Attenuation Correction in Evaluating Renal Function in Children and Adults by a Camera-Based Method

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Correction for soft-tissue attenuation is required to evaluate absolute renal function by a camera-based method, and an estimate of renal depth and an attenuation coefficient are commonly used for attenuation correction. The first goal of this study was to develop formulas for the calculation of renal depth in both children and adults. The second goal was to optimize the attenuation coefficient for the estimation of renal accumulation of a ^{99m}Tc-labeled agent. **Methods:** Renal depth was measured by CT in 74 children and 232 adults and compared with the depth calculated using previously published equations. Multiple stepwise linear regression analysis was conducted using data from children and adults together, and new formulas to calculate renal depth were derived. Using the resulting equations, percentage renal uptake at 2–2.5 min was computed from ^{99m}Tc-diethylenetriamine pentaacetic acid (DTPA) renography in 40 children and 92 adults. Percentage renal uptake was assessed using various values of an attenuation coefficient, and an optimized attenuation coefficient was determined to maximize the correlation coefficient between percentage renal uptake and glomerular filtration rate (GFR) measured from 2 blood samples. **Results:** Although the previously published equations appeared to be acceptable in predicting adult renal depth, they substantially underestimated pediatric renal depth. Renal depth (D, cm) was shown by stepwise regression analysis to depend on the ratio of body weight (W, kg) to body height (H, cm) and was successfully calculated in both children and adults using the derived equations (right: $D = 16.778 \times W/H + 0.752$; left: $D = 16.825 \times W/H + 0.397$). The correlation coefficient between percentage renal uptake of ^{99m}Tc-DTPA and measured GFR varied substantially according to the attenuation coefficient used and was the highest (0.947) with an attenuation coefficient of 0.087/cm. **Conclusion:** The equations presented here enabled estimation of renal depth irrespective of the patient's age. Attenuation correction using these equations and the optimized attenuation coefficient appears to aid in evaluating renal accumulation and, consequently, renal function in both children and adults.

Key Words: renal function; attenuation correction; ^{99m}Tc-diethylenetriamine pentaacetic acid; renal depth; attenuation coefficient

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Absolute renal function and relative function can be assessed using dynamic radionuclide renography with ^{99m}Tc-diethylenetriamine pentaacetic acid (DTPA) or ^{99m}Tc-mercaptoacetyltriglycine (MAG3). Camera-based methods without blood sampling are convenient and widely used in children (*1–5*) as well as in adults (*6–14*). In most camera-based techniques, renal function is estimated on the basis of the amount (*3–5,9–13*) or rate (*1,2,6–8*) of renal accumulation soon after injection. Correction for soft-tissue attenuation is necessary to quantitate renal accumulation, and an estimate of renal depth, distance from skin to kidney center, and a fixed value of attenuation coefficient are commonly used for attenuation correction.

The accuracy of a camera-based method depends on the accuracy of estimating renal depth. The formulas of Tonnesen et al. (*15*) are popular in calculating renal depth (*3,9,10,16*). Their equations were developed on the basis of sonographic measurements obtained from a posterior oblique angle in the sitting position, whereas images of renography are usually acquired in the supine position. Because of the substantial postural mobility of the kidney, renal depth should be determined in the same position as that used in renography. Calculation using the equations of Tonnesen et al. has been shown to underestimate renal depth in the supine position in children (*17*) and in adults (*18*). Taylor et al. (*18*) measured renal depth on CT with patients in the supine position and presented formulas to estimate renal depth in adults using age and the ratio of body weight to body height as variables. The measurement of renal function plays a major role in pediatric practice. Although the equations of Taylor et al. (*18*) appear to be successful in estimating adult renal depth, it remains to be determined whether their equations can be applied to the estimation of renal depth in children.

