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Influences of kidney depth and a linear attenuation coefficient on glomerular filtration rate by Gates' method.

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SUMMARY

The effects of kidney depth and a linear attenuation coefficient on glomerular filtration rate (GFR) by Gates' method were studied. Mean depth ±1SD for the right kidney was 5.2±1.0cm and for the left kidney was 4.8±0.8cm. There was no significant statistical difference between male and female students. Male weight and weight/height ratio were correlated with measured kidney depth. When kidney depth by Tonnesen's formula was larger than that measured by US, GFR was overestimated, while GFR was underestimated when the former was smaller than the latter. A linear attenuation coefficient (μ) of Mix-DP, polyacrylate plate and water were found to be 0.105, 0.115 and 0.121, respectively, and smaller than 0.144 of ham. Gates' GFR was overestimated in larger μ value, while underestimated in smaller μ value. It is important to consider the effects of kidney depth and μ value on GFR calculation, when the Gates' method is used.

INTRODUCTION

Since a new technique for determining glomerular filtration rate (GFR) was reported by Gates[1] in 1983, it has been used widely in clinical use[2] because of its usefulness and convenience. However, this method includes several factors which may cause improper estimation on GFR. Firstly, one is kidney depth. Gates calculated kidney depth using a formula derived by Tonnesen[3]. On the other hand, ultrasonography (US) has become a popular technique for imaging body organs. At present US is selected as the first modality in examining not only abdominal organs but also thyroid and mammary gland. Lewis[4] and Tajima et al[5] assessed kidney size using US. However, measurement of kidney depth was not performed in these studies. Ito[6] and Gruenewald et al[7] estimated the effect of kidney depth on Gates' GFR by measuring kidney depth using US for patients with various age. Sibamoto et al[8] described that

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kidney size gradually decreased with age. In order to exclude the effect of patient age on kidney depth, students with constant age were examined. Other factor affecting Gates' GFR is a linear attenuation coefficient (μ), which has been assumed to be 0.153[1]. Effects of μ value on Gates' GFR has not been described previously. It is unfavorable to measure μ value on human body directly from the viewpoint of radiation protection. Therefore, the substances such as Mix-DP, polyacrylate plate and water are selected to be examined in the form of phantom because they are expected to show μ value similar to that of human body. Measurements of μ value on such materials were also performed in this study.

The purpose of this paper is to evaluate effects of kidney depth and linear attenuation coefficient on GFR by Gates' method.

MATERIALS and METHODS

(A) Basic study

(1) Measurement of kidney depth

Thirty-seven students (male21, female16) were examined using real-time sonographic unit (Fansonic 190, Aloka) with 3.5-MHz sector array transducer. Their ages ranged from 19 to 22 years old (mean±SD : 19.5±0.9). Images of both kidneys were obtained in the supine position. The distance A (cm) between skin and outer margin of the kidney and B (cm) between skin and inner margin of it were measured on both kidneys (Fig.1). Mean value of (A+B)/2 (cm) was used as kidney depth. Care was taken to ensure that the ultrasound beam was perpendicular to the skin surface.

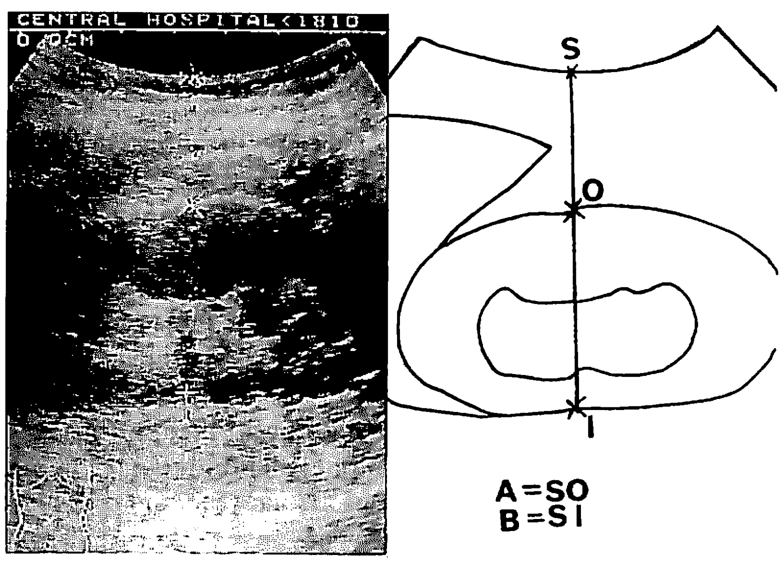

Fig. 1 Ultrasonograhic image on kidney and kidney depth
Kidney depth=(A+B)/2

(2) Measurement of a linear attenuation coefficient (μ)

