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Quantitative renography with the organ volume method and interporative background subtraction technique

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When quantification of renal activity is performed by planar imaging, many correction factors must be considered. To obtain quantitative renal images and renogram, we have examined our proposed method by using the organ volume for scatter, attenuation, and background activity, and the interporative background subtraction (IBS) technique in phantom and clinical studies. A renal phantom study was performed by varying the renal depth from 3 to 11 cm and the kidney-to-background activity concentration ratio from 5 to 80. Planar images were properly corrected for scatter, attenuation and background activity by our method and the corrected images were compared with the images obtained by the conventional method for the estimation of true renal activity. Clinical Tc-99m DTPA dynamic data for both a good and a poor renal function were also corrected by our method and volume-corrected renograms were obtained. For the phantom study, depth-independent images were obtained and these images gave a good estimation of the true count rate. In the clinical study, the conventional renogram was especially modified to allow for oversubtraction of background counts in the early phase (0–4 min). In conclusion, our proposed correction method can assess renal function qualitatively and quantitatively in both static and dynamic planar renal imaging.

Key words: planar scintigraphy, renal activity quantification, interporative background subtraction, Tc-99m DTPA

INTRODUCTION

TO EVALUATE RENAL FUNCTION, dynamic studies with radiopharmaceuticals are often performed by planar scintigraphy. Tc-99m-diethylene triamine pentaacetic acid (DTPA) is employed for renography and for measurement of the glomerular filtration rate (GFR). Gates developed a simple method of measuring GFR with planar images,[1,2] but it had some problems. For planar imaging by means of a single head gamma camera, we have developed a volume method which obtains a more accurate GFR than the Gates' method.[3,4] Our method accurately corrects for scatter, attenuation and background activity, and has shown a good correlation with the creatinine clearance in a clinical study.[4] It involves processing a single image obtained over 2–3 min after injection to calculate the renal uptake of Tc-99m DTPA. If this method is applied to a complete renogram study, it is possible that more information about renal function may be obtained.

To test this hypothesis, we created renal phantom images with both qualitative and quantitative information by the volume method and the interpolative background subtraction (IBS) technique. Furthermore, two dynamic data using Tc-99m DTPA for good and poor renal functions were processed in the same manner as the phantom images and renograms were obtained. These renograms were compared with those obtained by the conventional background subtraction method. For these studies the experimental and clinical data reported previously were used.[4]

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MATERIALS AND METHODS

The volume method

The volume method estimates the count rate C_c within the volume source as follows:[3,4]

$$C_c = (C - C_{BG} + C_{BGC}) / TF_v, \quad \text{Eq. 1}$$

where C is the count rate measured at the source area, C_{BG} is the background count rate normalized to the source area, C_{BGC} is the background count rate equivalent to the source volume: $C_{BG} \exp(-\mu_0 d) [1 - \exp(-\mu_0 t)] / [1 - \exp(-\mu_0 T)]$, TF_v is the volume transmission factor: $\int_d^{d+t} [1 - \{1 - \exp(-\mu x)\}^{B(\infty)}]dx$, μ is the linear attenuation coefficient, $B(\infty)$ is the buildup factor at infinite depth, d is the depth from the surface of the background to that of the source, t is the source thickness, T is the background thickness, and μ_0 is the narrow beam linear attenuation coefficient.

To estimate the qualitative and quantitative renal image, Equation 1 is modified as the following equation:

$$I_c(x,y) = (I_r(x,y) + I_{BGC}(x,y))/TF_v, \quad \text{Eq. 2}$$

where $I_r(x,y)$ is the renal image corrected for the background count rate by the IBS technique and $I_{BGC}(x,y)$ is the background image corresponding to the source volume.

Experimental and clinical study

We reported the application of the volume method in our previous study.[4] The technique is summarized briefly as follows.

A single-headed gamma camera equipped with a low-energy, high-resolution, parallel-hole collimator and a nuclear medicine computer were employed. Technetium-99m-pertechnetate and Tc-99m DTPA were used. All planar data were acquired by means of a 64 × 64 matrix with a pixel size of 5.4 mm and a 20% photopeak energy window centered at 140 keV.