The attenuation coefficient is also considered to have a substantial effect on the accuracy of attenuation correction. The linear attenuation coefficient for ^{99m}Tc in water is 0.153/cm, and this value is often used to correct for soft-tissue attenuation in renography with a ^{99m}Tc-labeled agent (*1,3,5,9–11*). However, the effective attenuation coefficient should be lower because of the presence of scattering photons, and reported values have a wide range, from 0.099 to 0.14/cm (*12,13,19–23*). The effective attenuation coefficient is usually determined based on phantom experiments. Experimental conditions, such as the energy window and the size and shape of the renal phantom and body phantom, appear to affect the estimates of effective attenuation coefficient, and the difference in experimental conditions may be responsible for the difference in estimated values. Although the same energy window used in patient imaging can be used in phantom experiments, patients vary widely and it is difficult to precisely simulate clinical conditions using phantoms. Phantom experiments may not provide a sufficiently reliable attenuation coefficient for radionuclide renography, and an appropriate attenuation coefficient does not appear to have been established.

In this study, we measured renal depth on CT in children and adults. The first goal of the study was to develop formulas that are applicable to the estimation of renal depth in children and adults. Next, attenuation correction was performed using various values of attenuation coefficient in assessing glomerular filtration rate (GFR) from renography with ^{99m}Tc-DTPA, and the relationship between the attenuation coefficient and accuracy of GFR estimation was evaluated. The second goal was to optimize the attenuation coefficient for the estimation of renal uptake of a ^{99m}Tc-labeled agent. This study aimed at adjusting the method of attenuation correction to the evaluation of renal function in both children and adults.

MATERIALS AND METHODS

Estimation of Renal Depth

Abdominal CT scans without contrast enhancement were evaluated retrospectively. They were obtained for clinical indications, with the patients in the supine position. Patients with a single kidney or gross distortion of normal anatomy were excluded. The patients studied included 74 children (34 boys, 38 girls; age range, 0–15 y; mean age ± SD, 6.9 ± 5.1 y) and 232 adults (120 men, 112 women; age range, 16–87 y; mean age, 53.8 ± 16.5 y). Eleven patients were younger than 1 y, and the youngest patient was 3 mo old.

Renal depth was determined from CT scans as described by Taylor et al. (*18*). Perpendicular distances from the dorsal skin to the anterior and posterior surfaces of the kidney were measured at the center of the renal hilum, and renal depth was defined as the mean value of the 2 distances.

Renal depth (D, in centimeters) was calculated using the equations presented by Taylor et al. (*18*):

$$D = 15.13 \times W/H + 0.022 \times A + 0.077$$

for the right kidney and:

$$D = 16.17 \times W/H + 0.027 \times A - 0.94$$

for the left kidney, where W is body weight in kilograms, H is body height in centimeters, and A is age in years. Error in predicting renal depth was defined as the absolute difference between the measured and predicted depths.

Multiple stepwise linear regression analysis was performed using all data, from both children and adults, and new equations to estimate the depths of the right and left kidneys were derived. The evaluated variables included age, ratio of body weight to body height, and body surface area (BSA). BSA was computed from body weight and body height (*24*). Renal depth was calculated using the obtained equations and compared with the measured renal depth.

Determination of Attenuation Coefficient

An attenuation coefficient optimized for the evaluation of renal function was determined on the basis of renal scintigraphy with ^{99m}Tc-DTPA in 132 patients. The patient data used in this investigation were the same as those previously used to develop a method for the evaluation of GFR (*25*). The patients included 40 children (22 boys, 18 girls; age range, 0–14 y; mean age, 5.8 ± 4.4 y) and 92 adults (50 men, 42 women; age range, 16–87 y; mean age, 51.7 ± 16.9 y). Three children and 9 adults had only a unilateral kidney; the others had bilateral kidneys.

After adequate hydration, the patients underwent renal scintigraphy with the injection of ^{99m}Tc-DTPA. The injected dose was determined on the basis of BSA, and 200 MBq/m^2 were administered. Posterior dynamic imaging was performed for 30 min with the patients in the supine position. Eighty 3-s frames were obtained in a 128 × 128 matrix with a 20% energy window centered at 140 keV, followed by the acquisition of 52 30-s frames. A γ camera (GCA901A/WG; Toshiba, Tokyo, Japan) equipped with a low-energy general-purpose collimator interfaced to a minicomputer (GMS5500; Toshiba) was used. The syringe containing ^{99m}Tc-DTPA was imaged with the γ-camera system before and after injection, and the injected counting rate (cpm) was assessed by subtracting the postinjection counting rate from the preinjection counting rate with decay correction to the injection time. The γ-camera system has an intrinsic circuit for deadtime correction, and the proportionality between the counting rate and activity in the syringe has been confirmed in the range of counting rates observed in this study.