Gates' method was made on the assumption that the μ value of Tc-99m in soft tissue was 0.153. In order to confirm this assumption, measurements of μ value on various materials were performed using a scintillation camera (GCA-401-5, Toshiba) equipped with a low-energy parallel hole all purpose collimator. A syringe including 4 MBq of Tc-99m (0.2ml) as a line source (1cm) was positioned 30cm apart from the surface of collimator and was counted for 1 min. Immediately after counting a syringe for 1 min, measurements were repeated with shielding material in the path of the γ rays. The thickness of shielding material such as Mix-DP, polyacrylate plate, water and ham (commercially available) was changed 1 to 10cm with 1cm interval except ham. The thickness of ham was changed 1 to 3.5cm. The μ value of shielding material was obtained by the following formula.

$$\mu = -(1/x) * \ln (I/I_0) \quad \text{---} \quad (1)$$

when I_0 : counts per min without shielding material (cpm)
I : counts per min with shielding meterial (cpm)
x : thickness of shielding material (cm)

(B) Clinical study

(1) Measurements of kidney depth in patients

In three patients with suspected renal dysfunction, kidney depths were measured using US (type SSA250A, Toshiba) with 3.5-MHz sector array transducer.

(2) Radionuclide study

After measuring kidney depth, radionuclide study was performed using the following procedure. All patients were administered 150MBq of Tc-99m DTPA. To obtain net counts administered, a syringe was counted 30cm apart from the surface of a collimator for 1 min before and after injection. A patient was placed in supine position with a scintillation camera underneath positioned to include both kidney area. Renal scintigraphy was obtained using a scintillation camera (GCA-401-5, Toshiba) equipped with a low-energy parallel hole all purpose collimator. Image data were acquired in a 64*64 matrix on a computer processing system (GMS-55A, Toshiba) at a frame rate of 5 sec per frame for 1 min from the time of injection and then serial images of 60 frame with 20 sec per frame were acquired. Using the counts within the region of interest (ROI) from 2 to 3 min after injection, GFR was obtained from the following formula[1].

$$GFR = 9.8127 * \%\ \text{kidney uptake} - 6.82519 \quad \text{---} \quad (2)$$

where % kidney uptake=(R+L)/D*100, D is given dose. R=(right kidney counts (cpm)-BKG (cpm))*exp(μXr), L=(left kidney counts (cpm)-BKG(cpm))*exp (μXl). BKG = background counts. Each kidney count was obtained on the whole kidney. BKG was obtained on the ROI surrounded semilunarly under both kidneys. μ is a linear attenuation coefficient of Tc-99m DTPA in soft tissue. Xr and Xl are right and left kidney depth (cm), respectively. To obtain Xr and Xl, Gates employed the following formulae[1].

$Xr = 13.3\ (W/H) + 0.7$ ---- (3)

$Xl = 13.2\ (W/H) + 0.7$ ---- (4)

where W is weight (kg), H is height (cm).

RESULTS

(1) Usefulness of ultrasonic screening test

In measuring kidney depth for a 19-years-old male student, his left kidney could not be detected at the corresponding site. The intravenous pyelography (IP) and computed tomography (CT) after IP showed the ectopic left kidney (Fig. 2). In such a case, split renal function using Gates' method is not correctly estimated because both kidneys can not be visualized simultaneously. Therefore, ultrasonic test before radionuclide study was very useful in examining the morphological information on both kidneys. In the following estimation of kidney depth, this case was excluded.

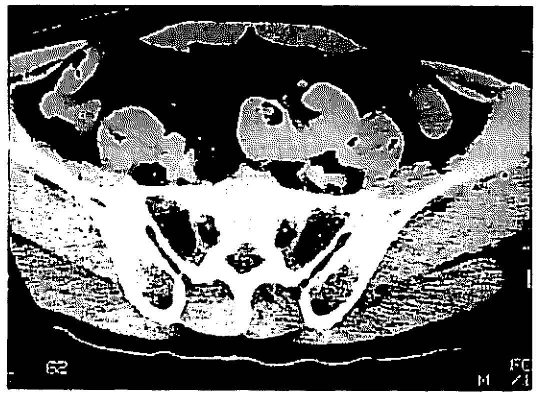

Fig. 2 Computed tomography after intravenous pyelography shows the ectopic left kidney

(2) Kidney depth

The right and left kidney depth for total students were 5.2±1.0cm (mean±SD, male 5.2±1.1cm, female 5.2±0.9cm) and 4.8±0.8cm (male 4.8±0.8cm, female 4.8±0.9cm), respectively. Kidney depth showed a good agreement between male and female. Furthermore, there was no significant difference ($p < 0.05$) between the depth of both kidneys, although the depth of the right kidney was larger than that of the left.

a) Kidney depth versus weight

Male weight was correlated with measured kidney depth, showing a coefficient of correlation (r) of 0.61 for the right kidney and 0.57 for the left kidney, while female weight was not correlated with measured kidney depth.

b) Kidney depth versus height

Male and female height were not correlated with measured kidney depth.

c) Kidney depth versus weight/height ratio

Male weight/height ratio was correlated with measured kidney depth, showing r of 0.63 for the right kidney (Fig. 3a) and 0.57 for the left kidney (Fig. 3b), while female weight/height ratio was not correlated with measured kidney depth. The following formulae for male students were derived.

