The Count Rate Performance of a Multiwire Gamma Camera Measured by a Decaying Source Method with 9.3-Minute Tantalum-178

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The multiwire gamma camera (MWGC) operates at high count rates with radionuclides of low energy and short half-life. We evaluate the count rate performance of the MWGC with tantalum-178 (^{178}Ta) by a decaying source method. Data acquired dynamically by the camera from a ^{178}Ta source in the NEMA Standards scatter phantom were corrected for deadtime loss by a trial paralyzing deadtime and converted to their natural logarithms. The trial deadtime, τ, was adjusted iteratively after curve fittings until a straight line was achieved. The paralyzing deadtime determined by this method was 0.41 μsec. Therefore, the camera can be operated up to 850,000 cps with ^{178}Ta without exceeding 50% data loss. This rate is 10 times greater than the performance of the typical scintillation camera. Moreover, high count rates are achieved without significant loss of spatial resolution.

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The multiwire gamma camera (MWGC) has been developed to operate at high count rates. Such high count rates are particularly useful in first-pass cardiac studies (*1,2*). Using short-lived radiopharmaceuticals, such as tantalum-178 (^{178}Ta) (*3–5*), the administered dose is limited only by the count rate performance of the camera, not by the radiation dose to the patient.

Count rate performance is affected by gamma energy and the presence of scatter. It is, therefore, essential to test it with the particular radionuclide of interest under simulated conditions of scatter. The two-source method to measure count rate performance (*6,7*) cannot be used with short-lived radionuclides. Thus, a decaying source method was utilized for the MWGC and ^{178}Ta. The method is similar to studies previously reported with the scintillation camera using 30-sec ^{195m}Au (*8*) and 5-sec ^{191m}Ir(*9*).

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Count rate data are acquired during only about two half-lives, which include a range of high count rates such as are typically used in first-pass cardiac studies. These data are then analyzed by a curve-fitting method.

MATERIALS AND METHODS

Data Acquisition

A prototype multiwire gamma camera was utilized in this investigation (*1*). An energy window of 20% was set to cover the 55–64 keV x-rays. Tantalum-178 eluted from the ^{178}W/^{178}Ta generator (*5*) was placed in the NEMA Standards scatter phantom (*6,7*), which was positioned in contact with the MWGC collimator. Data were acquired dynamically in 1-min frames for 30 min. The background was measured after 3 hr, with the source in place to include any ^{178}W breakthrough (half-life 22 days).

The spatial resolution at high count rates was evaluated with bar pattern images acquired intrinsically with an ^{241}Am (60 keV) source at 2 meters. A similar study was performed on a conventional scintillation camera utilizing technetium-99m.

Data Processing

If the deadtime of the MWGC were zero, a plot of the logarithms of cps values versus elapsed time would form a straight line, with the slope corresponding to the half-life of the source. A similar straight line can be obtained from real MWGC data if the measured cps values are corrected precisely for deadtime loss.

The object of data processing is, therefore, to correct all data points for deadtime loss, using various trial values of the deadtime (τ) until a straight line is achieved. The algorithm for data processing is as follows:

1. Measure count rate (cps) versus elapsed time.
2. Assign a trial deadtime (τ).
3. Correct each data point for deadtime loss.
4. Subtract background.
5. Take natural logarithms of net cps values.
6. Fit a second-order polynomial equation to the data:

$$\ln(R) = A + BT + CT^2, \qquad (1)$$

where R is the net corrected cps, and T is the elapsed time.

TABLE 1
Example of Correcting for Deadtime

$\tau = 0.4072\ \mu sec$	
Measured cps:	861,507
1st approximation:	1,327,040 cps
Newton-Raphson Iterations:	*(12)*

#	Corrected cps
1	1,708,798
2	1,772,310
3	1,774,406
4	1,774,408

TABLE 2
Example of Sequential Curve Fittings

Iteration no.	μsec	$C \times 10^{-7}$
1	0.360	−5702
2	0.370	−4953
3	0.380	−4036
6	0.410	+679
7	0.401	−1213
8	0.402	−1032
13	0.407	−24
14	0.408	+201
15	0.4071	−2
16	0.4072	+20

7. If C is negative, increment τ, or if positive, decrement τ, and repeat steps 3–7.
8. When C approaches 0, display the final value of τ, the measured half-life, and performance curves.

