Measurement of Skin-to-Kidney Distance in Children: Implications for Quantitative Renography

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Variation in skin-to-kidney center distance has been shown to have a significant influence on quantification of renal function with the gamma camera. Several techniques to compensate for this variability have been proposed in adults, yet it has been suggested that depth correction is not necessary for quantitative renography in children. Skin-to-kidney center distances were measured from computed tomograms in 53 supine pediatric patients. Nearly 40% of the kidneys examined varied more than 1 cm from the average renal depth, and 8% deviated more than 2 cm. Right kidney depth differed from left kidney depth by more than 1 cm in <10% of the patients. Measurements were in agreement with regression equations based on lateral scintigraphy in children, but were consistently underestimated by nomograms developed for skin-to-kidney center distance in adults. Failure to recognize interindividual variability in skin-to-kidney center distance can introduce significant errors in quantitative pediatric renography.

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Serial images obtained during radionuclide renography can provide a rapid and useful quantitative assessment of both absolute and differential kidney function. Fractional uptake methods, based on the second-phase of the technetium-99m- (^{99m}Tc) diethylenetriaminepentaacetic acid (DTPA) and iodine-131- (^{131}I) hippuran (OIH) renograms, have been reported to correlate with independent measures of glomerular filtration rate (GFR) and renal plasma flow (ERPF), respectively (*1*, *2*). Quantitative renography is particularly of interest in pediatrics because of the difficulties in performing continuous infusions of substrates such as inulin, obtaining multiple blood samples, or collecting complete 24-hr urine samples required for conventional evaluations of renal function.

The accuracy of gamma camera scintigraphy for estimation of GFR or ERPF depends on a number of factors including region of interest definition, background subtraction, counting statistics, and the attenuation of emitted radiation by tissues. Variation in the distance from skin-to-kidney center without correction for attenuation has been shown to introduce errors in absolute quantification of kidney activity (*3,4*). Considering only the attenuation by soft tissue and assuming a linear attenuation coefficient of 0.153 cm^{-1} for ^{99m}Tc, a 1-cm variation in organ depth will result in a 14-percent change in external measurements with the gamma camera (*5*). Correction for tissue attenuation has, therefore, been encouraged by many investigators attempting quantification of renography. Direct measurements of kidney depth, using ultrasound or lateral scintigraphy have been used by some investigators (*1*, *6*), while nomograms relating organ depth to patient height and weight have been employed by others (*7,8*).

Although the importance of accounting for skin-to-kidney center distance has been well recognized in adults, similar corrections have not generally been incorporated into algorithms which evaluate renal function in children (*9,10,11,12*). Some investigators in pediatric renography have used nomograms developed for adults (*13,14*), while others suggest that correction for kidney depth is unnecessary in children (*15,16*). Resolution of the importance of renal depth correction requires data from children over a range of ages and body habitus. The objective of this study was to measure kidney depth in a pediatric population, compare these findings with published nomograms, and comment on the influence of skin-to-kidney center distance as a confounding variable in the quantification of renal function with the gamma camera in children.

MATERIALS AND METHODS

Transmission computed tomograms (CTs) of the abdomen, obtained for valid clinical indications in a series of patients at St. Jude Children's Research Hospital, were retrospectively evaluated to determine renal depth. Single-kidney subjects

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and tomograms with gross distortions of normal anatomy were excluded from the study. Anthropometric evaluation was based on standard physical growth tables (*17*).

Computed tomograms were performed on a Somatom DRH scanner (Siemens Medical Systems, Des Plaines, IL) with the patient supine using a 4-sec scan time and a slice thickness of 8 mm. A majority of the patients had received low osmolality contrast media (isovue or iohexol 300 mg iodine/ml, 2 ml/kg) to enhance visualization of abdominal vasculature and viscerae. Renal depth was determined by identifying the mid-transverse section of each kidney and measuring the perpendicular distance from the dorsal skin surface to the kidney center. Right and left kidneys were measured independently from the CT hardcopy images using a microcomputer interfaced to an illuminated graphics tablet.

