Chula Med J. September - October 2025;69(5): 277 - 282 **DOI : 10.56808/2673-060X.**5497

Original article

Comparison of radiation attenuation correction techniques for relative renal function calculation in renal cortical imaging

Benchamat Phromphao[a,*], Sorasak Wanitchanan[b], Trai Chairat[b], Thunyaluk Sawatnatee[a], Tanawat Sontrapornpol[a]

[a] Department of Radiology, King Chulalongkorn Memorial Hospital, Bangkok, Thailand
[b] Department of Radiological Technology and Medical Physics, Faculty of Allied Health Sciences, Chulalongkorn University, Bangkok, Thailand

Abstract

Background: A ^{99m}Tc-dimercaptosuccinic acid (^{99m}Tc-DMSA) scan is used for renal cortical imaging, specifically for the detection of renal cortical abnormalities, ectopic kidneys, renal scars, etc. Furthermore, relative renal function (RRF) is performed using ^{99m}Tc-DMSA planar imaging and estimated from the radiopharmaceutical uptake in the kidneys with background subtraction and radiation attenuation correction. Generally, attenuation correction is calculated from mathematical methods using the kidney depth correction (KDC) to obtain an accurate renal function value.
Objectives: This research aimed to study the correlation of the RRF after background subtraction with radiation attenuation correction using the geometric mean (GM) method and KDC according to the Beer-Lambert law equation.
Methods: Researchers studied the spherical phantom, the kidney phantom, and patients' data. The phantom and patient data were acquired via gamma camera imaging. In all of the assessments, the background and kidney region of interest were created in planar images for subtracting the background counts and calculating the activity counts in the kidneys. This was used to record and analyze the data and then evaluate the RRF.
Results: For the RRF results with background subtraction and radiation attenuation correction in the phantom studies, the GM method was consistent with the KDC calculated using the Beer–Lambert law equation and the true kidney depth (intraclass correlation coefficient (ICC) > 0.8). The patient studies showed that the RRF results from the GM method correlated with the other KDC methods ($R^2 > 0.95$), and the GM method was not significantly different from that of the other KDC calculation methods ($P > 0.05$, ICC > 0.95).
Conclusion: Radiation attenuation corrected with the GM method and KDC calculation using the Beer–Lambert law equation method can be used to appropriately estimate the RRF in renal cortical imaging.

Keywords: Attenuation correction, kidney depth, relative renal function, renal cortical imaging.

In nuclear medicine imaging, renal cortical imaging with ^{99m}Tc-dimercaptosuccinic acid (^{99m}Tc-DMSA) is widely used to assess normal and abnormal renal function. It is especially beneficial for the detection of renal parenchymal defects, determining the long-term prognosis, and establishing appropriate follow-up.[(1)] DMSA imaging shows the renal size, shape, and morphology. Therefore, it is a valuable tool for the confirmation of nonfunctional multicystic kidneys, detection of ectopic kidneys, renal scarring, etc.[(2-5)]. The sensitivity of ^{99m}Tc-DMSA imaging is higher than that of ultrasound and intravenous urography for the detection of acute and chronic pyelonephritis.[(2)] However, the primary reason for performing ^{99m}Tc-

*Correspondence to: Benchamat Phromphao, *Division of Nuclear Medicine, Department of Radiology, King Chulalongkorn Memorial Hospital, Thai Redcross Society, Bangkok 10330, Thailand*
E-mail: Benchamat.phromphao@gmail.com
Received: June 20, 2024
Revised: July 13, 2025
Accepted: August 22, 2025

DMSA imaging using a gamma camera is to identify cortical abnormalities related to urinary tract infection. Moreover, relative renal function (RRF) is performed using ^{99m}Tc-DMSA planar imaging, which has clinical importance.

The RRF is measured by renal cortical imaging, where ^{99m}Tc-DMSA is taken up in the left and right kidney cortex. However, the planar images captured by the gamma camera of both kidneys do not provide net activity, as they only display the uptake of the soft tissue activity. Importantly, the depths of both kidneys are different. Therefore, background subtraction and radiation attenuation correction are applied to take this into consideration.(2, 6) Generally, radiation attenuation correction is calculated using mathematical methods with kidney depth correction (KDC) to establish an accurate renal function value. This research aimed to study the correlation of the RRF value from the geometric mean (GM) of the radiation attenuation correction and KDC using the Beer–Lambert law equation.

