Determining the Optimal Dose of Radioactivity for Measuring Glomerular Filtration using Gate’s Method and Obtaining Renogram

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Abstract

Objectives: Measuring Glomerular Filtration (GFR) using Gate’s method gives low radioactivity of approximately 74~111 MBq to a patient. Such low counts on image acquisition degrade image quality. The objective of this study was to limit the amount of radioactivity needed to acquire high-quality dynamic renal images when measuring GFR. Methods/Statistical Analysis: We performed experiments with different radio activities at matrix size of 128 x 128 or other matrix sizes to check overflow phenomenon of gamma-ray. Findings: Ideal total count was at radioactivity of approximately 37 MBq. However, measured total counts from acquire images showed certain counting loss. The average margin of error was −1.88 ± 1.61%. The mean value of GFR according to the radioactivity at more than 370 MBq was −2.91 ± 1.19 %. We could calculate GFR by substituting these results in GFR formula under the same condition. Conclusion: High-quality functional image could be acquired at the same time by increasing radioactivity to 370 MBq with higher matrix size. Improvements/Applications: With these results, we can improve diagnostic ability and make more accurate evaluation of renal function.

Keywords: Creatinine Clearance, GFR, Gate’s Method, Overflow Phenomenon, Renogram

1. Introduction

Glomerular filtration rate (GFR) and the total amount of nephron are very useful indicators of renal function. Creatinine clearance is commonly used to measure GFR. However, it requires urine samples with some errors in the measurement. Inulin clearance is the most ideal method for measuring GFR. However, it is difficult to perform inulin clearance in medical area. Recently, ⁹⁹mTc-diethylenetriamine penta acetic acid (DTPA) is widely used to measure GFR. Most ⁹⁹mTc-DTPA is excreted by glomerular filtration. Only a tiny percentage is excreted by renal tubules for measuring GFR and renogram. Of different methods used to measure GFR using gamma camera, Gate’s method is the mostly used one. In 1982, Gate developed the method to measure GFR using ⁹⁹mTc-DTPA and gamma camera. Although Gate’s method is less accurate than other methods using blood or urine samples, it takes shorter time with excellent reproducibility GFR values of each kidney and renogram can be obtained together through one experiment. Therefore, Gate’s method can be used to measure right and left renal function of kidney transplant patients separately. Gate’s method can measure relatively exact GFR in a short time without blood or urine sample. In addition, it can get split GFR of both kidneys. The GFR(mL/min) formula of Gate’s method is:

\[
GFR = \left[ \frac{C_{RV} - C_{REG}}{e^{-\frac{C_{REG}}{e^{\frac{T}{2}}}}} + \frac{C_{Lx} - C_{LREG}}{e^{-\frac{C_{LREG}}{e^{\frac{T}{2}}}}} \times 100 \right] \frac{(9.81270)}{(6.82519)}
\]

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Where $C_{RK}$ was gamma count of the right kidney, $C_{LK}$ was gamma count of the left kidney, $C_{RBg}$ was background gamma count of the right kidney, $C_{LBg}$ was background gamma count of the left kidney, $C_{preinj}$ was gamma count of syringe before injecting $^{99m}$Tc-DTPA, $C_{postinj}$ was gamma count remained in the syringe after injection, $u$ was attenuation coefficient of soft tissue with a value of 0.153, 9.81270 was the regression coefficient, -6.82519 was $y$-intercept, and $z$ was vertical distance between skin of the back and the center of kidney. It is expressed by

\[
\text{Right kidney depth(cm)} = \frac{13.3 \times weight(kg)}{height(cm) + 0.7} \\
\text{Left kidney depth(cm)} = \frac{13.2 \times weight(kg)}{height(cm) + 0.7}
\]

In this paper, we determined the effect of radiation dose on GFR measurement with the software used for Gate’s method using gamma camera. We also determined the optimal radiation dose that could be injected for GFR measurement while acquiring high-quality renal dynamic functional image simultaneously.