Nomograms previously utilized in pediatric renography (Table 1) were then compared to the measured distances from skin-to-kidney center. Surface area measures (BSA) were determined by the method of Gehan and George (*18*).

RESULTS

The CTs on 31 males and 22 females were included in the study. Patient age ranged from 9 mo to 15 yr with a median age of 7.3 yr. Only four children fell outside the 90% range of normal values for age-adjusted height and weight (*17*). The frequency distributions for right and left kidney depths are shown in Figure 1. Right kidney depth (mean = 4.79 ± 1.26 s.d.), measured from skin-to-kidney center, was found to be significantly greater (paired t-test, $p < 0.01$) than depth of the left kidney (4.48 ± 1.13). The differences between right and left renal depths ranged from −0.48 cm to 1.32 cm, with an average difference of 0.30 cm.

Comparison of skin-to-kidney center distances measured by CT with renal depths computed from the Tonnesen regression equations (*19*) is shown in Figure 2A. The predicted values underestimated the measurements in all but one of the 106 kidneys examined. The Tonnesen equations produced a mean prediction error (bias) of −1.19 cm for the right kidney and −0.91 cm for the left kidney in these pediatric patients.

Figure 2B demonstrates the relationship between the regression equation utilized by Shore et al. (*15*) and the CT measurements. Comparison of the measured depths with the weight-based regression relationship defined by Gordon et al. (*20*) using lateral scintigraphy is shown in Figure 2C, and comparison of the measurements with the predictions of Raynaud et al. (*21*) is shown in Figure 2D.

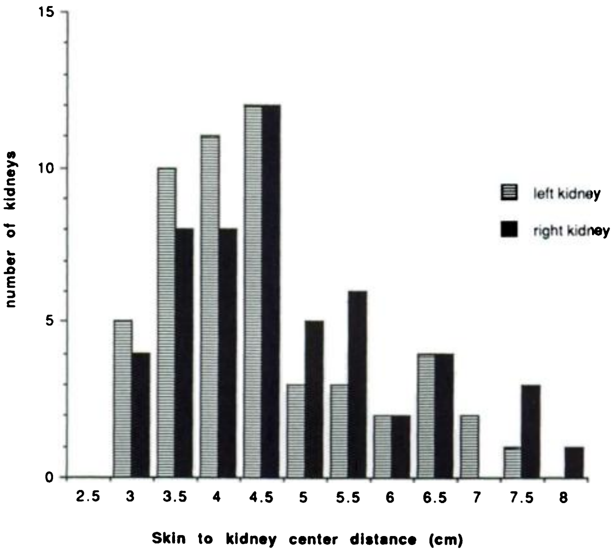

FIGURE 1
Histogram of left and right renal depth in 53 children.

TABLE 1
Regression Equations for Kidney Depth in Children

Source	Renal depth equation*
Gordon (weight) (Ref. 20)	d = 0.0742wt + 2.3
Gordon (BSA) (Ref. 20)	d = 2.82BSA + 1.42
Raynaud (0–9 yr) (Ref. 21)	d = 2.366 + .083wt − .00281ht
Raynaud (9–19 yr) (Ref. 21)	d = 3.686 + .028wt − .00248ht
Tonnesen (left kidney) (Ref. 19)	d = 13.2wt/ht + 0.7
Tonnesen (right kidney) (Ref. 19)	d = 13.3wt/ht + 0.7
Shore (15)	d = 1.37 + 0.0349wt

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* ht in cm, d in cm, wt in kg, BSA in m^2.

DISCUSSION

Piepsz et al. (*22*), in their pioneering work with [^{99m}Tc]DTPA in pediatrics, recognized the potential effect of tissue attenuation on external measurements of renal activity with the gamma camera. Consequently, these authors developed an algorithm for evaluation of renal function, which incorporated a depth correction factor determined from lateral view scintigraphy. Earlier efforts by Raynaud and his colleagues (*23*) emphasized the need to account for interpatient variation in kidney depth to quantitate renal uptake of radioactive mercury. Subsequent investigators attempting quantification of pediatric renograms, however, have concluded that correction for skin-to-kidney center distance is unnecessary in children (*15,16*). Although the errors associated with variability in renal depth are well recognized in adult renography, the importance of attenuation correction for quantitative renal scintigraphy in pediatrics remains controversial.