Materials and methods

Patient data collection

This study was reviewed and approved by the Institutional Review Board (IRB) of the Faculty of Medicine, Chulalongkorn University (IRB no. 996/64). Data was collected from 30 patients (age 5.6 ± 5.5 years old) who underwent a ^{99m}Tc-DMSA scan at the Nuclear Medicine section, King Chulalongkorn Memorial Hospital (KCMH) between 2019 and 2021. For data analysis, the scans were corrected for anterior and posterior planar images, and images from both kidneys did not reveal artifacts in the images. According to the clinical protocol at KCMH, Thai Red Cross Society, patients were intravenously injected with 185 MBq (5 mCi) of ^{99m}Tc-DMSA for a patient with a bodyweight of 70 kg. Static images were captured 2 h after injection.

Spherical phantom, kidney phantom, and patient studies

The spherical phantom study began with the radionuclide preparation.(7) The activity concentration was calculated from the average of the counts per pixel in both kidneys divided by the mean background counts in 10 patients. The average kidney-to-background activity ratio of these 10 patients was approximately 4:1. After radionuclide calculation, the spherical phantom was prepared using 3.7 MBq (0.1 mCi) of ^{99m}Tc-pertechnetate in 60 mL of water, and two spherical vessels were filled with the radionuclide. Meanwhile, 109.89 MBq (2.97 mCi) of ^{99m}Tc-pertechnetate was resuspended in 9,000 mL of water, which was used to fill the phantom background. In spherical phantom imaging, the spherical depth is variable. At each depth of the sphere, planar imaging is performed using the same ^{99m}Tc-DMSA scan protocol with a low-energy high-resolution (LEHR) collimator and a 256 × 256 matrix size. In the kidney phantom study, we used Oasis to design an object that was similar in shape and size to that of a human kidney. Oasis is a trademarked name for wet floral foam. It is a soft, water-absorbent, readily available phenolic foam material. This was placed in 55.5 MBq/ 350 mL (1.5 mCi/350 mL) of ^{99m}Tc-pertechnetate for approximately 10 min for uniform absorption. After phantom kidney preparation, they were fixed to a phantom base and filled with 148 MBq (4 mCi) of ^{99m}Tc-pertechnetate in 9,000 mL of water to determine the phantom background activity. Kidney depth was variable, and the planar images were acquired **(Figure 1)**.(7)

Images from 30 patients were acquired using a gamma camera with a LEHR collimator and a 256 × 256 matrix size. The patients' planar images were corrected from the picture archiving and communication system. Furthermore, the patient's data, sex, age, weight, height, and the patient's thickness and kidney depth were recorded in the patient record form. Finally, we used the anterior and posterior views of the ^{99m}Tc-DMSA images for data analysis.

Data analysis

Planar images from the spherical phantom, the kidney phantom at every depth, and the patient images were used to create the kidney and background region of interest (ROI). The background ROI counts must be size-normalized to the kidney ROI before subtraction from the kidney ROI counts. Each ROI was measured 10 times by three researchers to account for inter- and intra-operator variability estimation. After ROI determination, the total count, area (pixels), background count, and background area (pixels) from the anterior and posterior images were recorded. **(Figures 1 and 2)** Kidney net count of both kidneys is calculated with background subtraction from equation 1.