The clearance method using plasma taken at 2 and 3 h after injection was used as a reference to measure actual GFR (*26*). GFR was calculated by the following equation:

$$\text{GFR (mL/min)} = I \times \lambda/A,$$

where I is injected dose, λ is the exponential slope of the clearance curve, and A is initial plasma tracer concentration obtained by extrapolation of the clearance curve. The measured GFR was normalized for BSA and expressed as mL/min/1.73 m^2.

Percentage renal uptake of ^{99m}Tc-DTPA was calculated as previously described (*25*) except for the equations used to estimate renal depth and the value of the attenuation coefficient. The regions of interest (ROIs) were manually drawn for the kidneys and perirenal background areas. The perirenal background ROI was set around each kidney, excluding the area facing the renal hilum. Using these ROIs, the background-subtracted renal counting rate (cpm) was calculated 2–2.5 min after tracer arrival in the kidney and multiplied by $e^{A \times D}$ (where A is the attenuation coefficient and D is renal depth in centimeters) to correct for soft-tissue attenuation. Attenuation correction was performed using various values of attenuation coefficient ranging from 0 to 0.15/cm. Renal depth was estimated using the equations obtained earlier. The sum of the attenuation-corrected counting rates for the right and left kidneys was divided by the injected counting rate, and percentage renal

TABLE 1
Comparison of Actual and Predicted Depths of Right Kidney

	Renal depth (cm)			Error (cm)	
	Measured	Taylor et al.	This study	Taylor et al.	This study
Children and adults	6.11 ± 1.81	5.84 ± 1.88	6.11 ± 1.67	0.69 ± 0.50	0.54 ± 0.44
Children	3.87 ± 1.38	3.07 ± 1.23	3.90 ± 1.25	0.82 ± 0.44	0.36 ± 0.30
Adults	6.82 ± 1.26	6.72 ± 0.98	6.81 ± 1.06	0.64 ± 0.51	0.60 ± 0.47

Measured = results of measurement on CT; Taylor et al. = results of prediction of renal depth using equations of Taylor et al. (*18*); This study = results of prediction with equations presented in this article.
Data are presented as mean ± SD.

uptake was calculated. Percentage uptake was correlated by linear regression analysis, with GFR measured by the reference method and normalized for BSA. The optimal attenuation coefficient was determined to maximize the correlation coefficient between percentage renal uptake and BSA-corrected GFR. Then, GFR was predicted using the obtained regression equation and compared with the measured GFR by linear regression.

RESULTS

Estimation of Renal Depth

The results of renal depth measurement on CT are presented in Tables 1 and 2 for the right and left kidneys, respectively. The formulas of Taylor et al. (*18*) successfully predicted renal depth in adults. The correlation between measured and predicted adult renal depths appeared to be acceptable for both right and left kidneys (Fig. 1), and mean predicted depth was close to the mean measured depth (Tables 1 and 2). However, the formulas tended to underestimate renal depth in children. Although the correlation between measured and predicted depths was excellent (Fig. 1), mean predicted depth in children was substantially less than mean measured depth, especially for the left kidney (Tables 1 and 2).

Multiple stepwise linear regression analysis showed that the important variable in estimating the depth of each kidney was the ratio of body weight to body height. The obtained equations were as follows:

$$D = 16.778 \times W/H + 0.752$$

for the right kidney and:

$$D = 16.825 \times W/H + 0.397$$

for the left kidney.