Recently, Heyman and Duckett have reported the fractional uptake of [^{99m}Tc]DTPA, computed without correction for renal depth, to be an accurate index of GFR in children. These authors argued that skin-to-kidney center distance varies little in the pediatric population, thereby minimizing its effect on absolute uptake measurements with the gamma camera (*16*). Shore et al. considered the influence of tissue attenuation, but were unable to show a statistically significant influence

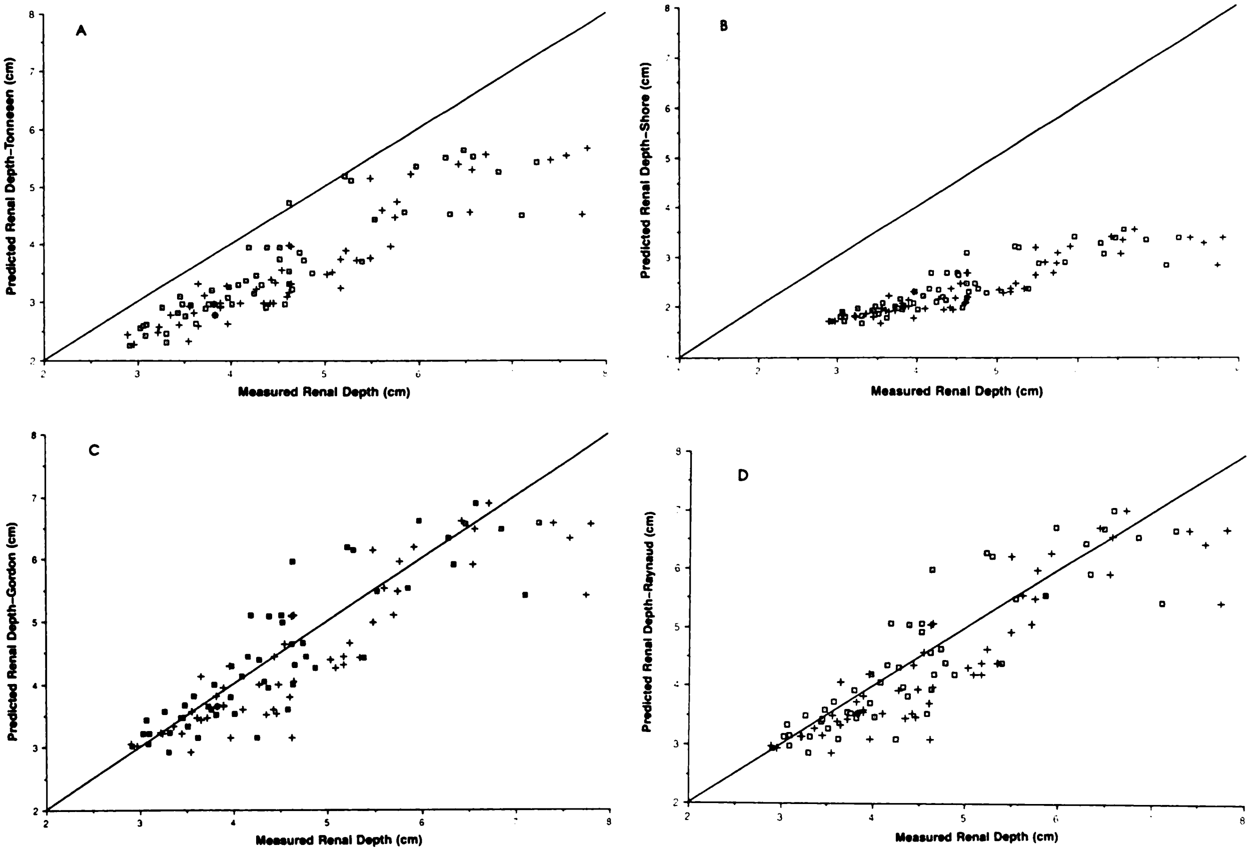

FIGURE 2
Relationship between CT measurements of left (☐) and right (+) renal depth and regression equations reported by (A) Tonnesen (*19*), (B) Shore (*15*), (C) Gordon (*20*), and (D) Raynaud (*21*).