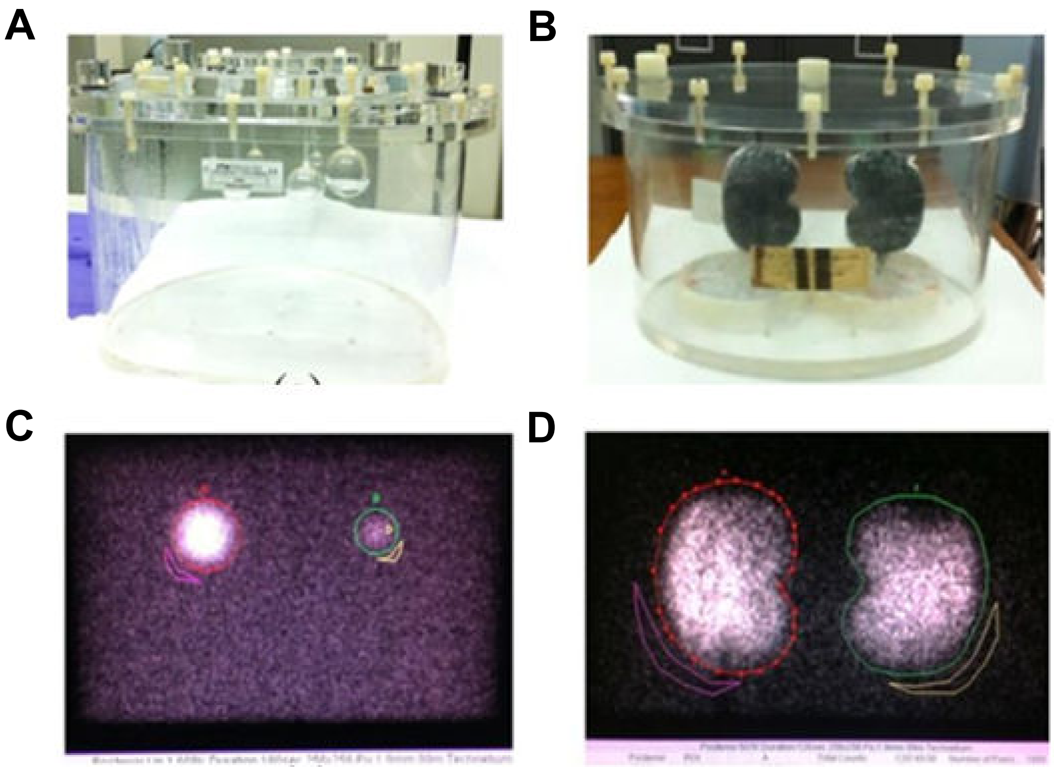

Figure 1. **(A)** Body phantom and two hollow sphere phantoms with radioactivity inside at activity concentration ratio of 1 : 4; **(B)** Home-made kidney phantoms with radioactivity inside body phantom; **(C)** Imaging of 2 sphere phantoms of different diameters and count density; **(D)** Imaging of kidney phantoms.[7]

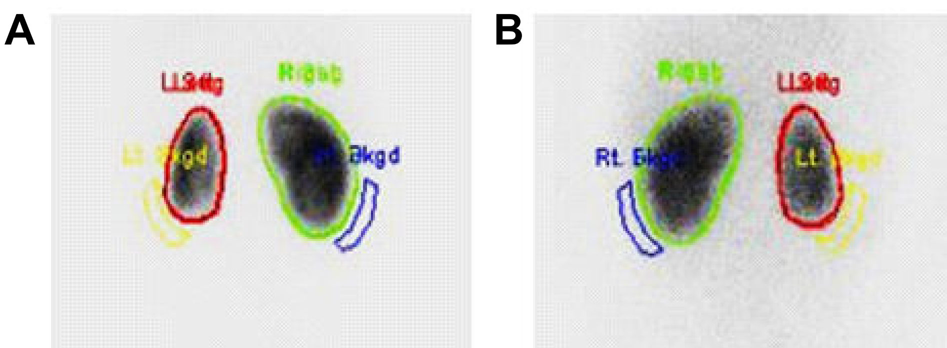

Figure 2. Both patient's kidney and background region of interest (ROI) in **(A)** anterior; and **(B)** posterior view.

Equation 1:

$$C_{cor\ in\ kid} = C_{kid} - Bg_{kid}$$

$$Bg_{kid} = (C_{Bg} / No.pixel_{Bg}) \times No.pixel_{kid}.$$

where

C_{kid}: Total kidney ROI count

Bg_{kid}: Background of the kidney

C_{Bg} : Total background ROI count

No. $pixel_{kid}$: Number of pixels in the kidney ROI

No. $pixel_{Bg}$: Number of pixels in the background ROI

After the net count in the left and right kidneys is calculated, radiation attenuation correction is estimated using the GM and KDC by the Beer-Lambert law equation. The GM is calculated from equation 2, and the KDC is calculated from 5 equations (equations 3–7).