The prediction of renal depth using these new equations was successful in both children and adults. The renal depth predicted in adults was well correlated with measured depth (Fig. 2), and mean predicted depth was almost the same as mean measured depth (Tables 1 and 2). They also held true in children. Although the difference between errors using the equations of Taylor et al. (*18*) and the new equations was small in predicting adult renal depth, the error in children was significantly less for both kidneys with the new equations than with the equations of Taylor et al. (*18*) ($P <$ 0.0001, Student paired t test).

Determination of Attenuation Coefficient

The GFR measured from 2 blood samples ranged from 8.3 to 182.5 mL/min/1.73 m^2 in children and from 5.7 to 146.7 mL/min/1.73 m^2 in adults. Percentage renal uptake of ^{99m}Tc-DTPA was calculated using renal depths predicted with the new equations. The correlation coefficient between percentage renal uptake and BSA-corrected GFR varied substantially according to the attenuation coefficient used in calculating percentage uptake and was the highest (0.947) with an attenuation coefficient of 0.087/cm (Fig. 3). Thus, the attenuation coefficient optimal for the estimation of GFR from renography was determined to be 0.087/cm. The regression equation between percentage renal uptake

TABLE 2
Comparison of Actual and Predicted Depths of Left Kidney

	Renal depth (cm)			Error (cm)	
	Measured	Taylor et al.	This study	Taylor et al.	This study
Children and adults	5.77 ± 1.80	5.37 ± 2.08	5.77 ± 1.67	0.78 ± 0.58	0.51 ± 0.42
Children	3.67 ± 1.36	2.28 ± 1.33	3.56 ± 1.25	1.38 ± 0.45	0.32 ± 0.31
Adults	6.44 ± 1.35	6.35 ± 1.06	6.47 ± 1.06	0.59 ± 0.47	0.57 ± 0.43

Measured = results of measurement on CT; Taylor et al. = results of prediction of renal depth using equations of Taylor et al. (*18*); This study = results of prediction with equations presented in this article.
Data are presented as mean ± SD.

