Improved Formulas for the Estimation of Renal Depth in Adults

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Commercial techniques are available to calculate effective renal plasma flow (ERPF) or glomerular filtration rate (GFR) based on the percent injected dose in the kidney 1–2 or 2–3 min postinjection; renal depth is estimated by the Tonnesen equations. Since the Tonnesen equations were derived from ultrasound measurements obtained at an oblique angle in sitting patients, we compared the renal depths obtained from the Tonnesen equations with the renal depth measured by computed tomography in supine patients, the most common position for radionuclide renography. The renal depth, height, weight, age and sex were determined for 126 patients undergoing CT scanning. Patients with obvious renal or abdominal pathology were excluded. The Tonnesen equations significantly underestimated renal depth. Using stepwise linear regression analysis, we derived a set of equations based on age, height and weight and applied these prospectively to a new set of 75 patients. In addition, a second set of equations were derived for the new data. There was no difference in the results for the two equations. We then pooled both studies and derived a combined set of equations: right renal depth (mm) = 153.1 weight/height + 0.22 age + 0.77 and left renal depth (mm) = 161.7 weight/height + 0.27 age − 9.4, where weight is in kilograms and height is in centimeters. The correlation coefficients were 0.81 and 0.83 for the right and left kidneys respectively with standard errors of the estimate of 10.2 and 10.1 mm. These equations provide a much better estimate of renal depth in the supine patient than the Tonnesen equations.

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Camera-based techniques to measure glomerular filtration rate (GRF) or effective renal plasma flow (ERPF) are generally considered to be less accurate than single plasma sample techniques (*1–3*). Nevertheless, camera-based techniques are more popular than plasma sample techniques because they avoid the necessity of delayed plasma sample(s) and meticulous in vitro technique. A number of camera-based techniques to estimate GFR apply a regression equation to the percent of injected dose of ^{99m}Tc-DTPA accumulated in the kidney 1–2 or 2–3 min postinjection (*4–7*). Similar types of measurements are used to estimate the clearance of ^{131}I-orthoidohippurate (OIH) and ^{99m}Tc-mercaptoacetyltriglycine (MAG3) (*7–9*). However, camera-based techniques are dependent on an accurate estimate of renal depth to correct for soft-tissue attenuation.

The Tonnesen formulas for estimating renal depth have been incorporated into popular commercially available algorithms to determine GFR and ERPF (*6–10*). Tonnesen et al. used ultrasonography to measure renal depth with the patient in the sitting position. In addition, renal depth was measured with the ultrasound probe positioned at an oblique angle to the kidney (Fig. 1). Since kidney position may vary with a change in posture, nomograms to determine the kidney depth in the sitting patient may not apply if the patient is supine. Since the majority of renography studies are performed with the patient supine (*11*), we measured renal depth by transmission computed tomography (CT) with the patient in the supine position (Fig. 1) and compared the results with renal depth estimated from the Tonnesen equations. We then used the CT data to develop an algorithm to calculate renal depth and then applied this algorithm prospectively to CT in a second set of patients.

MATERIALS AND METHODS

CT scans of 126 adult patients were randomly selected and the following data were recorded: age, height, weight and renal depth of each kidney. Renal depth was determined by measuring from the skin to the anterior and posterior surfaces of the kidney at the renal hilum and then taking an average of these values to determine a mean depth (Fig. 2). Patients with ascites, a single kidney or masses that might distort the normal renal depth were excluded. Actual renal depth was compared to the calculated renal depth based on the Tonnesen equations: right kidney depth (cm) = 13.3 (weight/height) + 0.7; left kidney depth (cm) = 13.2 (weight/height) + 0.7, where weight is in kilograms and height in centimeters (*10*).

A multiple linear stepwise regression analysis was carried out to determine the relative importance of each of several variables in order to develop new regression equations for estimating right and left kidney depth. Variables under evaluation included age, sex, height, body surface area, weight, weight/height, height/weight, and the squared and cubed values of the latter three variables and (height/weight)$^{1/2}$.

These regression equations were applied prospectively to a new set of 75 adult patients. A separate multiple-linear stepwise regression analysis was also conducted on the new set of data and the regression equations based on the 75 patients and were com-

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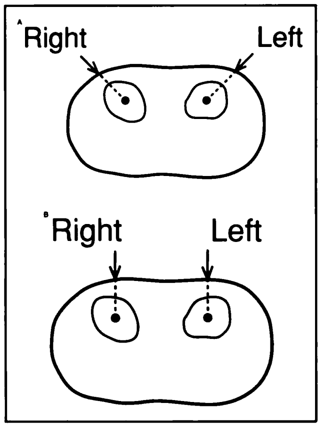

FIGURE 1. (A) Diagram showing the oblique angle used by Tonnesen and coworkers to measure renal depth in sitting patients. (B) Diagram showing perpendicular angle used to measure renal depth in supine patients.