A 180 m*l* renal phantom filled with a Tc-99m water solution of 26.6 MBq was placed in a 25 × 20 × 20 cm tall lucite container and its planar images were obtained with the gamma camera in the lateral position. The depth from the background surface to the geometric center of the phantom was varied from 3 to 11 cm and the phantom-to-background activity concentration ratio ranged from 5 to 80. The count rate in the phantom was estimated by the volume method and the Gates' method and compared with the true count rate obtained with a syringe count rate.

Forty patients with renal dysfunction underwent Tc-99m DTPA renography. Dynamic renal images were acquired with a frame rate of 30 sec per image over a 21-min period (a total of 42 images). The renal depth, renal thickness and body thickness were measured by using lateral images. The total 2–3 min renal uptake was calculated by the volume method and the Gates' method and correlated with 24 hour creatinine clearance.

In this study, the above mentioned data were reanalyzed as follows.

Phantom study

First, the image of the renal phantom, $\dot{I}_r(x,y)$, was separated from the background image by the interpolative background subtraction (IBS) technique.[5] A region of interest (ROI) for the renal phantom was generated with a count-threshold technique semiautomatically and an elliptical ROI for the IBS was set around the phantom at 5 pixels from the edge of the phantom's ROI. Next, the image of the phantom thus obtained was corrected for oversubtraction of the background count rate on the basis of the phantom volume.[3,4] This oversubtraction occurred because the IBS method excessively subtracted the background count rate for the region which was occupied by the source within the background from the source count rate. The additive background image, $I_{BGC}(x,y)$, within the phantom's ROI was obtained by multiplying the above mentioned background image by a factor calculated from the depth (3–11 cm) and size of the phantom (cross-sectional area of 40 cm^2 and 4.5 cm-thickness) and the size of background (20 cm-thickness). Finally, the background correction image, $I_r(x,y) + I_{BGC}(x,y)$, was corrected for scatter and attenuation by the volume depth-independent buildup factor (DIBF) method.[3,4,6] The value of the volume transmission factor (TF_v) calculated ranged from 0.263 to 0.744.

With the image corrected for scatter, attenuation, and background activity, the count rate (C_c) for the phantom's ROI was obtained and divided by the true count rate (C_t) (C_c/C_t ratio). Furthermore, with the original image, a semilunar background ROI and an attenuation coefficient of 0.15 cm^{-1}, the C_c/C_t ratio for the Gates' method was calculated and compared with that for our method.

Patient study

Dynamic renal images (a total of 42 images) of two patients who had good and poor renal function, respectively, were processed in the same manner as the phantom images, utilizing the renal depth, renal thickness, and body thickness measured on the lateral image. The renal ROI was drawn either manually or semiautomatically (a count-threshold technique). In Gates method using the conventional background subtraction technique, ring and semilunar background ROIs were employed. The ring background ROI with the width of 2 pixels was set around the kidney at 2 pixels off the edge of the renal ROI. The 2 pixel wide semilunar background ROI was placed below the kidney at 2 pixels off the edge of the renal ROI. The modified renograms obtained by our method were compared with those obtained by Gates' method with the conventional background subtraction technique.

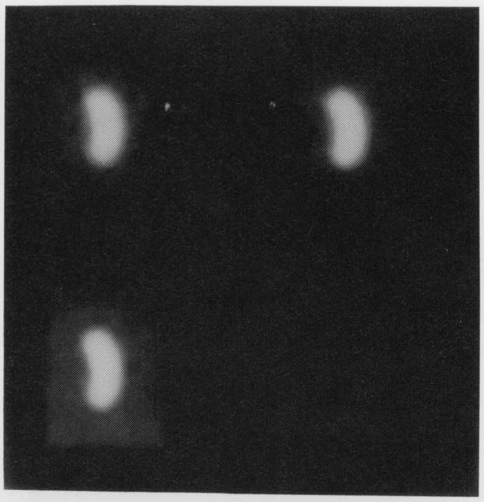

Fig. 1 Comparison of planar images of the renal phantom with background activity acquired under three different conditions: phantom-to-background activity concentration ratio (S ratio) of 40 and depth from the inner surface of the container to that of the renal phantom (d) of 11 cm (upper left), S ratio = 20 and d = 7 cm (upper right), and S ratio = 10 and d = 3 cm (lower left).