Correcting for Deadtime Loss

The multiwire gamma camera closely approximates a purely paralyzable system throughout count rates of clinical usefulness. Therefore, correction for deadtime loss is given by the following (*10*):

$$R = R_0 e^{R\tau}, \quad (2)$$

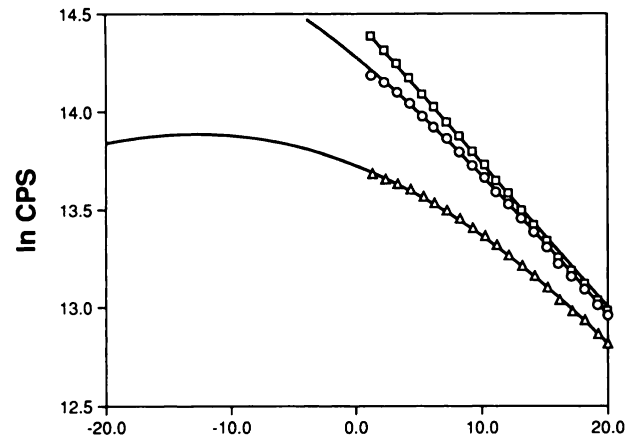

FIGURE 1
Logarithms of measured and corrected cps values superimposed on fitted parabolas. Although not mathematically related, the coefficient C of the squared term is a convenient indicator of a linear fit, approaching zero when the correct value of τ is achieved. Curve 1 (triangles) is measured ^{178}Ta data. Curve 2 (line) is the fitted 2nd order polynomial:

$$\ln cps = 13.703 - 0.02543\ T - 0.00104\ T^2.$$

Curve 3 (circles) is measured data corrected by the first trial deadtime τ, 0.36 μsec. Curve 4 (line) is the fitted polynomial:

$$\ln cps = 14.263 - 0.0554\ T - 0.00057\ T^2.$$

Curve 5 (squares) is measured data corrected by the 16th and final trial deadtime, 0.407 μsec. Curve 6 (straight line) is the fitted polynomial:

$$\ln cps = 14.47 - 0.0756\ T - 0.0000\ T^2$$

$$T_{1/2} = \ln(2)/0.0756 = 9.17\ min.$$

where R_0 is the observed count rate, and τ is the paralyzing deadtime. The unknown R in the exponential prevents direct calculation, and R must be determined by numerical methods.

To a first approximation, the corrected count rate (R_n) is obtained by the equation for a nonparalyzable system (*11*):

$$R_n = R_0/(1 - R_0\tau) \quad (n = 1), \quad (3)$$

where R_n is a first approximation, R_0 is the measured cps, and τ is the trial paralyzing deadtime.

Corrections are then continued with Newton-Raphson iterations (*8,9,12*):

$$R_{n+1} = [R_0(1 - R_n\ \tau)]/[e-(R_n\tau)-R_n\tau]. \quad (4)$$

Iterations are continued until $(R_{n+1} - R_n) < 1$ cps.

The equation converges rapidly to the true value of the corrected count rate, usually requiring only one to three iterations (Table 1).