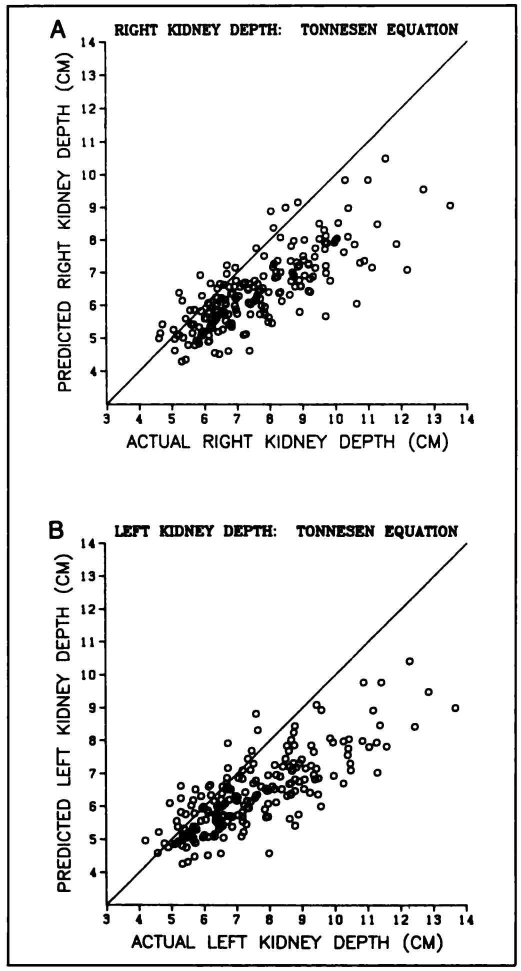

FIGURE 3. The solid line represents the predicted renal depth of the right kidney (A) and left kidney (B) using the Tonnesen equations; the circles represent renal depth determined by CT.

pared to the original regression equations based on the initial 126 patients. Finally, all 201 patients were pooled to generate a final set of regression equations.

RESULTS

The Tonnesen formulas tended to underestimate renal depth for both kidneys and the error increased as renal depth increased (Fig. 3).

The initial 126 subjects included 68 females and 58 males. Their sex, age, height, weight and renal depths are presented in Table 1. A multiple linear stepwise regression analysis of the initial 126 subjects showed that sex had no independent predictive value in determining renal depth. The important variables were weight/height and age. Using these variables, the following regression equations were obtained with weight in kilograms and height in centimeters: (1) left kidney depth (mm) = 170.7 (weight/height) + 0.29 age − 14.4; and (2) right kidney depth (mm) = 162.3 (weight/height) + 0.23 age − 6.1. The correlation coefficient for left renal depth was 0.83 and the standard error of the estimate was 10.6 mm. The correlation coefficient for the right kidney was 0.84 with a standard error of the estimate of 9.8 mm.

These equations were applied prospectively to an additional 75 subjects with a mean age of 54.7 ± 16.2 yr and mean renal depths of 73.9 mm (left kidney) and 75.2 mm (right kidney) (Table 2). The correlation coefficients were 0.81 (left kidney) and 0.75 (right kidney). These 75 subjects were then used to generate a second set of regression equations for renal depth: left renal depth (mm) = 145.2 (weight/height) + 0.25 age − 1.3; and right renal depth (mm) = 131.4 (weight/height) + 0.22 age + 7.9 with weight in kilograms and height in centimeters. The correlation coefficient for the right kidney was 0.75 with a standard error of the estimate of 10.7 mm. The correlation coefficient for the left kidney was 0.81 with a standard error of

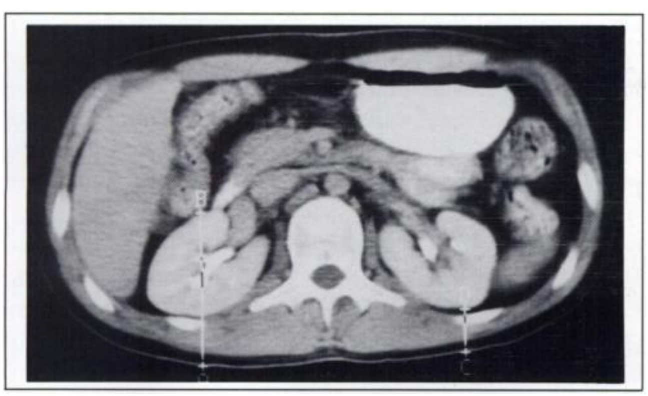

FIGURE 2. CT scan showing skin to anterior and posterior renal surfaces at the level of the renal hilum. Renal depth was determined by averaging the anterior and posterior depths at the renal hilum.