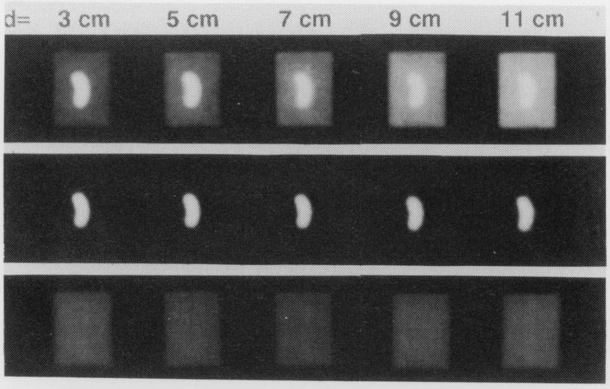

Fig. 2 Original images (top row), and renal phantom images (middle row) and background images (bottom row) obtained by the interpolative background subtraction technique and the volume method at an S ratio of 10. The phantom depth (d) was varied from 3 cm to 11 cm.

RESULTS

Phantom study

The three renal phantom images shown in Fig. 1 were obtained at three different phantom-to-background activity concentration ratios (S ratios) and depths. These images were found to have almost the same phantom-to-background contrast ratio. Figure 2 shows the original images as well as the renal phantom and background images obtained by the IBS technique and the volume method at different depths and an S ratio of 10. On the original images, the phantom-to-background contrast ratio decreased as the phantom became deeper, in contrast to this, the phantom images corrected for depth and background activity had almost the same phantom-to-background contrast regardless of the depth of the renal phantom. The ratios of the count rate obtained from the phantom image (C_e) to the true count rate (C_t) are listed in Table 1 and are compared with the ratios obtained by the Gates' method.

Table 1 The ratios of the estimated count rate (C_e) to the true count rate (C_t) measured by the volume method with and without correction for oversubtraction of background activity, and Gates' method for five different phantom-to-background activity concentration ratios (S ratios) at various phantom depths

S ratio	Method	C_e/C_t Depth (cm)				
		3	5	7	9	11
80	Volume	1.01	1.01	1.00	0.99	0.95
		(0.98)	(0.97)	(0.97)	(0.95)	(0.92)
	Gates	1.38	1.46	1.52	1.54	1.53
40	Volume	1.02	1.01	1.00	0.98	0.95
		(0.97)	(0.96)	(0.95)	(0.94)	(0.90)
	Gates	1.37	1.44	1.49	1.52	1.50
20	Volume	1.01	1.01	1.00	1.00	0.96
		(0.92)	(0.91)	(0.91)	(0.91)	(0.87)
	Gates	1.30	1.37	1.43	1.47	1.44
10	Volume	1.01	0.99	1.01	0.99	0.97
		(0.83)	(0.82)	(0.84)	(0.83)	(0.80)
	Gates	1.18	1.24	1.32	1.34	1.34
5	Volume	1.03	0.99	1.05	1.01	1.01
		(0.72)	(0.67)	(0.74)	(0.71)	(0.71)
	Gates	1.02	1.01	1.17	1.15	1.18

The values in the parentheses mean the C_e/C_t ratio by the volume method without correction for oversubtraction of background activity.

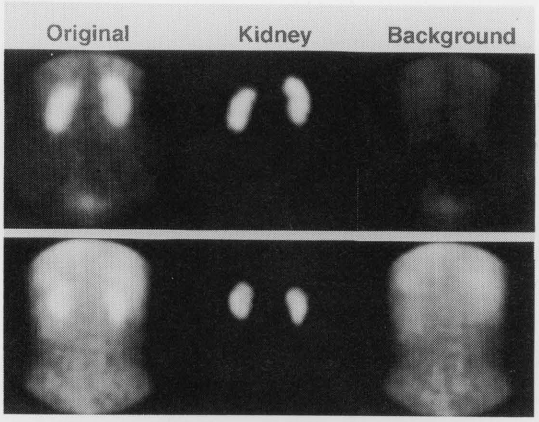

Fig. 3 Comparison of posterior renal images obtained in two patients at 3 min after the injection of Tc-99m DTPA. One patient had normal renal functions (top row: creatinine clearance = 130 m*l*/min, right renal depth = 8.1 cm and left renal depth = 7.3 cm) and other patient had poor renal function (bottom row: creatinine clearance = 26 m*l*/min, right renal depth = 5.5 cm and left renal depth = 5.4 cm). The kidney and background images were obtained by the interpolative background subtraction technique and the volume method.