2. Materials and Methods

2.1 Experiments and Equipment

INFINIA Gamma camera (General Electric Healthcare, Wisconsin, MI, and USA) with Low-Energy Parallel Hole (LEHR) collimator and Infinia Functional Imaging Scanner Ver. 2.105 were used. $^{99m}$TcO$_4^-$ radioactive source was used in mega-Becquerel (MBq) using Radioisotope calibrator CRC-12 Carpenters. Xeleris™ Functional Imaging Workstation Ver. 2.1753 (General Electric Company) was used to measure counts of acquired image.

2.2 Experiment Methods

$^{99m}$TcO$_4^-$ source was measured at 37 MBq (1 mCi) using 1 cc syringe for 60 seconds and visualized using Infinia Functional Imaging Scanner Ver. Infinia_2.105. To prevent radioactivity loss due to half-life, those experiments were performed without time loss.

The distance from the source to the detector was 30 cm. Zoom factor was set at 1.28 and Energy Window was set at 140 keV ($\pm$10 %) (Figure 1). In the first experiment, the size of video matrix was set at 128×128. This matrix size was used for most GFR measurement. To confirm the characteristics of detection, images were acquired by changing radioactivity from 37 (1 mCi) to 851 MBq (23 mCi) in 37 MBq (1 mCi) increment. In the second experiment, images were acquired by changing radioactivity to 74(2), 148(4), 222(6), 296(8), 370(10), 444(12), 518(14), and 1,110(30) MBq (mCi) by changing matrix size to 64×64, 128×128, 256×256, and 512×512 to confirm the overflow phenomenon of pixels. Acquired images were counted by using Xeleris™ Functional Imaging Workstation Ver. 2.1753 (General Electric Company) in the same way as in the GFR Protocol. To minimize errors between measured data and counts of source, Region of Interest (ROI) was set using total counts of exposed matrix size.

![Figure 1. Infinia Functional Imaging Scanner. A, 128×128 Matrix, 60 sec. B, Energy Windows at 140 keV (±10).](image-url)
3. Results and Conclusion

Total counts acquired for 60 second using matrix size of $128 \times 128$ in the first experiment are shown in Table 1. We determined whether there were significant differences in total counts of acquired images at matrix size of $128 \times 128$ by increasing the radioactivity in 37 MBq (1mCi) increment. Compared to ideal total count based on radioactivity at 37 MBq, measured total counts from acquire images showed certain count loss. The average margin of error was $-1.88 \pm 1.61 \%$. Especially, the average value of overflow phenomenon at radioactivity of more than 370 MBq was $-2.91 \pm 1.19 \%$ with a wide range of fluctuation. GFR could be calculated by substituting these results in GFR formula under the same condition. The mean GFR at radioactivity at 37 MBq was $-1.89 \pm 1.62 \%$. It was $-2.93 \pm 1.2 \%$ at radioactivity of more than 370 MBq. In the second experiment, the acquired data using matrix sizes of $64 \times 64$, $128 \times 128$, $256 \times 256$, and $512 \times 512$ at radioactivity of 74 to 1,110 MBq are shown in Table 2. We also determined whether there were overflow phenomena depending on matrix size. These experiments showed that there was a grotesque distortion at matrix size of $64 \times 64$ and radioactivity of more than 148 MBq (Figure 2). At matrix size of $128 \times 128$, there was a gap in counts according to the increase of radioactivity. A small distortion occurred at radioactivity of less than 518 MBq that could be ignored. There was no distortion at matrix size of more than $256 \times 256$ show in figure 3.