of kidney depth on either slope or area methods for evaluating renal function (*15*). As a result, he suggested that "...the additional effort required to measure renal depth is unlikely to be worthwhile." However, it is important to recognize that Shore et al. measured kidney depth from the skin to the posterior aspect of the kidney (see Fig. 2B), neglecting self-attenuation by the organ.

In contrast, measurements from the CTs presented here indicate that variability in skin-to-kidney center distance is considerable among children and has important implications for quantitative renography. Nearly 40% (42 of 106) of kidneys varied more than one centimeter from the average study population depth, with 8 kidneys differing by a distance of >2 cm (Fig. 1). With ^{99m}Tc renography, the corresponding errors in kidney uptake measurements resulting from attenuation alone can be expected to exceed 14% and 26%, respectively (*5*). Thus, neglecting correction for interpatient variability in renal depth can result in significant errors when kidney function is measured with the gamma camera in children.

Computed tomogram measurements of renal depth also demonstrate that the often utilized Tonnesen (*19*) equations generate biased, inaccurate estimates of skin-to-kidney center distance for the pediatric population. Although these equations have been used to estimate renal depth in children (*13,14*), a regression equation defined from oblique ultrasound measurements of adult patients in the sitting position has questionable relevance for the supine child (Fig. 2A). Inappropriate use of the Tonnesen equations may help to explain some of the variability reported using quantitative [^{99m}Tc] DTPA renography in children (*14*).

The skin-to-kidney distances measured with computed tomography provide an independent verification of nomograms previously developed for renal depth in children using lateral scintigraphy (Figs. 2C-D) (*20,21*). Such confirmation supports the suggestion that lateral imaging after renography should be used to measure individual kidney depth (*1,5,22*). Techniques which incorporate the geometric mean of conjugate projections may provide a more precise method to account for tissue attenuation effects on quantification of renal activity with the gamma camera (*24*). However, lateral measurements from the kidney center to the skin surface have been used to provide accurate measures of absolute organ uptake (*25*) and may be more practical for routine clinical studies.

Measurement of renal depth from CTs provides a degree of precision not possible with lateral scintigraphy. However, renal swelling from osmotic diuresis, a well known effect of injected contrast media, could influence CT measurements of skin-to-kidney center distance. Such an effect is likely to be minimal in our study because the patients evaluated received low osmolality contrast agents. In support of this, measurements of renal depth were unchanged in two patients studied both before and after injection of contrast material.

The difference between the right and left kidney depth in an individual has been reported to be >1 cm in 34% of the adult population (*5*). Measurement of differential kidney function in adults with the gamma camera will, therefore, be in error if differential kidney depth correction is not employed. A smaller percentage of children (only 4 of 53 (7.5%) in the present study) have variations in skin-to-kidney center distant >1 cm. As in adults, patient-to-patient variation in skin-to-kidney center distance can significantly influence absolute quantification of renal function with the gamma camera. However, smaller absolute changes in differential kidney depth suggest that split renal function measurements in children are less influenced by the effects of tissue attenuation.

CONCLUSION

The attenuation by tissues between the skin and kidney center is often ignored in quantitative approaches to pediatric renography. Measurements from CTs indicate substantial interindividual variability in kidney depth, and this variability can introduce significant errors in quantification with the gamma camera. Nomograms commonly used to estimate renal depth in adults generate biased estimates of skin-to-kidney center distance in children. Individual measurements from lateral scintigraphy appear to be accurate measures of kidney depth and should be directly incorporated for the quantitative evaluation of the renogram in children.