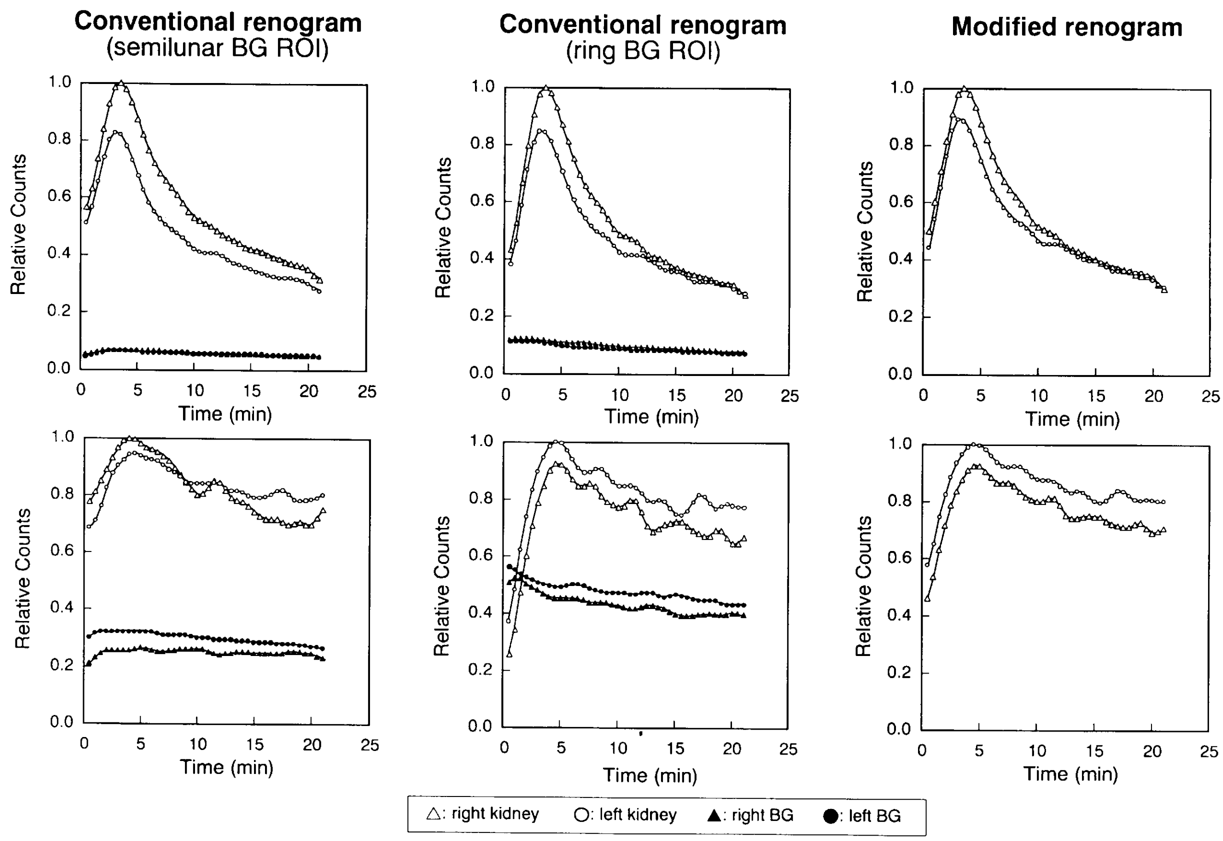

Fig. 4 Renal and background time-activity curves for Patient 1 (top row) and Patient 2 (bottom row) shown in Fig. 3. The conventional renograms were obtained from the original planar images using both semilunar background ROIs below the kidneys and ring background ROIs around the kidneys. The curves were corrected for renal depth (d) using a factor, exp(0.15d) (Gates method). The modified renograms were obtained from images corrected for renal depth and the background count rate using the interpolative background subtraction technique and the volume method. The term BG means background.

For all depths and all S ratios, the C_c/C_t ratio had errors below 5% with the volume method, but the errors ranged from 1% to 54% with the Gates' method. Nevertheless, the volume method without correction for oversubtraction of background activity underestimated the true count rate progressively when S became smaller.