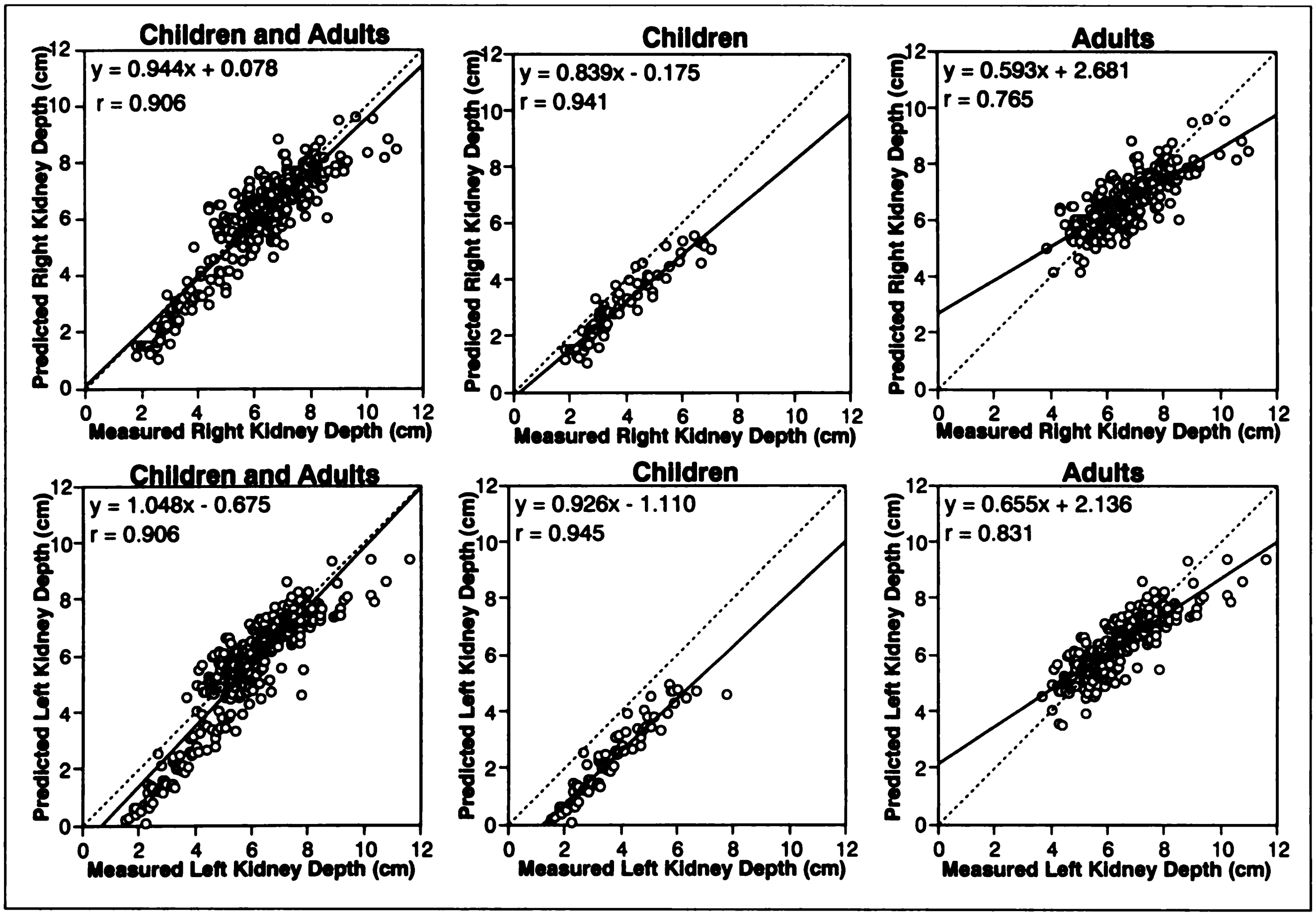

FIGURE 1. Renal depth calculated using equations of Taylor et al. (*18*) (upper row, right kidney; lower row, left kidney). Solid and broken lines represent regression line and line of identity, respectively.

(%uptake) and GFR using the optimized attenuation coefficient was:

$$\text{GFR (mL/min/1.73 m}^2) = 18.300 \times \text{\%uptake} - 0.25.$$

GFR was successfully predicted with this equation in both children and adults (Fig. 4).

DISCUSSION

There are many camera-based methods without blood sampling by which to estimate renal function from dynamic radionuclide renography (*1–14*). Most have been validated in either children or adults, thus necessitating the use of 2 different techniques in nuclear medicine departments to which both pediatric and adult patients are referred. This can be troublesome for operators and, furthermore, may cause problems in the long-term observation of pediatric patients, because the method of estimating renal function should be changed at adolescence. Switching from a technique for children to one for adults may produce discontinuity in serial measurements, possibly leading to misinterpretation of temporal changes in renal function.

We showed a close correlation between BSA-corrected GFR and fractional renal accumulation of ^{99m}Tc-DTPA in patients, including children and adults, and described a method that allows estimation of renal function in both children and adults (*25*). Although soft-tissue attenuation does not necessarily have a considerable effect on the calculation of relative renal function, attenuation correction is essential in evaluating absolute renal function, even in children (*17*). In our method of GFR estimation, renal depth was calculated with the formulas described in papers published previously. Like camera-based methods of estimating renal function, previous equations used to assess renal depth have been validated in either children (*1,22,27,28*) or adults (*15,18*). Although Raynaud et al. (*27*) described a technique to estimate renal depth in children and adults, they used different equations for patients aged 0–9, 9–19, and more than 19 y. We selected the equations of Raynaud et al. for children and those of Taylor et al. (*18*) for adults in developing our method of GFR estimation, because they have been verified with CT measurements (*17,18*). Because different equations are used in predicting renal depths depending on the patient's age, some discontinuity in estimating renal depth and, consequently, renal function may occur even with our method.