Equation 2: Geometric mean

$$C_{o\,(Rt.or\,Lt.)} = \sqrt{C_{A\,(Rt.or\,Lt.)} \times C_{p\,(Rt.or\,Lt.)}},$$

where

C_o : Net count in the kidney
C_A : Net count in the anterior kidney
C_P : Net count in the posterior kidney
Rt. : Right kidney
Lt. : Left kidney

Equation 3: Beer-Lambert law [7]

$$x = \frac{1}{2}\left(d - \frac{ln\frac{C_P}{C_A}}{\mu}\right).$$

where

x : Kidney depth
d : Patient thickness (cm)
μ : Attenuation coefficient of ^{99m}Tc in tissue (0.2 cm^{-1})

Equation 4: Standard (Tonnesen) [7]

Right kidney depth (cm) = 13.3 (weight/height) + 0.7
Left kidney depth (cm) = 13.3 (weight/height) + 0.7

Equation 5: Emory [7]

Right kidney depth (cm) = 15.3 (weight/height) + 0.022 (Age) + 0.1
Left kidney depth (cm) = 16.2 (weight/height) + 0.027 (Age) - 0.9

Equation 6: Itho [7]

Right kidney depth (cm) = 13.6361 $(weight/height)^{0.6996}$
Left kidney depth (cm) = 14.7577 $(weight/height)^{0.7554}$

Equation 7: T. Itho [8]

Right kidney depth (cm) = 16.6 (weight/height) + 0.7
Left kidney depth (cm) = 17.1 (weight/height) + 0.1

However, after the kidney depth is calculated from equations 3–7, we used the Beer–lambert law equation (equation 8) for the net count in the kidney calculation. After attenuation correction, the RRF value was calculated from equation 9.

Equation 8:

$$C_{O\,(Rt.or\,Lt.)} = C_{P\,(Rt.or\,Lt.)}\,e^{\mu x(Rt.or\,Lt.)},$$

where

C_o : Net count in the kidney
C_P : Net count in the posterior kidney
x : Kidney depth
μ : Attenuation coefficient of Tc-99m in tissue (0.153 cm^{-1})
Rt. : Right kidney
Lt. : Left kidney

Equation 9:

$$Rt.kidney\ function = \frac{C_{O\,(Rt.)}}{C_{O\,(Rt.)} + C_{O\,(Lt.)}} \times 100\%$$

$$Lt.kidney\ function = \frac{C_{O\,(Lt.)}}{C_{O\,(Rt.)} + C_{O\,(Lt.)}} \times 100\%$$

where

$C_{o\,(Rt.)}$:Net count in the right kidney
$C_{o\,(Lt.)}$:Net count in the left kidney

Statistical analysis

The RRF values after radiation attenuation correction were compared for each method. The intracorrelation coefficient (ICC)[9] and paired sample *t*-test were performed using the Statistical Package for the Social Sciences version 20.0. $P < 0.05$ was considered statistically significant.

Results

The RRF values were calculated after background subtraction and radiation attenuation correction using GM and KDC by the Beer–Lambert law equation. For the phantom studies, the RRF values with radiation attenuation using the GM, KDC calculated according to the Beer-Lambert law equation, and true kidney depth are shown in **Table 1**.

Moreover, this study presents the correlation of the RRF values after radiation attenuation correction using the GM and KDC with the Beer–Lambert law methods. This was assessed using a paired *t*-test with data from 30 patients, and results of the mean, variance (S^2), Pearson correlation (r), etc., are shown in **Table 2.**

Table 2 shows the correlation of the RRF after radiation attenuation correction between the geometric mean method was not significantly different from other kidney depth correction methods ($P > 0.05$, ICC = 1). Furthermore, the RRF after attenuation correction using every equation was compared in **Table 3**.

Table 1. Comparison of correlation (ICC) for the relative renal function after attenuation correction in spherical phantom and kidney phantom study.

RRF methods	RRF-GM		RRF-KDC	
	Spherical phantom	Kidney phantom	Spherical phantom	Kidney phantom
RRF-KDC (depth calculation)	1.000	1.000		
RRF-KDC (depth measurement)	0.844	0.849	0.844	0.849

KDC, kidney depth correction; GM, geometric mean; RRF, relative renal function.