Patient study

Figure 3 compares the original images of two patients obtained at 3 min after the injection of Tc-99m DTPA and the images obtained by our technique. The background images separated by the IBS technique are also shown. Patient 1 had good renal function (creatinine clearance = 130 m*l*/min) and patient 2 had chronic renal failure (creatinine clearance = 26 m*l*/min).

The renograms of patients 1 and 2 were obtained over a 21-min interval (42 frames) by processing the original data by the Gates' method (with both semilunar and ring background ROI subtraction) and our method (Fig. 4). The background curves were normalized by the maximum value of the renogram curves corrected for renal depth. Rapid uptake and clearance of Tc-99m DTPA with low background activity were observed in patient 1, whereas patient 2 had delayed uptake, slow clearance and high background activity. Figure 4 also shows that although the renograms obtained by the three different techniques were similar in the patient with good renal function, these curves showed different uptake patterns for the patient with poor renal function, especially in the early period up to 4 min. In this period, use of the ring background ROI gave rapid uptake that was less marked with the volume method. Figure 5 shows the uptake rate (the count rate divided by the injected count rate) plotted against time for both patients. A difference between the slopes for the patients with good and poor renal function is also seen in the period from 0 to 4 min.

DISCUSSION

The volume method corrects for scatter and attenuation by means of the volume DIBF technique and corrects for oversubtraction of the background activity by consider-

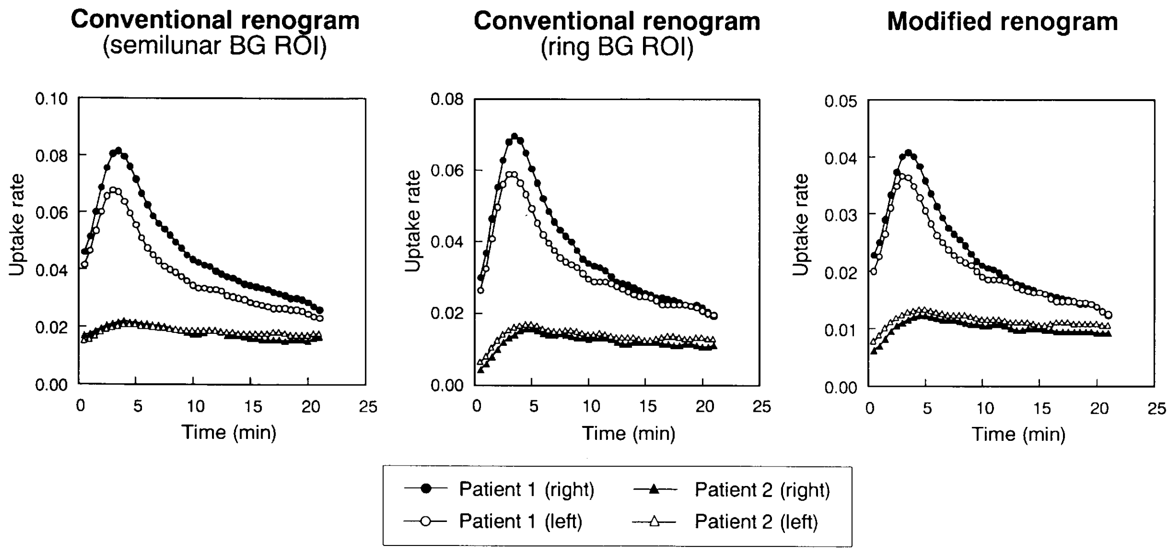

Fig. 5 Renogram curves for the two patients shown in Figs. 3 and 4. The uptake rate (i.e., the renal count rate divided by the injected count rate) is plotted against time. The term BG means background.

ing it in relation to organ volume. We evaluated this method in both the phantom experiment and patient study by Tc-99m DTPA and found that it showed renal activity more accurately than the Gates' method.[3,4] In this study, the renal phantom images originally shown in Ref. 4 were re-analyzed to investigate changes in the relationship between phantom and background activity as the phantom depth and the source-to-background activity concentration ratio (S ratio) were varied, as well as to determine how well the IBS technique could separate phantom and background images.

The kidney-to-background image contrast plays an important role in the visual assessment of renal function. Our results showed that for a given S ratio the phantom images had a lower phantom-to-background contrast at a greater depth, and this phenomenon was more pronounced at low S ratios. This phenomenon may cause errors in the qualitative evaluation of renal function with planar images unless information on renal depth is taken into account. Conrad et al.[7] also reported the depth-related errors during the assessment of renal perfusion and function.