In this study, we measured renal depth on CT in children and adults. We confirmed that the equations of Taylor et al. (*18*) can predict renal depth in adults. However, renal depth

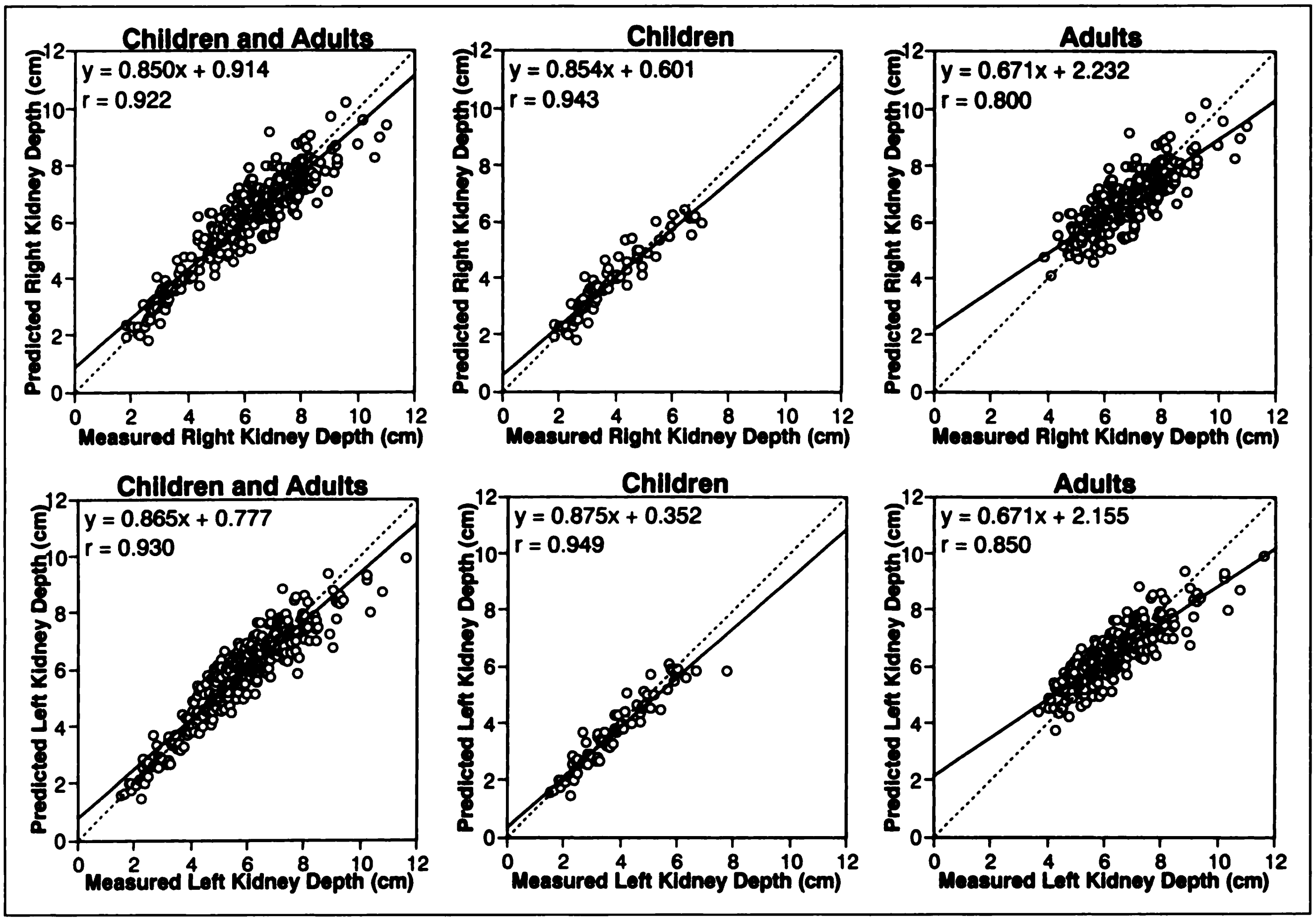

FIGURE 2. Renal depth calculated using equations presented in text (upper row, right kidney; lower row, left kidney). Solid and broken lines represent regression line and line of identity, respectively.

in children was underestimated. The equations of Taylor et al. (*18*) were developed using data from adult patients and were considered to be inadequate for the estimation of renal depth in children.