ACKNOWLEDGMENT

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Selected manuscripts from the issues of the Journal of Nuclear Medicine published 15 and 30 years ago.
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MARCH 1960

Fallout: One of Several Sources of Radiation Exposure to the Total Population

Charles L. Dunham

At the recent fallout hearings held by the Joint Committee on Atomic Energy Special Subcommittee under the chairmanship of Mr. Chet Holifield, a panel of experts convened to make predictions on the exposures which would result from fallout from all weapon testing to date and also to estimate the ^{90}Sr accumulation in soil and in humans.

There is good evidence now that debris introduced into the upper stratopshere just north of the equator, at say 10° North, has a half-residence time in the stratosphere of several years and perhaps as much as one-third of it will come down in the southern hemisphere. If it is introduced in the lower stratosphere at the same latitude, the half-residence time will be shorter, perhaps only two or three years. If the debris is introduced in the North Temperate Zone or further north, the half-residence time appears to be on the order of, only a year to 18 months.

One of the readily identifiable recurring annual costs of our defense effort is some 1,400 accidental deaths in our armed forces and an additional number of serious injuries. For comparison, one can easily calculate possible effects of fallout from weapon tests to date on the basis of the quite unsubstantiated hypothesis that radiation effects are directly proportional to total dose irrespective of dose rate. This I did, using 10 strontium units for average-body burden and 0.15 rad for total-body exposure and came up with the following figure: over the next 70 years in the U.S., an average of some 500 greater or lesser tragedies per year, including gross genetic defects–miscarriages, etc., as well as leukemia and bone cancer cases. ■

MARCH 1975

Application of Annihilation Coincidence Detection to Transaxial Reconstruction Tomography

Michael E. Phelps, Edward J. Hoffman, Nizar A. Mullani, Michel M. Ter-Pogossian

A study was conducted to investigate the use of annihilation coincidence detection (ACD) in emission transaxial reconstruction tomography. The ACD was evaluated in terms of spatial resolution and sensitivity with depth, detection efficiency, effect of pulse-height analysis on resolution and efficiency, correction for attenuation, and cold spot contrast. A prototype positron emission transaxial tomograph (PETT), consisting of a hexagonal array of 24 Nal(Ti) detectors employing ACD, was constructed.

To evaluate the overall resolution and the effect of pulse-height analysis of the PETT, three capillary tubes, 2.0 mm in diameter, were placed in an 18-cm diameter cylindrical phantom filled with water. Data were collected with the PETT using only the photopeak and then accepting pulses from 100 keV and above. The reconstructed images contained 200,000 counts. The LSFs were constructed from the numerical printout.

The positron emission transaxial tomograph can be designed to utilize the radiation emitted by radionuclides more efficiently than is generally possible with SPC systems. The prototype PETT used here employed only the coincidence between directly opposing pairs of detectors. However, a much more efficient utilization of the annihilation radiation is accomplished by the use of a multiple coincidence logic. This type of logic would increase the number of coincidence outputs from 12 to 48, an increase in efficiency of approximately a factor of 4. ■

MARCH 1990

Insider

Michael E. Phelps

"Exciting times" is how Michael Phelps described the early days of PET research. Working in Michel Ter-Pogossian's laboratory, one of many that had recognized the potential of positron emitting isotopes of natural elements, Phelps and others developed what they referred to as the "lead chicken," a cluster of 32 Nal detectors positioned around the head. Later, upon word of the development of x-ray CT, Phelps and others realized that applying the same principle of mathematically reconstructed tomographic images, the lead chicken might take wing.

The "Lead Chicken" was disassembled, and from its parts the world's first positron CT device was constructed. Out of affection, as much as anything else, Phelps named the device PETT, for positron emission transaxial tomography.

"It was my child then, and I fussed over it night and day, as anyone might fuss over a child," Phelps said. "That was a great feeling. The feeling that what we were doing was really valuable. It's a strange feeling now, like watching a child grow up and go out into the world. Realizing it's not my baby anymore." ■