BODY SURFACE AREA (BSA) AS THE PREDICTOR OF RENAL PARENCHYMAL VOLUME IN HEALTHY ADULT

H. Chunadi Ermanta*, Elysanti Dwi Martadiani**, Windhu Poernomo***

ABSTRACT

Purpose of Study: To determine whether body surface area (BSA) as an indicator for body size correlates with renal parenchymal volume in healthy adult. Body surface area is a simple indicator to predict renal parenchymal volume. Materials and Methods: A randomly selected 41 healthy adult volunteers were subjected to body weight and body height measurement, BSA calculation and ultrasound examination in supine and/or lateral decubitus position to measure renal dimensions. Renal parenchymal volume was calculated through subtraction of renal volume with central echogenic area. Data were analyzed with Pearson's correlation and regression analysis. Results: Median volumes of right and left renal parenchyma were 86.48 cm$^3$ and 113.3 cm$^3$, respectively. We found that right kidney parenchymal volume had best correlation with body weight ($r = 0.576; p < 0.05$), followed by BSA ($r = 0.569; p < 0.05$) and body height ($r = 0.435; p < 0.05$). Left kidney parenchymal volume had best correlation with BSA ($r = 0.672; p < 0.05$), followed by body weight ($r = 0.644; p < 0.05$) and body height ($r = 0.562; p < 0.05$). Prediction formula: (1) right kidney parenchymal volume $= -96.889 + 116.684 \cdot$ BSA; (2) left kidney parenchymal volume $= -108.735 + 141.254 \cdot$ BSA. Conclusion: Kidney parenchymal volume can be predicted by body weight and BSA, but body height can predict it slightly poorer than body weight and BSA.

Keywords: body surface area; kidney parenchymal volume; ultrasound

INTRODUCTION

As the primary excretory organ, the main function of the kidney is to produce urine and maintain homeostasis through the excretion of metabolic waste products, maintain blood volume, and be responsible for body fluid volume circulation and electrolyte composition (Patton et al, 1989). Renal functional capacity is mostly determined by the basic functional unit of the kidney, the nephron. The volume of each kidney reflects renal mass, which is containing more than one million microscopic nephron existing in renal parenchyma (Curry et al, 1995; O'Neill, 2000). However, nephron does not constitute the whole renal volume. Renal parenchyma comprised of renal cortex and medulla, in which filtration process takes place in renal cortex and reabsorption occurs in the medulla (Curry et al, 1995), whereas, the pelviocalyceal system in central echogenic area does not contain nephron components, but it serves more as a collecting system that drained urine to the ureter.

Glomerular filtration rate (GFR) is affected by the existing surface area in renal parenchyma where the filtration process takes place (Patton et al, 1989). The measurement of renal parenchymal area provides a more accurate estimation of renal function compared to one-dimensional renal measurement only, because not the whole part of the kidney filled with parenchyma (Cost et al, 1996; O'Neill, 2000). It is important to identify renal parenchymal volume in relations to renal functional capacity in healthy adults. However, so far there is no agreement on the interval of normal renal parenchymal size. To evaluate renal condition and carry out measurement to renal parenchymal volume, ultrasonography (USG) is an ideal examination, as it may provide an accurate measurement. Kidney can be easily visualized and it may provide limited spectrum of anatomic variation and pathological changes. In addition, the examination is quite simple, safe, non-invasive, and cost-saving (O'Neill, 2000).

Several literatures mentioned that in the cases of renal transplantation from cadaveric donors, late graft failure might occur in recipient with large body size receiving kidney from donor with smaller body size (Berg, 2001; Kasiske et al, 2002; Nakatani et al, 2002). This condition is related to the theory that kidney from donor with smaller body size transplanted to recipient with larger body size may experience hyperfiltration due to inadequate nephron mass. The occurrence of compensatory change in glomerular capillary flow and pressure may directly or indirectly result in progressive renal damage (Kasiske et al, 2002).

Razak (1996) had studied renal biometry in healthy Indonesians, but he did not carry out correlation test
between body size area and renal parenchymal volume. Based on above literatures, we investigated the presence or absence of correlation between body size area and renal parenchymal volume in healthy adults. Does healthy adult with large body surface area have high renal parenchymal volume, or conversely? It was expected that renal parenchymal volume, which representing an individual's renal functional capacity, could be predicted from his body size area. Thereby, in the cases of renal transplantation, the difference of body size area between donor and recipient can be included in the considerations to select donor and recipient in order to reduce the risk of late graft failure.