TABLE 1
Characteristics of the First 126 Subjects

	Male	Female	Total
Number	58	68	126
Age (yr)	52.3 ± 15.4	55.8 ± 15.4	54.6 ± 16.2
Weight (kg)	84.9 ± 14.9	67.1 ± 14.3	76.2 ± 16.8
Height (cm)	179.6 ± 6.7	163.7 ± 7.0	171.0 ± 10.5
Left renal depth	81.7 ± 17.8	71.7 ± 19.0	76.0 ± 19.7
Right renal depth	81.1 ± 19.5	72.9 ± 17.5	77.0 ± 18.1

mean ± s.d.

TABLE 2
Characteristics of the Second 75 Subjects

	Male	Female	Total
Number	30	45	75
Age (yr)	55.0 ± 16.7	54.4 ± 16.0	54.7 ± 16.2
Weight (kg)	81.8 ± 16.6	65.6 ± 13.3	72.1 ± 16.6
Height (cm)	179.3 ± 6.6	163.5 ± 7.9	169.8 ± 10.7
Left renal depth	79.5 ± 16.9	70.7 ± 15.6	74.2 ± 16.6
Right renal depth	79.0 ± 13.6	72.0 ± 17.4	74.8 ± 16.2

mean ± s.d.

9.6 mm. There was no significant difference in the results obtained by the two equations. The correlation coefficient between the right renal depths predicted by the first and second set of equations was 0.99; the correlation coefficient for left renal depth was also 0.99.

All 201 subjects were then pooled to generate equations for left and right renal depth with weight in kilograms and height in centimeters: left renal depth (mm) = 161.7 (weight/height) + 0.27 age − 9.4; and right renal depth (mm) = 151.3 (weight/height) + 0.22 age + 0.77. The correlation coefficient for the left kidney depth was 0.83 with a standard error of the estimate of 10.2 mm; for the right kidney, the correlation coefficient was 0.81 with a standard error of the estimate of 10.1 mm. Plots of predicted renal depth versus actual renal depth are illustrated for each kidney (Fig. 4).

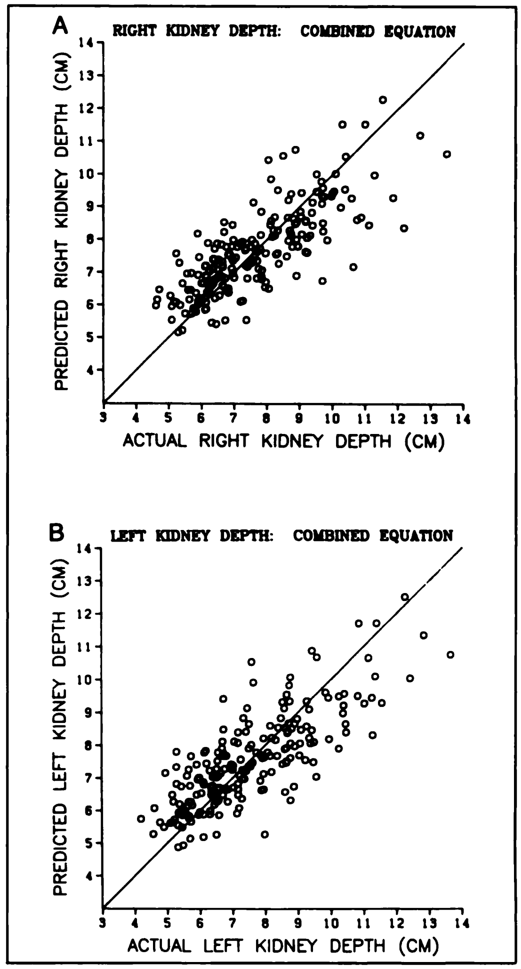

FIGURE 4. The solid line represents the predicted renal depth based on the combined equations for the right (A) and left (B) kidneys. The circles represent the CT determined depths.