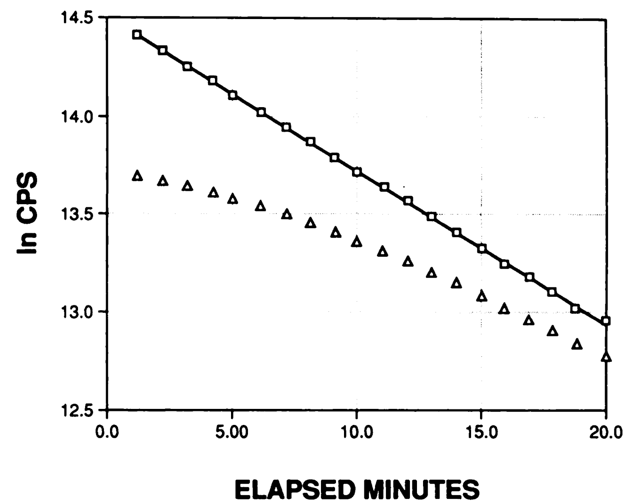

FIGURE 2
Data from the multiwire gamma camera, assuming the paralyzable model. Logarithms of cps values vs elapsed minutes. Three sets of data are shown: (1) the observed count rate (triangles); (2) the same data corrected for deadtime loss by the paralyzing 0.407 μsec (squares); and (3) the final fitted equation, now a first-order polynomial (line). The slope yields a half-life for ^{178}Ta of 9.17 min, close to the true value of 9.3.

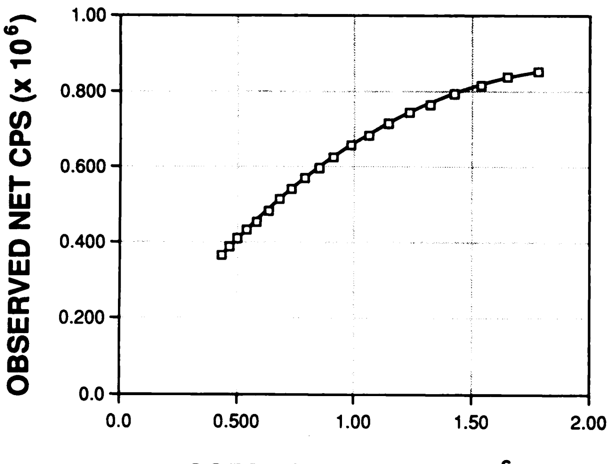

FIGURE 3
From the data of Figure 2, the observed cps vs. cps corrected by the paralyzing deadtime.

Curve Fitting

Fortuitously, the logarithms of the count rate versus elapsed time fall reasonably close to a segment of a parabola, and a second-order polynomial equation can be fitted to the data (Fig. 1). The coefficient C of the squared term is a convenient and highly sensitive indicator of a linear fit as it approaches zero (Table 2).

After the corrected count rate values are calculated for each data point, the 2nd order polynomial (Equation 1) is fitted to the data. The trial deadtime (τ) is adjusted by sequential approximations until C approaches zero to obtain the final value of τ to the nearest 0.001 μsec (Table 2). The final values of A and B are used to generate the fitted curve (Fig. 2) and the input versus the observed count rate curve (Fig. 3). The measured half-life of the source is ln(2)/-B.

RESULTS AND CONCLUSIONS

Logarithms of cps values versus elapsed minutes are shown in Figure 2. Observed versus corrected cps values are plotted in Figure 3. The resulting value of the deadtime τ is 0.41 μsec, and the measured half-life (ln(2)/-B) is 9.17 min. The validity of the paralyzable model is supported by the close agreement between the corrected and fitted data points of Figure 2 and by the rather precise measurement of the half-life of ^{178}Ta, which is only 1.4% below the actual value of 9.3 min.

TABLE 3
cps Count Rates Incurring Data Losses

%	MWGC	Scintillation cameras	
data loss	0.4 μsec	1.7 μsec	4 μsec
10	240,000	56,000	24,000
20	450,000	110,000	45,000
30	620,000	150,000	62,000
40	770,000	180,000	77,000
50	870,000	200,000	87,000

The study demonstrates that the MWGC can be operated up to 850,000 observed cps with ^{178}Ta under clinical conditions of scatter without exceeding 50% data loss. This rate is ten times faster than that of the typical NaI camera and four times greater than with the fastest commercial models (Table 3).