**Table 1.** Measured total count and ideal count at matrix size of $128 \times 128$

| Activity (MBq) | Total count [count/sec] | Ideal count [count/sec] |
|----------------|--------------------------|--------------------------|
| 37             | 2,281                    | 2,281                    |
| 74             | 4,556                    | 4,562                    |
| 111            | 6,829                    | 6,843                    |
| 148            | 9,088                    | 9,125                    |
| 185            | 11,360                   | 11,406                   |
| 222            | 13,657                   | 13,687                   |
| 259            | 15,923                   | 15,968                   |
| 296            | 18,219                   | 18,249                   |
| 333            | 20,401                   | 20,530                   |
| 370            | 22,627                   | 22,811                   |
| 407            | 24,824                   | 25,092                   |

There was a limitation in measuring each max count at 65,534 count/sec per pixel. To measure GFR and acquire high-quality functional image at the same time, we increased the injected radiation dose to 370(10) MBq (mCi) in consideration of effective attenuation coefficient of technetium at 0.12/cm. It did not affect the measured values of GFR.

Considering GFR at 80∼120 mL/min in in-vitro experiments, we could increase radiation dose up to 370 (10) MBq (mCi) to measure GFR and acquire high-quality renal dynamic functional image simultaneously. This study confirmed that we could obtain GFR and renogram together in one experiment by increasing the amount of radioactivity. This method will cause little pain to the patient. It can also reduce experimental cost and the amount of radiation exposure. (Figure 4)
**Table 2.** Total measured count after increasing radioactivity at different matrix sizes (Unit: count/sec)

| Matrix MBq | 64x64 | 128x128 | 256x256 | 512x512 |
|------------|-------|---------|---------|---------|
| 74         | 4,869 | 4,789   | 4,779   | 4,768   |
| 148        | 9,439 | 9,527   | 9,505   | 9,477   |
| 222        | 13,151| 14,169  | 14,111  | 14,093  |
| 296        | 16,032| 18,714  | 18,648  | 18,596  |
| 370        | 18,307| 22,869  | 22,837  | 22,791  |
| 444        | 21,015| 27,640  | 27,575  | 27,550  |
| 518        | 22,819| 31,446  | 31,356  | 31,246  |
| 1,110      | 30,504| 57,364  | 61,077  | 60,977  |

**Figure 3.** Comparison of total counts at different matrix sizes.

**Figure 4.** Renal Scintigraphy using $^{99m}$Tc-DTPA & GFR Study. The estimated GFR using Gate’s camera method was at 93 mL/min (Lt: 49, Rt: 44) (6 mCi).

### 4. Discussion

To measure GFR using Gate’s method with a gamma camera, the following three sources should be considered: net count of syringe, depth of the kidney, and background activity. This paper was based on the premises that background activity and depth of the kidney were constants. Therefore, it had a limitation in that we only evaluated the changes using various amounts of injected radioactivity which could affect the measured GFR values and the acquired images. Radio pharmaceuticals at about 74 to 111 MBq (mCi) used to measure GFR with Gate’s method could degrade the quality of image. Therefore, we determined the optimal radiation dose to acquire high-quality dynamic renal images at the same time when measuring GFR. When we injected more than 370 (10) MBq (mCi), the amount of radioactivity commonly used in renogram, GFR was underestimated. This could be due to excessive measurement caused by scattered rays from large amounts of radioactivity when measuring gamma counts of syringe before injection. The differences in GFR could also be caused by setting ROI when calculating actual injected radioactivity rather than counting the loss at the matrix size of more than 128 $\times$ 128.

In addition, there is limitation in GFR measurement when $^{99m}$Tc-DTPA clearance is measured lower than the actual GFR value due to the combination of $^{99m}$Tc-DTPA and small amounts of protein. The more radio activities were injected, the bigger errors occurred in GFR measurement. Using the amount of minimal radioactivity can reduce measurement error in GFR. However, proper lower limit should be maintained to get high-quality image. Thus, this problem merits more clinical discussion. When measuring gamma counts of syringe before injection, constant volume of syringe should be maintained to achieve stable measurement with Max Pixel. It requires great attention when setting ROI to calculate the actual dose. Appropriate functions for Korean body types such as depth of kidney used in formula also need attention. Based on clinical data, the amount of radioactivity and the matrix size can be changed. By obtaining GFR and high-quality renogram simultaneously, we can improve diagnostic ability and make more accurate evaluation for renal function.

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