Table 2. Paired sample *t*-test between the relative renal function after attenuation correction using geometric mean and Beer-Lambert law equation with kidney depth correction methods.

	GM					KDC				
	Beer-Lambert law equation	Tonnesen	Emory	Itho	T.Itho	Beer-Lambert law equation	Tonnesen	Emory	Itho	T.Itho
Mean	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000	50.0000
Variance (S^2)	396.7695	396.7694	396.7694	396.7694	396.7694	396.7695	400.2713	382.2576	397.3471	389.5252
Pearson's correlation (r)	1.0000	0.9927	0.9811	0.9917	0.9891					
P (T $\leq$ t) two-tail	0.569069	1.0000	0.569069	1.0000						

Table 3. Comparison of the relative renal function after attenuation correction with intra correlation coefficient

RRF - methods	RRF-GM	RRF -Beer-Lambert law	RRF -Tonnesen	RRF -Emory	RRF - Itoh
RRF -Beer-Lambert law	1.000				
RRF - Tonnesen	0.993	0.993			
RRF - Emory	0.981	0.981	0.991		
RRF - Itoh	0.992	0.992	1.000	0.991	
RRF - T. Itoh	0.989	0.989	0.989	0.998	0.998

GM, geometric mean; RRF, relative renal function.

Discussion

In this study, the RRF with attenuation correction was estimated by the GM and KDC by the Beer-Lambert law method in three studies. From the spherical and kidney phantom studies, the RRF from the GM was consistent with KDC using the Beer-Lambert law equation and the true kidney depth (ICC > 0.8). In addition, the patient study showed a good correlation between the RRF from the GM and the KDC via the Beer-Lambert law equation methods; the GM method was not significantly different from other KDC methods in all equations. This aligns with other relevant studies.[7, 10]

The majority of patients in this study who underwent renal cortical imaging were pediatric patients. According to the study by Sontrapornpol T, *et al*.[7] the KDC using the Beer–Lambert law equation revealed good correlation with values obtained from the equations proposed by Tonnesen, Emory, and Itoh. While no significant differences were observed among these methods in adult patients, the differences were significant in pediatric patients. This supports the validity and applicability of the Beer–Lambert law equation for estimating kidney depth, particularly for pediatric patients.

Furthermore, the use of the Beer-Lambert law enhances the accuracy of radiation attenuation correction when applying the GM method. As there was a strong correlation between the GM method and KDC via the Beer–Lambert law, with no significant difference, the GM method is demonstrated as a reliable approach. All methods used to calculate the RRF exhibited high intraclass correlation coefficients (ICC > 0.95), which indicates strong agreement. Notably, the GM method exhibited excellent reliability and offers practical advantages in clinical settings. Unlike other methods, it does not require patient-specific parameters, such as weight, height, or body thickness, thus making it efficient and