We attempted to establish formulas suitable for use in children as well as in adults. Multiple stepwise linear regression analysis of data from patients aged 0–87 y showed that renal depth depends on the ratio of body weight to body height, and renal depth was successfully predicted in both children and adults using the obtained equations. The use of these equations appears to add further sophistication to the method of estimating renal function irrespective of the patient's age.

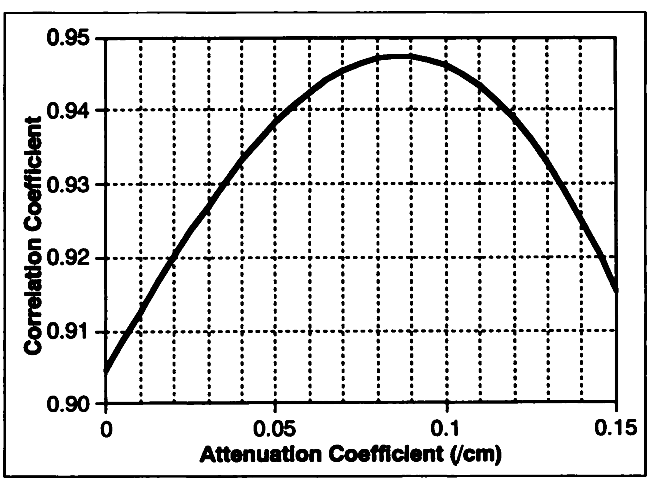

FIGURE 3. Attenuation coefficient and correlation coefficient between percentage renal uptake of ^{99m}Tc-DTPA and BSA-corrected GFR.

Because our equations were developed using data from Japanese patients, it is possible that constitutional differences might render our equations inappropriate for predicting renal depth in patients in Europe and the Americas. However, the successful prediction of adult renal depth using the equations of Taylor et al. (*18*) in this study seems to serve as evidence against this possibility. Although mean measured depths in children in our study (3.87 and 3.67 cm for the right and left kidneys, respectively) were considerably different from mean depths predicted with the equations of Taylor et al. (*18*), the mean measured depths were close to mean depths predicted using the formulas of Raynaud et al. (*27*) (3.70 cm for the right and left kidneys). The failure to predict pediatric renal depths using the equations of Taylor et al. (*18*) appears to be attributable to inapplicability of these equations to the estimation of pediatric renal depth

