Count-based monitoring of Anger-camera spectra—local energy shifts due to rotation

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This study reports on a spectral monitoring method in which (1) a small source fixed to the camera is used, (2) a narrow, offset window is set on the side of the photopeak, and (3) variations in count rate are measured to assess energy shifts in the vicinity of the source. For one camera model, the count rate drops from 100% to 76% over a rotation of 180°, implying a local energy shift of 1.4 keV. Also looked for are local count-rate variations with rotation for (1) wide-symmetric, (2) 20%-symmetric, and (3) 10%-asymmetric windows. The last is in limited use to partially compensate for Compton scattering. The effects of background and time stability are assessed.

I. INTRODUCTION

The scintillation camera can be used to measure absolute activity for gamma-emitting radiopharmaceuticals in order to calculate radiation-absorbed dose delivered to tumors after administration of therapeutic amounts of radioisotope.[1-5] This calculation requires accurate quantification of tumor uptake, but such accuracy suffers from scattering of gamma radiation in human tissue before reaching the scintillation detector. Applying the dual-energy-window correction to quantification in single-photon emission-computed tomography (SPECT) studies has been discussed.[6,7] Older, more complex correction techniques have also been reviewed.[8] Errors from changes in the amplitude of the camera energy signals with camera rotation may cancel out in some of these corrections. This cancellation seems quite unlikely in several newer methods, however. Among these are a spectral fitting method[9] where the Compton-scattered component is to be separated from the unscattered component at each spatial location (i.e., locally) over the camera face. A second is an energy-weighted acquisition method[10] wherein events of all energies contribute to image formation through processing each energy with its own short-range spatial filter.

In this study, we report on a spectral monitoring method in which we (1) use a small source fixed to the camera, (2) set a narrow, offset window on the side of the photopeak, and (3) measure variations in count rate to assess energy shifts in the vicinity of the source. We also look for local count-rate variations with rotation for (1) wide-symmetric, (2) 20%-symmetric, and (3) 10%-asymmetric windows. The last is in limited use to partially compensate for Compton scattering.[5,11,12] The effects of background and time stability are assessed.

II. EXPERIMENTAL METHODS

Measurements were undertaken on a GE 400 AC and AT rotating Anger camera. Each was equipped with a low-energy general-purpose collimator. The AC camera was interfaced to a Siemens Microdelta computer and the AT to a GE STAR. Measurements were performed with the following windows for the AC camera. (Values are thumbwheel settings, that is, they are in nominal keV. See results to convert to true keV.):

(1) narrow window on the high-energy side of the photopeak (149–153 keV);

(2) narrow window on the low-energy side of the photopeak (135–139 keV);

(3) wide window (122–176 keV) chosen to end on flat portions of the energy spectrum;

(4) 20% symmetric window (130–158 keV) visually centered about peak;

(5) 10% asymmetric window (143–158 keV).

The camera was rotated over 360 deg from stop 0 to 128 in eight intervals. Counts per 40 s at each stop were recorded directly from the counter of the camera electronics. The source was 19.3 MBq of Tc-99m solution in a syringe. All data were corrected for radioactive decay.

For the AC camera, the slope dN/dE for the linear dependence of the nominal energy N on the true gamma-ray energy E was determined. The two peak channels for ^{111}In (172 keV and 247 keV) were measured along with that from ^{99m}Tc (140 keV). Then, to estimate the actual energy shifts from the changes in count rate, we also kept the camera fixed at stop 64, varied the nominal energy window settings ± 1 keV, and observed the fractional change in count rate. The rate of change of fractional count rate with nominal energy change dC/dN, was calculated. Then the rate of change of count rate with energy is

$$\frac{dC}{dE}=\frac{dC}{dN}\frac{dN}{dE}. \tag{1}$$

Finally, one estimates the energy shift ΔE caused by rotation measured from the fractional count change ΔC by

$$\Delta E=\Delta C\left(\frac{dC}{dE}\right)^{-1}. \tag{2}$$

III. RESULTS

Room background measurements for the AC camera with window 1 indicate a very stable background count rate which is, on average, only 0.01% of the source rate and so was neglected. The average count for 20 successive measurements at stop 80 using window 4 has a relative standard

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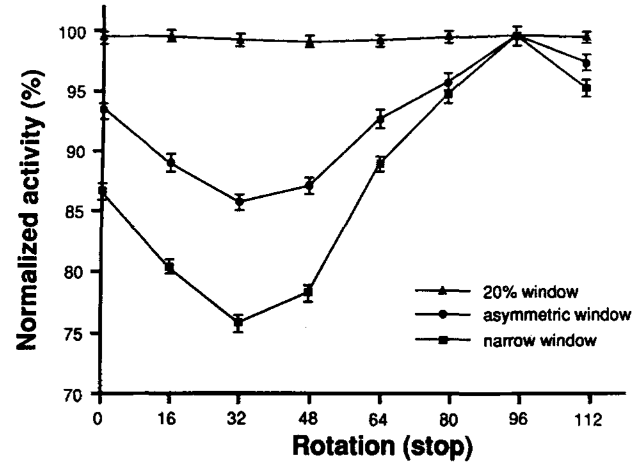