For the right kidney,

$Xr = 14.6\ (W/H) - 0.2$ ---- (5)

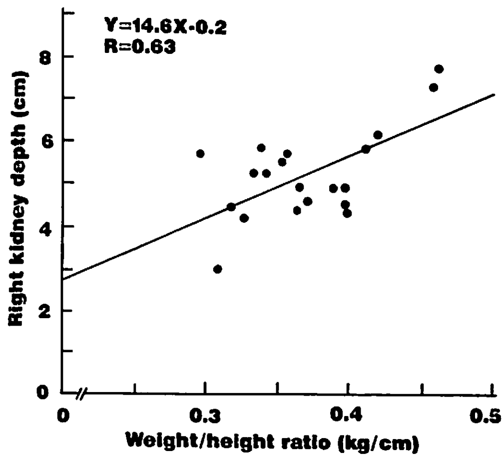

Fig. 3a Measured right kidney depth versus weight/height ratio

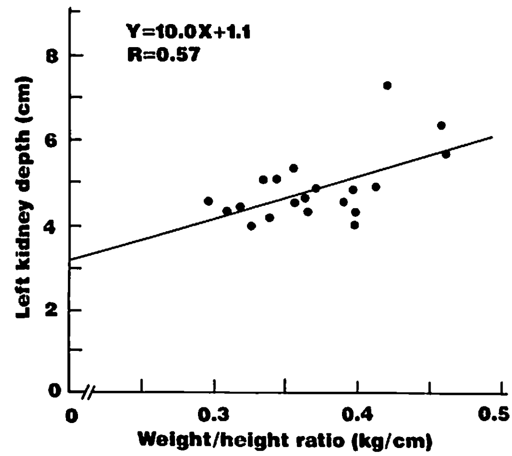

Fig. 3b Measured left kidney depth versus weight/height ratio

For the left kidney,

$$Xl = 10.0 \text{ (W/H)} + 1.1 \quad \text{----} \quad (6)$$

(3) A linear attenuation coefficient (μ)

In semilogarithm chart, I/I_0 ratio in formula (1) decreased linearly with increasing thickness of material (Fig. 4). The μ value of Mix-DP, polyacrylate plate and water were found to be 0.105, 0.115 and 0.121, respectively and smaller than 0.144 of ham.

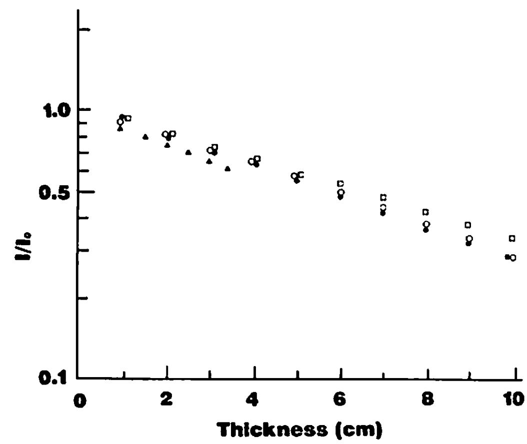

Fig. 4 I/I_0 versus thickness
□ : Mix-DP,
○ : Polyacrylate plate,
● : Water,
▲ : Ham

(4) Effects of measured kidney depth and a linear attenuation coefficient on Gates' GFR

a) Effect of kidney depth on Gates' GFR

Table 1 shows the comparison of calculated and measured kidney depth in three patients and of GFR values using them. Usually, GFR was overestimated when the calculated kidney depth was larger than the measured kidney depth, while GFR was underestimated when the former was smaller than the latter. The deviation of GFR using the measured kidney depth was less than 20%, compared with GFR using the calculated kidney depth.

b) Effect of a linear attenuation coefficient on Gates' GFR

In three patients GFR was obtained using μ values of 0.153, 0.1 and 0.2. As shown in Table 2, GFR was underestimated at 0.1 of μ, while GFR was overestimated at 0.2 of μ. The deviation was within approximately 30%, compared with GFR using μ of 0.153.