The high count rate performance of the MWGC is

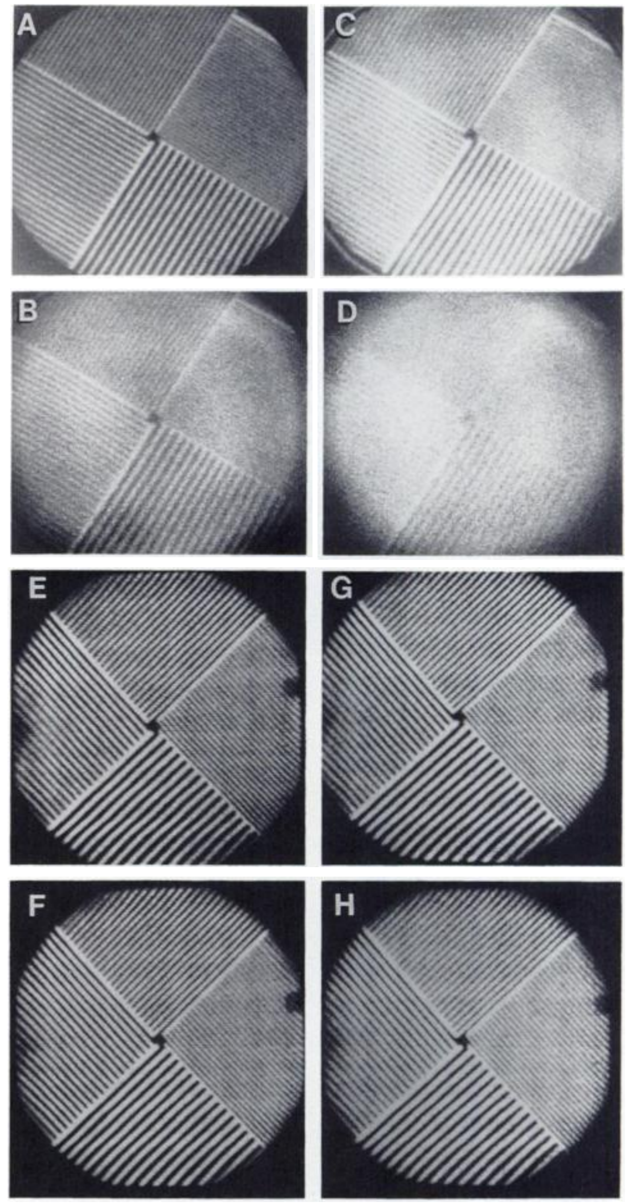

FIGURE 4
Comparison of spatial resolutions of a scintillation camera (GE 300A, General Electric Corp., Milwaukee, WI) and the MWGC at widely varying count rates. Bar thicknesses are 2, 2½, 3, and 4 mm. The bar pattern was imaged with the scintillation camera and ^{99m}Tc at 2 meters as follows: (A) 25K cps, normal mode. (B) 100K cps, HCR mode (corrections disabled). (C) 150K cps, HCR mode (corrections disabled). (D) 193K cps at foldover, HCR mode (corrections disabled). The bar pattern was imaged with the MWGC and an ^{241}Am (60 keV) source at 2 meters as follows: (E) 50K cps, (F) 100K cps, (G) 300K cps, and (H) 600K cps.

achieved without compromising the spatial resolution and image uniformity (Fig. 4). A new model scintillation camera is reported to preserve good spatial resolution up to 100,000 cps, with pulse tail extrapolation electronics (*10*).

The superior count rate capability of the MWGC and its preservation of image quality at peak count rates are particularly beneficial in first-pass radionuclide angiography studies. The statistical quality of such first-pass cardiac studies is limited by the brief duration of ventricular transit of the radionuclide, which is often only a few seconds, and by the fast framing rates of ideally 40 or more per second. The use of relatively larger administered doses is permitted by the very low tissue dosimetry of ^{178}Ta. Twenty times the number of millicuries of ^{178}Ta are required to deliver a whole-body dose equivalent to that from technetium-99m. Tungsten-178 breakthrough contributes <0.2% of the whole-body dose (*5*). The use of clinically acceptable doses up to 100 mCi ^{178}Ta provides five times the statistical content of clinically acceptable doses of technetium-99m with the fastest available scintillation camera (*2*). This statistical quality permits refined measurements in first-pass cardiac studies, such as ventricular rates of ejection and filling, and regional analysis.

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