FIG. 1. Plot of counts normalized to 100% versus rotation. Stop 64 is a 180-deg rotation from stop 0. A large sinusoidal variation is present for the narrow asymmetric window located on the side of the photopeak. The 20% symmetric window is relatively stable. The curve for the 10% asymmetric window is about midway between the other two.

deviation of 0.13% and with window 1 0.85%. It is concluded that changes in count rate greater than 1% are not from short-term time drift.

With window 1 and the source at the center of the AC camera face, the variation of count rate with angle is given in Fig. 1. Three rotations produced essentially the same results. The minimum at stop 32 (90 deg) has only 75.8% the count rate of stop 96 (270 deg). A comparison of the results with the narrow window on either side of the photopeak is given in Table I. The results are consistent with the hypothesis that the energy window is fixed but the energy signals shift in amplitude, being largest at 270 deg and smallest at 90 deg. That is, at 270, with the energy signals presumably being larger than their mean value, the high-side window is nearer the peak and has a higher counting rate while the low-side window is farther from the peak and has a lower counting rate. At 90, with the energy signals now being smaller than their mean value, the reverse is true.

The effect of camera rotation with the 20% symmetric window usually used for clinical imaging is shown in Fig. 1. The normalized count rate varies only from 100% to 99.30%. With window 3, the count rate is again stable with a minimum of 99.37% (not shown). The stability of these windows is presumable due to compensating count-rate gain and loss on the two sides of the peak. Last, with window 5, the count rate follows a variation that is similar to that of window 1 but smaller in magnitude (see Fig. 1).

TABLE I. Variation of count rate (normalized to its maximum) with camera rotation for narrow asymmetric windows. GE 400 AC camera.

Rotation angle (deg)	Normalized count rate Narrow window at high-energy side	 Narrow window at low-energy side
0	86.60 ± 0.66%	89.40 ± 0.68%
45	80.44 ± 0.62	95.48 ± 0.70
90	75.85 ± 0.57	100.00 ± 0.76
135	78.32 ± 0.58	98.86 ± 0.76
180	89.07 ± 0.67	87.07 ± 0.67
225	94.95 ± 0.69	83.60 ± 0.65
270	100.00 ± 0.71	78.50 ± 0.63
315	95.59 ± 0.69	82.35 ± 0.65

With the source at the center and window 1, the results for the AT camera are similar to those for the AC except that the magnitude of the variation is smaller. The minimum at 135 deg is 91.2%. Also, the AC has no observed dependence of energy shift on source position while the AT shows a variation and, with the source at the edge, has a minimum of 85.0%.

For the AC camera, linear least-squares fitting gives the equation for nominal energy as a function of true energy as $N = (6.39 \text{ nominal keV}) + (0.97 \text{ nominal keV/keV}) * E$. The intentional shifts of the high, narrow window at stop 64 produce a value for dC/dN of 19.54%/nominal keV. From Eq. (1) we then evaluate dC/dE as 18.95%/keV. Using (1) this value, (2) the ΔC values relative to stop 64, and (3) Eq. (2), we calculate the energy shift from stop 32 to 96 as 1.4 keV.

IV. DISCUSSION

We conclude, without direct pulse-height-analyzer measurements, that the local energy shift at the center of a GE 400 AC Anger camera is 1.4 keV over a 180-deg rotation. Our clearly sinusoidal variation of count rate with angle for a narrow window on the side of the photopeak matches the shape of a finely steped, independent measurement with a 20% window (Ref. 13, see Fig. 4). That author used 60 stops and determined the global (for the entire camera face) count-rate variation of a Siemens Orbiter with a flood source fixed to its face. The small magnitude of our local variation with a 20% window is also similar to their magnitude (99.3% vs 99.7%). The differences we measured for two camera models can be ascribed to either (1) model, (2) different site locations (separate buildings), (3) different orientation of the axis of rotation relative to North (about a 90 deg change), or (4) proximity to magnets (the AT near an MRI unit[13] but with magnetic fields within specs, the AC not).

Using Monte Carlo simulations of energy spectra, we can estimate the effect of the 1.4-keV shift on Compton-scatter correction by spectral fitting. With a sixth-order polynomial for the scatter, and choosing the direction of shift that maximizes the error, there is a loss of 24% of the calculated unscattered counts. We consider a loss of this magnitude quite significant.

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