**MATERIAL AND METHODS**

This study was carried out at the Department of Radiology, Dr Soetomo Hospital, Surabaya, from December 2003 to February 2004. Using simple random sampling, a number of 41 healthy adults were enrolled as subjects. The inclusion criteria were as follows: (1) Adult male or female, aged 25 - 50 years; (2) not suffering from or having history of acute or chronic diseases that results in renal disorder; (3) results of examination are normal; (3) blood urea nitrogen level: 10-20, creatinine serum in male < 1.5, female < 1.2; (2) (5) Body mass index (BMI) < 25 kg/m².

Body weight and body height were also measured. Body surface area (BSA), as an indicator of body size, was also measured using the formula from Du Bois (Kasiske, 2002; National Kidney Foundation, 2001; Rombeau, 1993), as follows:

\[
\text{BSA}(\text{m}^2) = \text{body height (cm)}^{0.725} \times \text{body weight (kg)}^{0.425} \times 0.007184
\]

Additionally, BMI measurement was also carried out using following formula (DeHoog, 1996):

\[
\text{BMI} (\text{kg/m}^2) = \frac{\text{body weight (kg)}}{\text{body height (m)}^2}
\]

Subsequently, USG examination was undertaken to left and right kidney directly by the author (USG Logiq-500 from General Electric, probe 3.5 MHz, standard setting). Subjects were positioned supine or right or left lateral decubitus. The length, width, and thickness of each kidney, as well as its central echogenic area, were measured. The volumes of kidney, central echogenic area, and right and left renal parenchymal volume were then measured using the following formulas (Allan, 1994; Bossi, 1996): (1) Renal volume = length x width x thickness x 0.5; (2) Central echogenic area volume = (length x width x thickness) central echogenic area x 0.5, (3) Renal parenchymal volume = renal volume - central echogenic area volume (Emamian et al, 1993).

Renal length is the longest distance from the upper edge of renal upper pole to the lower edge of renal lower pole at longitudinal section. The difference of right and left renal length should not exceed 2 cm. Renal width is the longest renal distance at transversal section, perpendicular to renal thickness. The length of central echogenic area is the longest distance from the upper edge to lower edge of renal sinus at longitudinal section. The width of central echogenic area was the longest distance from anterior to posterior renal sinus at transversal section. The thickness of central echogenic area is the longest distance of renal sinus at transversal section, perpendicular to the width of renal sinus. Renal USG image at longitudinal section should expose one of the following criteria: (1) upper to lower pole with the longest longitudinal diameter; (2) upper to lower pole, ureteropelvic junction and/or proximal ureter. In transversal section, renal hilus should also be exposed.

Data obtained were processed manually and using computer. First, a scattered plot was charted, and correlation analysis was carried out to prove the presence of correlation between body size area, body weight, and body height, and the volume of renal parenchyma. Correlation test was undertaken between body weight and body height and renal parenchymal volume, as these variables could not be controlled. Correlation coefficient (r) was estimated, followed with regression analysis to create mathematical prediction model. Results were regarded as statistically significant if p < 0.05.

**RESULTS**

<table>
<thead>
<tr>
<th>Age</th>
<th>% ( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 – 30</td>
<td>17 % (7)</td>
</tr>
<tr>
<td>31 – 35</td>
<td>21 % (9)</td>
</tr>
<tr>
<td>36 – 40</td>
<td>41 % (17)</td>
</tr>
<tr>
<td>41 – 45</td>
<td>9 % (4)</td>
</tr>
<tr>
<td>46 – 50</td>
<td>9 % (4)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100% (41)</strong></td>
</tr>
</tbody>
</table>

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**Table 1. Subject distribution according to age**

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Table 1 and 2 describe subjects' data in general. Table 1 shows that most of the subjects (41%) belong to age group of 36 - 40 years. Subjects' age is ranging between 27 and 50 years. Table 2 shows that samples are distributed evenly between male (51%) and female (49%).

Table 2. Sample distribution according to sex

<table>
<thead>
<tr>
<th>Sex</th>
<th>% (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>51% (21)</td>
</tr>
<tr>
<td>Female</td>
<td>49% (20)</td>
</tr>
<tr>
<td>Total</td>
<td>100% (41)</td>
</tr>
</tbody>
</table>

Table 3 demonstrates that from 41 subjects, the average body weight was 57.69 ± 7.16 kg. Subjects' body weight is ranging from 41 and 71 kg. The average value of body height is 159.30 ± 6.21 cm, with the lowest body height is 150 cm, and the highest 175 cm. The average value of body size area is 1.58 ± 0.11 m², with the largest of 1.36 m², and the smallest 1.81 m². The average value of right renal parenchymal volume is 88.04 ± 24.53 cm³, and the average value of left renal parenchymal volume is higher, 115.13 ± 25.16 cm³. The average value of right or left renal parenchymal volumes in male is higher than that in female.