For correction of background activity two methods are generally employed: that with background ROI near an organ and the IBS method. We used the IBS technique reported by Goris et al.[5] and Brown[8] to separate the renal image from the background. This technique can correct for nonuniform background counts. Hurwitz et al.[9] reported that use of the IBS technique reduces variation in the measurement of renal function, particularly in patients with renal failure, when compared to conventional background subtraction with a crescent ROI. Piepsz et al.[10] also discussed a comparison of IBS and conventional background subtraction with an ROI surrounding the kidney. In our renal phantom study the phantom image was successfully separated from the uniform background image by the IBS technique and corrected for depth and oversubtraction of the background count rate by means of the volume method. These corrected images were independent of the phantom depth (Fig. 2) and gave an accurate count rate for the renal phantom (Table 1). In addition, the data listed in Table 1 indicate that the IBS technique which uses background data from around the kidney achieves a quantitatively similar result to the ring ROI,[4] but as we reported in Ref. 3, if the correction for oversubtraction of background activity is not applied, the volume method causes large errors at the smaller S.

In our previous study[4] we only analyzed the image obtained from 2 to 3 min after the injection of Tc-99m DTPA. In the present study, however, the volume method which uses the IBS technique was applied to all the dynamic images collected over a 21-min period (a total of 42 images). Renogram curves corrected for scatter, attenuation and background activity were obtained and were compared with the conventional renogram curves obtained by the Gates' method with both semilunar and ring background ROIs. According to the method employed for background activity correction, various renogram patterns were obtained. As shown in Fig. 4, the mean count rate per pixel within the ring ROI is greater than that within the semilunar ROI, because activity from other organs such as the liver and spleen is included or scattered photons from these organs enter the ROI. In addition, the shape of the time-activity curve for the ring ROI is similar to that for the liver and spleen with a comparatively high early uptake. Conventional background correction with a ring ROI therefore leads to oversubtraction of background counts, especially in the early part of a dynamic study (0–4 min) or in patients with poor renal function. Sennewald et al.[11] have demonstrated that selection of the background ROI causes greater variation in estimating the renal function of patients with renal impairment with Tc-99m mercaptoacetyltriglycine (MAG3) because of high early (1–3 min) uptake of this tracer by the liver.

Data obtained during this early period are often employed to evaluate renal function quantitatively. Gates[1,2] estimated the GFR by calculating the uptake of Tc-99m DTPA from images obtained 2–3 min after injection, while Piepsz et al.[12,13] measured GFR from the slope of the second phase of the renogram curve. A renal study in children indicated that the slope method gave a better estimation of GFR than the Gates' method.[14] In addition, many investigators have attempted to assess renal function by a deconvolution technique.[15–17] It is therefore important to accurately estimate the change in renal activity in the early period. As the IBS volume method accurately corrects for the background count rate regardless of the kidney-to-background activity concentration ratio, it has the potential to obtain a more reliable renogram.

The actual renal uptake and the background count rate overlap within the renal ROI. The background count rate is a combination of the extrarenal background and the vascular background within the renal vascular bed. Our method estimates the true renal count rate by accurately correcting for this extrarenal background. Gullquist et al.[18] reported that the extrarenal background was the major source of error in the estimation of relative renal function and measurement of the mean transit time in poorly functioning kidneys, and stated that the vascular background only had a minor effect. Accurate extrarenal background correction therefore appears to be important.

In our study the volume method was validated in the experiment by using a phantom with uniform activity within a uniform medium, but as the radioactivity within the human's kidney is not uniform (different cortical and pelvic activities), the volume method may have limitations for the assessment of the renal function by the cortical activity only. Further investigation is needed in this practical issue. In the future, this method should be evaluated in a larger number of patients with various grades of renal function.

CONCLUSIONS

In renal dynamic studies with Tc-99m DTPA, planar imaging produces various kidney-to-background contrast ratios that depend on both renal function and renal depth. It is necessary to properly correct for these factors in order to accurately assess renal function by visual evaluation or quantification of the renal activity. As the volume method has the potential to accurately correct for scatter, attenuation, and background activity, the GFR can be calculated more precisely and a more reliable renogram can be obtained, especially in patients with poor renal function.

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