Table 1 The relation between GFR using calculated kidney depth and GFR using measured kidney depth

		case 1		case 2		case 3	
		L	R	L	R	L	R
depth (cm)	T	6.1	6.2	5.2	5.2	4.4	4.4
	US	5.6 (8.2%)	5.9 (4.8%)	4.6 (11.5%)	5.9 (13.5%)	5.8 (31.8%)	5.2 (18.2%)
GFR (ml/min)	T	34.1	38.4	31.1	43.8	37.3	46.6
	US	31.2 (8.5%)	36.8 (4.2%)	32.3 (4.2%)	45.4 (3.7%)	44.6 (19.6%)	55.6 (19.3%)

T: kidney depth by Tonnesen's formula(cm)
US: kidney depth by ultrasonography(cm)
L: left kidney
R: right kidney

Table 2 The change of GFR with different linear attenuation coefficient

μ value	case 1	case 2	case 3
0.153	72.5	74.9	84.0
0.100	50.4(-30.5%)	55.3(-25.8%)	65.3(-22.2%)
0.200	99.0(+36.6%)	97.2(+29.8%)	104.7(+24.6%)

(ml/min)

DISCUSSION

Gates reported the new technique estimating GFR using Tc-99m DTPA and scintillation camera. This technique was based on the fact that percent renal uptake to given dose was proportion to creatinine clearance[1]. His method has been used in many institution because it facilitates to estimate GFR. However, this method includes the calculation of kidney depth and the assumption of a linear attenuation coefficient. Tonnesen's formulae[3] which Gates employed were derived from 55 patients using a static B-mode ultrasound scanner. Tonnesen reported a coefficient of correlation (r) of 0.865 between weight/height ratio and kidney depth. Ito et al[6] measured kidney depth in forty-eight patients ranging 3 to 76 years old (mean 37.3 years old) and reported that kidney depth measured by US had a good correlation with weight/height ratio ; r of 0.849 for the right kidney and r of 0.823 for the left kidney. In addition, they obtained the formulae for determining kidney depth ; right kidney depth=16.55(W/H)+0.66, left kidney depth=17.05(W/H)+0.13. On the other hand, Gruenewald et al[7] described that the kidney depth calculated from weight/height ratio had a poor correlation with the kidney depth measured by real-time ultrasound. His results showed r of 0.52 for the right kidney and r of 0.69 for the left kidney. Similarly our result showed a poor correlation between calculated and measured kidney depth. In our results, kidney depth for male students correlated with weight and weight/height ratio, while kidney depth for female students did not correlate with the weight, height and weight/height ratio. Tajima et al[5] described that female kidney size was larger than male in adolescence. It seems to be the greater individual difference on young people's growth that caused a poor correlation between weight or weight/height ratio and measured kidney depth.

In Gates' method, a linear attenuation coefficient (μ) was assumed to be 0.153. To confirm this assumption, measurements of μ were performed. When γ-ray penetrates through thick material, bildup factor should be considered. With regard to bildup factor (B), formula (1) is modified to $\mu=(-1/X)\ \ln\ (I/BI_0)$. In this study, however, bildup factor was neglected. As a result, μ of Mix-DP, polyacrylate plate and water were found to be 0.105, 0.115 and 0.121, respectively. The μ value of ham was 0.144 and similar to 0.153 which Gates employed. Therefore, the value of 0.153 seems to be reasonable.

In conclusion, ultrasonic screening test before starting radionuclide study was useful in obtaining the morphological information on both kidneys. Measurements of kidney depth may be useful in raising the reliability of Gates' GFR. It is important to consider the effects of kidney depth and a linear attenuation coefficient on GFR evaluation by the use of Gates' method.

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Gates法による糸球体濾過量に及ぼす腎の深さと線減弱係数の影響

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要　　旨

Gates 法による糸球体濾過量（GFR）の評価には腎の深さや線減弱係数（μ）の評価が重要である。今回，超音波装置を用いて腎の深さを測定し，またシンチレーションカメラを用いて Mix-DP，アクリル板，水などの μ を測定し，これらの因子が GFR の評価に及ぼす影響について考察した。19.5±0.9歳の男女37人について，超音波検査による右腎の深さは5.2±1.0 cm, 左腎の深さは4.8±0.8 cm, であり，男女差は全く認めなかった。男子の体重および体重身長比は，約0.6の相関係数で腎の深さと相関した。Tonnesen の式により計算した腎の深さよりも実測値が大きい時には GFR は過大評価され，小さい時には過少評価されたが，誤差は20%以内であった。超音波検査で正常位置に左腎が認められず，その後の検査で骨盤内に左腎を認めた１例を経験した。核医学検査前に超音波検査を施行することは腎の形態的情報を把握する上で非常に重要であると思われた。また Mix-DP，アクリル板，水の μ は各々0.105, 0.115, 0.121であり，ハムの0.144よりも小さい値を示した。μ が大きい時には GFR 値は過大評価され，小さい時には過少評価された。以上，Gates 法を用いた GFR の評価には腎の深さや μ などの影響を考慮する必要がある。