Table 3. Statistical data of the variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Median</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>58.00</td>
<td>57.69</td>
<td>7.16</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>158.00</td>
<td>159.30</td>
<td>6.21</td>
</tr>
<tr>
<td>Body size area (m²)</td>
<td>1.61</td>
<td>1.58</td>
<td>0.11</td>
</tr>
<tr>
<td>Right renal volume (cm³)</td>
<td>108.55</td>
<td>111.40</td>
<td>29.24</td>
</tr>
<tr>
<td>Left renal volume (cm³)</td>
<td>151.20</td>
<td>150.11</td>
<td>33.39</td>
</tr>
<tr>
<td>Right central echogenic area volume (cm³)</td>
<td>22.28</td>
<td>23.32</td>
<td>7.97</td>
</tr>
<tr>
<td>Left central echogenic area volume (cm³)</td>
<td>31.81</td>
<td>35.00</td>
<td>12.41</td>
</tr>
<tr>
<td>Right renal parenchymal volume (cm³)</td>
<td>86.48</td>
<td>88.04</td>
<td>24.53</td>
</tr>
<tr>
<td>Left renal parenchymal volume (cm³)</td>
<td>113.30</td>
<td>115.13</td>
<td>25.16</td>
</tr>
<tr>
<td>Right renal parenchymal volume in male (cm³)</td>
<td>90.40</td>
<td>93.86</td>
<td>26.80</td>
</tr>
<tr>
<td>Right renal parenchymal volume in female (cm³)</td>
<td>84.96</td>
<td>81.93</td>
<td>20.84</td>
</tr>
<tr>
<td>Left renal parenchymal volume in male (cm³)</td>
<td>115.56</td>
<td>123.55</td>
<td>22.01</td>
</tr>
<tr>
<td>Left renal parenchymal volume in female (cm³)</td>
<td>105.13</td>
<td>106.29</td>
<td>25.73</td>
</tr>
</tbody>
</table>

The result of correlation test revealed significant correlation between body weight and right renal parenchymal volume ($r = 0.576$; $p = 0.000$) (Figure 1), with regressive equation as follows: right renal parenchymal volume = 1.970 x body weight. Body weight also has significant correlation with the volume of left renal parenchyma ($r = 0.644$; $p = 0.000$) (Figure 2) with regressive equation as follows: left renal parenchymal volume = 2.26 x body weight.
Figure 1. Scattered plot of body weight and right renal parenchymal volume

Figure 2. Scattered plot of body weight and left renal parenchymal volume

Figure 3. Scattered plot of body height and right renal parenchymal volume
Significant correlation was found between body height and right renal parenchymal volume \( (r = 0.435; p = 0.004) \) (Figure 3), with regressive equation: right renal parenchymal volume \( = -185.687 + 1.718 \times \text{body height} \).

The volume of left renal parenchyma also had significant correlation to body height \( (r = 0.562; p = 0.000) \) (Figure 4), with regressive equation as follows:

left renal parenchymal volume \( = -247.461 + 2.276 \times \text{body height} \).
Significant correlation was found between body size area and right renal parenchymal volume \((r = 0.569; p = 0.000)\) (Figure 5), with regressive equation: right renal parenchymal volume = -96.887 + 116.684 x body size area. Body size area also had significant correlation to left renal parenchymal volume \((r = 0.672; p = 0.000)\) (Figure 6), with regressive equation: left renal parenchymal volume = -108.735 + 141.254 x body size area.