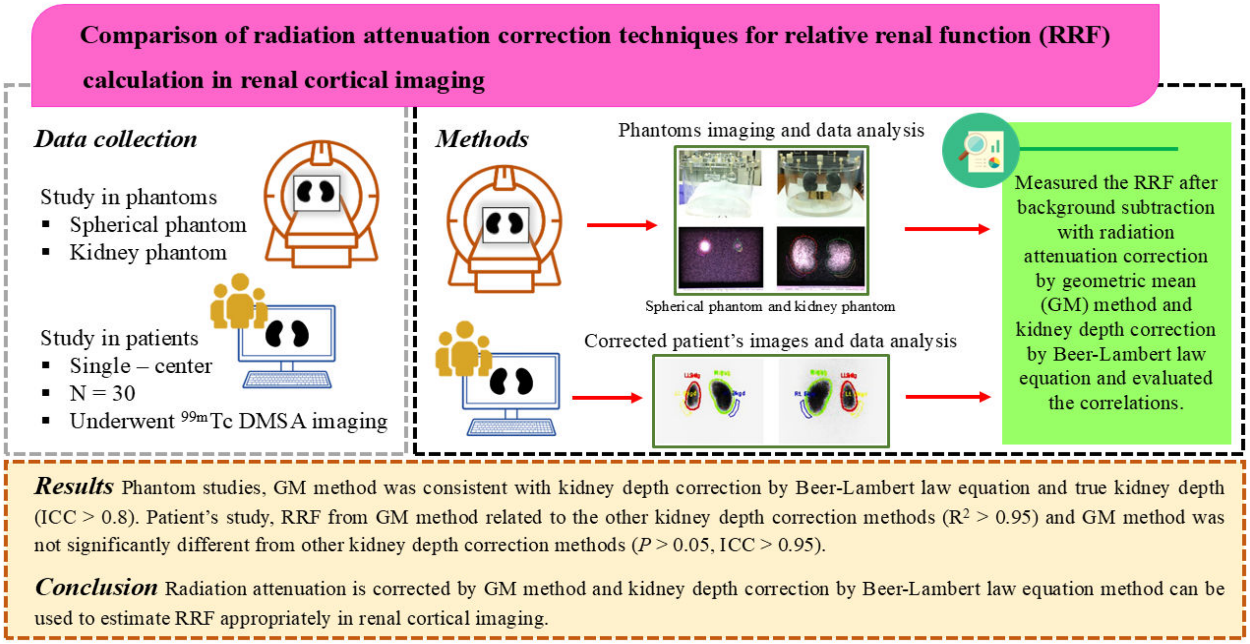

Figure 3. Summary of RRF calculation in renal cortical imaging comparison of radiation attenuation correction techniques.

user-friendly for routine clinical use. However, future research will increase reliability if more examples are considered **(Figure 3)**.

Conclusion

The calculation of the RRF using radiation attenuation correction with the GM method did not differ significantly from other KDC techniques. Therefore, both attenuation correction approaches are appropriate and reliable for estimating the RRF in renal cortical imaging.

Acknowledgements

The authors would like to express their deep gratitude to the participants who were involved in this study.

Conflicts of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported.

Data sharing statement

All data generated or analyzed during the present study are included in this published article. Further details are available for non-commercial purposes from the corresponding author upon reasonable request.

References

1. Marceau-Grimard M, Marion A, Côté C, Bolduc S, Dumont M, Moore K. Dimercaptosuccinic acid scintigraphy vs. ultrasound for renal parenchymal defects in children. Can Urol Assoc J 2017;11:260-4.
2. Piepsz A, Colarinha P, Gordon I, Hahn K, Olivier P, Roca I, et al. Guidelines for 99mTc- DMSA scintigraphy in children. Eur J Nucl Med 2001:28;BP37-41.
3. Lee KW, Bin KT, Jeong MS, Shong MH, Shin YT, Ro HK. Tc-99m dimercaptosuccinic acid (DMSA) renal scintigraphy in patients with acute pyelonephritis. Korean J Intern Med 1995;10:43-7.
4. Vali R, Armstrong IS, Sever ZB, Biassoni L. SNMMI procedure standard/EANM practice guideline on pediatric [^{99m}Tc] Tc-DMSA renal cortical scintigraphy: an update. Clin Transl Imaging 2002:10;173-84.
5. Guarino S, Capalbo D, Martin N, Campana G, Rambaldi PF, Miraglia Del Giudice E, et al. In children with urinary tract infection reduced kidney length and vesicoureteric reflux predict abnormal DMSA scan. Pediatr Res 2020;87:779-84.
6. Lythgoe MF, Gradwell MJ, Evans K, Gordon I. Estimation and relevance of depth correction in paediatric renal studies. Eur J Nucl Med 1998;25:115-9.
7. Sontrapornpol T, Chaiwatanarat T, Kamklon N, Kawinthammasak C, Rattanamonrot R. Kidney depth calculation by anterior and posterior renal scintigraphy using attenuation - related techniques. Chula Med J 2017:61;425-38.
8. Xue J, Deng H, Jia X, Wang Y, Lu X, Ding X, et al. Establishing a new formula for estimating renal depth in a Chinese adult population. Medicine (Baltimore) 2017;96:e5940.
9. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15:155-63.
10. Chroustová D, Trnka J, Šírová V, Urbanová I, Langer J, Kubinyi J. Comparison of planar DMSA scan with an evaluation based on SPECT imaging in the split renal function assessment. Nucl Med Rev Cent East Eur 2016;19:12-7.