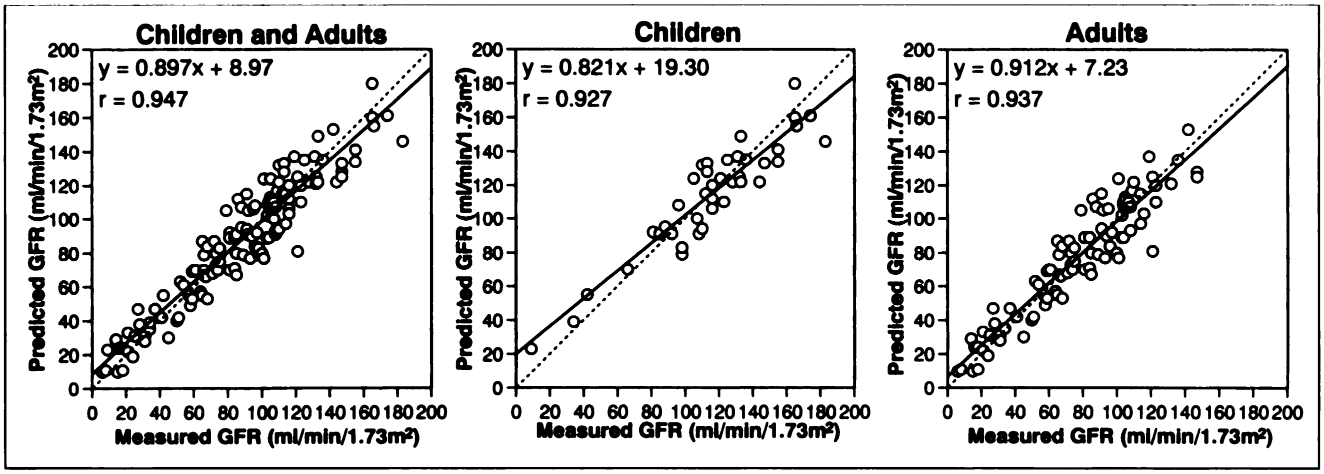

FIGURE 4. Relationship between predicted and measured GFR. Attenuation coefficient was set at 0.087/cm. Solid and broken lines represent regression line and line of identity, respectively.

rather than to constitutional differences between Western and Japanese children. It seems unlikely that our equations would not be appropriate for use in Western patients, although a validation study would be useful for confirmation.

Renal depth is sometimes measured on lateral views of renal scintigraphy. Renal scanning with ^{99m}Tc-dimercaptosuccinic acid provides clear, stable images of renal parenchyma, making the measurement of renal depth on lateral views easy and reliable. However, in dynamic renal scintigraphy with ^{99m}Tc-DTPA or ^{99m}Tc-MAG3, the administered tracer rapidly leaves the renal parenchyma, and clear visualization of the renal contour is not necessarily attained on lateral images acquired after the end of dynamic posterior imaging of 20- to 30-min duration. Moreover, tracer retained in the collecting system may disturb delineation of the renal parenchyma. Although depth measurement on lateral views of ^{99m}Tc-DTPA renography was reported to improve the accuracy of estimating renal function (*29*), other investigators have not found this improvement (*30,31*). Omitting lateral views and predicting renal depth using empiric equations appears to be justified especially in dynamic renal scintigraphy.

The accuracy of attenuation correction is also dependent on the attenuation coefficient. In this study, we derived the attenuation coefficient from the results of renal scintigraphy with ^{99m}Tc-DTPA. Our assumption was that a value that provides the highest correlation between BSA-corrected GFR and fractional renal accumulation of ^{99m}Tc-DTPA should be an attenuation coefficient that is optimal for the estimation of renal function. On the basis of this assumption, an appropriate attenuation coefficient was estimated as 0.087/cm. The evaluation of GFR from renal scintigraphy with ^{99m}Tc-DTPA was successful in both children and adults using the attenuation coefficient and equations described for the prediction of renal depth in this article. The optimized attenuation coefficient may contribute to improving the accuracy of estimating renal function from renal scintigraphy with a ^{99m}Tc-labeled agent.

Renal radioactivity does not derive from a single point. The kidney is a broad and thick source of radioactivity, and its long axis is not parallel to the body surface, which complicates measurement of true renal depth. We measured perpendicular distances from skin to anterior and posterior surfaces of the kidney at the center of the renal hilum and defined renal depth as the mean of the 2 distances. Renal depth as defined in this study may differ from the distance that represents the actual degree of attenuation. The use of the attenuation coefficient optimized for the estimation of renal function may compensate for the difference between them. The application of the optimized attenuation coefficient should be limited to attenuation correction in renography. Different definitions of renal depth may also result in different values of the optimal attenuation coefficient.

In this study, we incorporated the improved method for attenuation correction into our camera-based method of GFR estimation. This modification eliminates discontinuity in estimated GFR between children and adults and appears to make the quantitative assessment of renal function by a camera-based method more reliable. The accuracy of a camera-based method may depend on various factors, including imaging protocol, physical characteristics of the γ camera and operator-dependent ROI setting. Validation in other institutions is a matter for future investigation.

CONCLUSION

We developed equations to estimate renal depth in both children and adults and determined an attenuation coefficient optimized for the evaluation of renal function with a ^{99m}Tc-labeled agent. The new equations and optimal attenuation coefficient were incorporated into a method to estimate GFR from ^{99m}Tc-DTPA renography, which provided reliable estimates of GFR in both children and adults. The method of attenuation correction presented in this article may contribute to improving the methods used to estimate renal function from radionuclide renography.

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