DISCUSSION

Body Surface Area (BSA) is a parameter to designate an individual's body size (Navaratne, 1998). Body Mass Index (BMI) is not used to measure body size, because it is actually the definition of body adiposity level. BMI is used to determine whether an individual is obese and to define the level of obesity. BMI value of more than 25 kg/m\(^2\) indicates condition that may lead to obesity. Obesity may affect renal condition and dimension. A study by Bonnet et al (2001) stated that the BMI value of more than 25 kg/m\(^2\) is an independent risk factor for the occurrence of systemic hypertension as well as clinical and pathological progressiveness towards advanced renal disease. The kidney of obese subjects shows significant focal glomerulonecrosis and other morphological changes, similar to those observed in patients with diabetic nephropathy (Hannegar et al, 2001; Praga et al, 2001). Due to obesity, adipose tissue accumulates around the kidney and the increase of renal matrix occurs, resulting in compression against medulla and the increase of intrarenal haemodynamics, which finally leads to hypertension (Sugarman, 2001). Hanegar et al (2001) found that in experimental animals at the first stage of obesity, there was an increase in arterial pressure, hyperinsulinemia, renin-angiotensin activation, glomerular hyperfiltration, and structural changes within the kidney, all of which may become the precursor of more severe glomerular abnormality along with the increased level of obesity. The BMI values of subjects observed in this study were ranging between 16.5-24.9 kg/m\(^2\). We excluded subjects with BMI of > 25 kg/m\(^2\) to reduce bias in renal size due to obesity.

The average body surface area of 41 observed subjects were 1.58 ± 0.11 m\(^2\), which was not significantly different from the average value obtained by Razak (1996) in 1994 - 1995 in his study in Ujung Pandang, Indonesia, which was 1.55 m\(^2\). We expected that this value could represent the body size area of Indonesians in general.

Renal parenchymal volume depends largely on renal size, because the values are obtained from the result of multiplication of renal dimensions, comprising the dimension of the kidney itself as well as the dimension of renal sinus (Emamian et al, 1993).

In this study, the age of subjects observed was limited to 25 - 50 years, since renal size has correlation with age. In male and female, kidney may reach its maximum size at around the age of 25 years. In male, renal size remains constant to the age 50 years, and subsequently the size reduces gradually 1 - 1.5 cm in age 80 years. In female, renal size reduction starts at the age 35 - 40 years, and the reduction reaches 1 cm in age 70 years. The reduction is primarily due to the decrease of renal blood flow approximately 1% per year after the third decade. Fernandez et al and Emamian et al observed that the consistent and significant reduction of renal dimension starts at seventh decade. Emamian et al suggested that the reduction of renal volume, which is along with the increase of age, almost entirely results from the reduction of renal parenchymal volume (Meschan, 1984; Emamian et al, 1993; Fernandes et al, 2002).

Sex is also suggested to play a role in renal size, in which male renal size is higher than that of female (Allan, 1994; Curry et al, 1995). However, after being corrected with body size, it was found that sex had no significant effect on renal size (Fernandes et al, 2002; O'Neill, 2000; Schmidt et al, 2001; Zeier et al, 2002).

Renal size can be varied in one individual, depending on hydraulic status during examination. Pregnancy also has influence in the increase of whole renal size due to the effect of progesterone and uterine pressure on the ureter (Wiknjosastro, 1992). Additionally, body height and weight also affect renal length as well as renal parenchymal volume (Emamian et al, 1993).

In healthy adult, the renal length is 9 -12 cm (however, there is a wide range of size, in which renal length of 7 - 14 cm can be found in individuals with normal renal function), renal thickness 2.5 - 4 cm, and renal width 4 - 6 cm. Kidney may also shrink due to atrophic changes that relate to age, circulation insufficiency, as well as renal disease (Allan, 1994; Curry et al, 1995; Tanagho, 2000). The difference of right and left renal length is also a significant factor. In renovascular hypertension, the difference of length of more than 2 cm is an indicator of renal arterial stenosis in kidney with smaller size (O'Neill, 2000). Due to these considerations, we included the difference of length of more than 2 cm between both kidneys in the exclusion criteria.

The average value of renal parenchymal volume obtained in this study was 88.04 cm\(^3\) for the right kidney and 115.13 cm\(^3\) for the left kidney, and the median value was 86.48 cm\(^3\) and 113.30 cm\(^3\) for the...
right and left kidney, respectively. To our knowledge, previous studies on the average value of healthy renal parenchymal volume, particularly among Indonesians, are limited. A study carried out by Razak (1996) mentioned that the average percentage of right renal cortex volume (in male and female) is 55.8% and that of left kidney is 54.6%, with the average volume of right and left kidney are respectively 80.1 cm$^3$ and 85.2 cm$^3$.

The average value of left renal parenchymal volume is significantly higher than that of right volume (p < 0.05). This may be explained as follows: (1) as spleen is smaller than liver, left kidney has more space to develop; (2) as left renal artery is shorter and straighter than right renal artery, a larger amount of blood flows to left kidney, and it relatively results in the increase of left renal volume (Emamian et al, 1993). This is in contrast to the finding of Razak (1996), in which no significant difference was found between left and right renal cortex volume, both in male and female.

