cortical volume or thickness and renal weight. Renal length is a good indication of kidney size [18]. Renal volume has been proven to be a more sensitive means of detecting renal abnormalities than any other single linear measurement and correlates better with renal mass than any other single linear measurement [19]. However, it is rarely used for therapeutic decisions because of the difficulty of obtaining measurements. Renal length measurement is associated with less interobserver variation than volume estimation and therefore is more reproducible [20]. Recently developed abdominal CT systems can be used for direct three-dimensional measurements of renal size and should be evaluated for this purpose.

In this study, we performed IVP and CT and these two procedures carried the increased exposures to X-ray and contrast media. Due to this problem, we set up spiral CT which allows to evaluate angiography and urography all together. Therefore, using spiral CT, we evaluated kidney transplantation donors more accurately and less harmfully.

Estimation of renal size is required for investigation of renal disease. However, there is no accurate method for estimating kidney size. Abdominal coronal CT section predicted kidney length more accurately than other radiological methods, but all radiological methods were associated with prediction errors. As kidney length was correlated with body index, it is suggested that body index is the most useful and simplest method
of predicting kidney size as an adjunct to treatment decisions concerning renal disease.

Conflict of interest statement. None declared.

References


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