DISCUSSION

Tonnesen's equations were developed from 31 females and 24 males with a mean age of 46 yr (*10*). Renal depth was determined with the patients in the sitting position using B-scan ultrasonography; renal depth was measured from a posterior oblique angle rather than a direct posterior projection (Fig. 1). Renal depth in the sitting position may vary by a centimeter or more from that in the recumbent posture and the kidneys may move anteriorly and inferiorly when the patient changes from a supine to an upright (*12–15*). The difference in renal depth can be minimized by imaging the patient supine (*15*). Since we wanted to minimize the differences in renal depth and since most patients are imaged supine in the United Kingdom (*11*), and probably also in the United States, we measured renal depth with the patients supine. In view of the differences in patient positioning, it is not surprising that Tonnesen's equations provided relatively poor estimates of renal depth in our supine patient population.

In our study, we found that age correlated significantly with renal depth, independent of body weight. This observation may be related to an age-associated loss of muscle mass with the central deposition of adipose tissue. An age-related central deposition of adipose tissue could explain the correlation between age and renal depth.

Errors in absolute and relative function measurements can be introduced when the kidneys are assumed to lie at the same depth but these differences may be interpreted as differences in renal function. How serious are these errors? Most previously reported studies of renal depth in adults have been conducted with the patient in either the erect, sitting or prone position (*10,16–18*). Although some differences in the depths of the two kidneys have been reported, the relevant measurement is the position in which the patient is actually scanned. Based on our series, the average absolute difference in renal depth ranged from 0 to 26 mm, with an average value of 6.1 mm and 84% of patients having a difference of less than 1 cm (Fig. 5).

The actual effect of differences in renal depth on absolute uptake and relative function measurements will depend on renal depth, the tissue attenuation coefficient and the size and shape of the kidney. The linear attenuation coefficient for ^{99m}Tc in tissue is 0.153/cm; however, due to scatter, the effective attenuation coefficient is lower and has been reported to range between 0.10 and 0.14/cm (*5,11,19*). If we assume an attenuation coefficient of 0.12/cm and a true renal depth for each kidney of 7 cm, then a 6.1-mm error in the renal depth estimate for one kidney would change the relative uptake from 50/50 to 52/48; a 1-cm error would give a relative uptake measure-

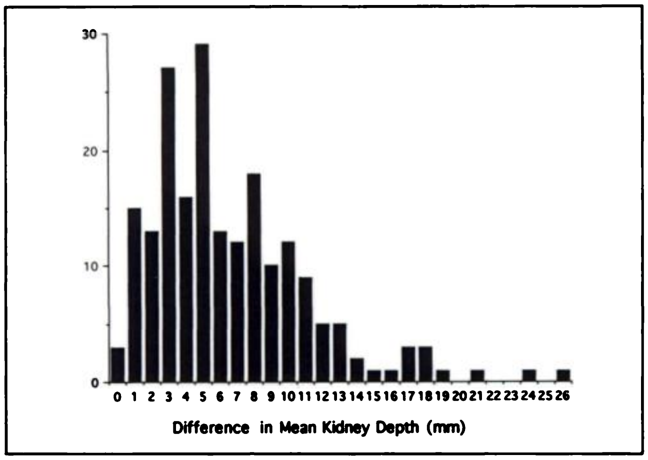

FIGURE 5. Bar graph depicting the differences in renal depth between the right and left kidneys in all 201 subjects.

ment of 53/47 and a 2-cm error would give a value of 56/44. Since the renal depths differed by more than 2.0 cm in only 1.5% of patients, it is quite unlikely that a relative uptake measurement outside the 56/44 range will represent differences in tissue attenuation due to differences in renal depth when the patient is imaged in the supine position.

It is important to note that these data were obtained in adults and our equations should not be used to estimate renal depth in children. Maneval et al. measured renal depth using computed tomography in children (*19*) and found that the equations published by Gordon et al. (*20*) and Raynaud et al. (*21*) provide good estimates of renal depth. In their study, less than 10% of patients had differences in renal depth exceeding 1 cm; consequently, errors in measuring relative function in children are apt to be small.

Some investigators have suggested lateral views to determine renal depth rather than empirical formulae (*7,11*). However, when tracers such as ^{99m}Tc-DTPA, OIH or ^{99m}Tc-MAG3 are administered, the lateral depth measurement has to be made at the conclusion of the renogram 20–30 min after the radiopharmaceutical injection. By this time, most of the tracer has left the kidney or is in the collecting system and an accurate lateral measurement of renal depth may be quite difficult. In fact, both Chachati et al. and Ginjaume et al. conducted clinical studies to evaluate camera-based methods of calculating renal clearances and concluded that lateral measurement of renal depth failed to offer any improvement over the Tonnesen equations (*7,22*).

In conclusion, the new regression equations provide superior estimates of renal depth in supine patients compared to the Tonnesen equations. Incorporation of these equations into camera-based protocols to determine renal clearances may lead to more accurate measurements of renal function.

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