Right renal parenchymal volume apparently has moderate correlation with body weight ($r = 0.576; p < 0.05$), followed with body size area ($r = 0.569; p < 0.05$) and has low correlation with body height ($r = 0.435; p < 0.05$), while left renal parenchymal volume has highest correlation with body size area ($r = 0.672; p<0.05$), followed with body weight ($r = 0.644; p < 0.05$) and body height ($r = 0.562; p < 0.05$). These results confirmed those of Emamian et al (1993) with larger number of samples, in which they found correlation between renal parenchymal volume and total body area, although the level of correlation was not mentioned. From regression analysis, we found predictive formulas of renal parenchymal volume based on anthropometric measurement. The predictive formulas are as follows:

1. right renal parenchymal volume = 1.970 x body weight;
2. right renal parenchymal volume = -96.887 + 116.684 x body size area;
3. right renal parenchymal volume = -185.687 + 1.718 x body height;
4. left renal parenchymal volume = -108.735 + 141.254 x body size area;
5. left renal parenchymal volume = 2.26 x body weight;
6. left renal parenchymal volume = -247.461 + 2.276 x body height.

The number of nephron in human beings has been determined since prenatal period. The first renal development occurs during embryogenesis, when the number of nephron is increasing during the period of metanephric blastema differentiation. Metanephric kidney starts at week 5 of pregnancy (Hammerman, 2000). Kidney experiences critical development during the last period of pregnancy. Nephron development in human beings generally ends at week 36 pregnancy, and no other nephron formed after delivery. The perfect development of nephron complements is influenced by conditions affecting intrauterine development, including maternal nutrition, vitamin deficiency, infection, antibiotic exposure, and the consumption of alcohol and cigarette smoking. Inadequacy in nephron numbers is not reversible, resulting in compensatory hypertrophy, so that the individuals may have predisposition either to progressive renal disease or essential hypertension (Hammerman, 2000; Spencer et al, 2001; Marchand et al, 2001). The second growth period is manifested by the increased size and functions of nephron, which has been at constant number, along with the maturation of body size during childhood and adolescence (Hammerman, 2000).

The results of this study confirmed theory suggesting that postnatal increase of renal size is triggered or related to the increase of body size. This process is potentially limited by: (1) the capacity of nephron to enlarge, a physiological process; (2) prenatal-determined nephron numbers (Zidar et al, 1998; Spencer et al, 2001).

Body development is regulated by the integration of environmental signals (such as nutrition), together with endogeneous neuroendocrine as a response to genetic program that may determine body pattern of an individual (Le Roith et al, 2001). Biochemical evidences confirm that growth hormone (GH) affects growth and development of various body tissues, including liver, muscle, kidney and bone (Ohlsson et al, 1998). GH plays a role in the development of renal size, GFR, and renal plasma flow (RPF). GH activity in increasing renal size, GFR and RPF is not directly through its own activity, but through a mediator, the insulin-like growth factor I (IGF-I). IGF is an integral component of various systems controlling growth and metabolism. Some authors suggest that IGF-I plays a role in renal organogenesis (Hammerman, 1999; Haylor et al, 2000). It also plays an important role in somatic development both during embryonic and postnatal period (Navab et al, 2001; Le Roith et al, 2001). The plasma IGF-I level in an individual is correlated to his body size. A tall child constitutionally has a higher level of plasma IGF-I. In some experimental models, recombinant human IGF-I (rhIGF-I), given as infusion, may increase body size and body weight (Le Roith et al, 2001). Based on these findings, we hypothesized that GH, through IGF-I, underlies the correlation between body size and renal parenchymal volume.

The obstacle in determining renal parenchymal value mostly came from the difficulties in finding distinct border between renal parenchyma and central echogenic area. In addition, appropriate angle taking also has remarkable effect on measured renal dimension. We had...
attempted to reduce erroneous measurement of renal dimension by carrying out measurement from several angles that mostly close to renal axis and taking the largest measure.

The determination of renal parenchymal volume in healthy individual is rarely carried out as it needs several calculations that may be regarded as unpractical in daily clinical setting. However, in certain conditions, the determination of renal parenchymal volume can be used to estimate nephron capacity as a representation of renal functional capacity. In abnormal condition, such as renal failure or hydronephrosis, the measurement of renal parenchymal volume may provide a more accurate parameter in estimating renal size and function compared to renal measurement from one dimension only (Mazzotta et al, 2002; Cost et al, 1996).

REFERENCES


