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Simple method to measure gamma camera energy resolution

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ABSTRACT

Purpose: Energy resolution is one of the major limitations of gamma camera performance, mainly affecting image contrast and resolution. There is a need for a simple method of measuring gamma camera energy resolution, which is practical for technology students as well as for routine quality control.

Materials and methods: A 37 MBq (1 mCi) MBq $^{99}Tc^{m}$ point source was prepared and positioned 1.5 m away from the gamma camera. Eleven static images were acquired with the same acquisition time (60 s), using 1 keV windows at intervals of 5 keV from 115 to 165 keV. The counts for each image were recorded and plotted graphically (counts vs. energy). Gaussian fitting was used to estimate the full-width-at-half-maximum height (FWHM), and the energy resolution (FWHM%) was calculated as a percentage of the photopeak (~140 keV).

Results: The FWHM% of the energy peak was measured to be ~7%. Most values for the energy resolution (FWHM%) of our system were significantly lower (i.e., higher energy resolution) than the commissioning measurement, and were comparable to the recent preventive maintenance values. There were no significant energy resolution differences between the two detectors of the dual head gamma camera.

Conclusions: This simple method for the evaluation of the energy resolution of a gamma camera system can be easily implemented within routine quality assurance. The measure will help prevent image deterioration through early detection of serious energy resolution issues which can be resolved in routine gamma camera corrective maintenance.

Introduction

The performance characteristics of a gamma camera should be assessed at scheduled time intervals, and should include such characteristics as energy resolution, intrinsic resolution, spatial linearity, uniformity, and counting rate performance. Limitations in the performance of the detector and its associated circuitry, and with the collimator, are the main causes affecting image contrast and resolution.[1–3]

The assessment of gamma camera performance characteristics is standardized by the National Electrical Manufacturers Association (NEMA). NEMA publishes documents that describe how to perform, analyze, and report gamma camera performance characteristics. Most recent NEMA standards for single-photon emission computed tomography (SPECT) cameras are reported in NU-1 2007.[4–6] In Europe a comprehensive description of procedures to be performed in clinical departments has been developed by the Institute of Physics and Engineering in Medicine (IPEM).[7] Despite becoming a standard reference in Nuclear Medicine Departments, providing scientific staff with practical advice on the implementation of an effective quality control program, original sections of the previous IPEM were revised and enhanced substantially by report 86[7] to incorporate up-to-date developments in gamma camera technology.

The NEMA recommendations facilitate unambiguous measures of gamma camera performance,[8] so that different systems can be compared consistently. By contrast, other performance characteristics rely on the manufacturer's initial specifications without any guarantee of NEMA conformity.[2,8] Energy resolution is expressed by the spectrum broadening on the detector caused primarily by random statistical variation of the events that form the output signal.[1] The width of the photopeak, ΔE, measured across its points of half-maximum amplitude is the energy resolution; usually it is expressed as a percentage of the photopeak energy, E_γ:

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$$\text{FWHM }(\%) = (\Delta E/E_\gamma) \times 100\% \qquad (1)$$

NEMA recommendations for measuring energy resolution require interfacing the gamma camera un-corrected signal (Z-pulse) into an external multichannel analyzer or single channel analyzer.[2] Nowadays, energy resolution and correction software which is provided by the manufacturer is usually camera-specific. This often means that data from different cameras cannot be conveniently measured and compared. AAMP recommends that energy resolution is measured annually,[9] and this is generally carried out by the manufacturer as part of the warranty policy.

To avoid having to access the Z-pulse and potentially voiding the camera's warranty, we have developed a straightforward method for measuring and analyzing gamma energy resolution which conforms to the most recent NEMA standards. A somewhat similar method was suggested previously by Elliott,[10] but neither practical experimental work nor results were presented. As part of a physics of medical imaging laboratory,[11] our method has been used successfully by nuclear medicine students for more than a decade using Siemens E. Cam and GE Millennium gamma cameras. Our method allows multiple detector system energy resolution data to be analyzed in a consistent way, which is essential in comparing performance.[12,13] Energy resolution is known to vary with scintillation crystal size, radionuclide energy, and field of view (FOV).[14,15] Inter-camera energy resolution variability should be observed and reported.

Materials and methods

Our preparation and acquisition settings adhered to the recommendations of the National Electrical Manufacturers Association (NEMA), the Institute of Physics and Engineering in Medicine (IPEM) and the American Association of Physicists in Medicine (AAPM), i.e., the collimator was unmounted, the count rate was within the system count rate capability (less than 15 K cps is a good compromise), and a small source (less than 2 cm in diameter) was placed at a distance of at least 2 crystal diameters along the central axis. The outer 10% of the crystal area (or 5% of the diameter) was masked with a circular lead mask, at least 3 mm thick, carefully centered to ensure that the edge packing was covered. For $^{99}Tc^m$, the channel position of the center of the photopeak (140 keV) was determined.

A $^{99}Tc^m$ point source of 37 MBq was prepared and positioned 1.5 m away from the crystal. Prior to running this experiment, the field of view (FOV) intrinsic uniformity, which is routinely measured at the same distance during quality control, was determined to be within the specifications. Eleven static images of 5 keV intervals were acquired using a GE Millennium MP gamma camera with the same acquisition time (60 s), using 1 keV windows at intervals of 5 keV from 115 to 165 keV. Counts were repeated five times at each energy window, and corrected for decay. The counting uncertainty at each energy window was calculated.

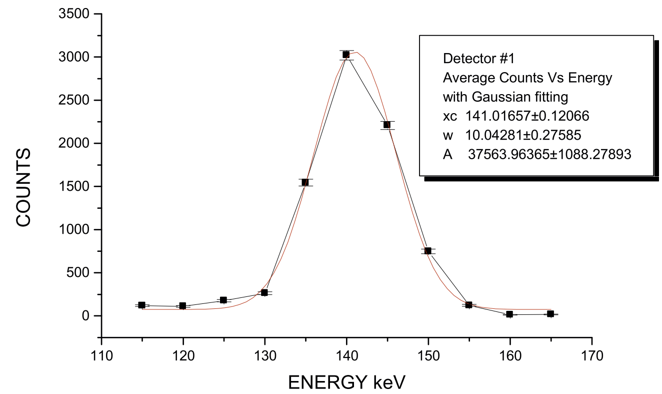

Figure 1. Average counts acquired at one detector versus energy window (black), and fitted to a Gaussian (red). (For $^{99}Tc^m$ point source).

Since energy resolution may vary at different energy levels, the energy resolution was also measured for ^{131}I (photopeak at ~364 keV).

Results

The counts acquired at each energy window and their averages were tabulated. An example for one detector is summarized in Table 1. ANOVA Statistical analysis shows no significant difference between FWHMs of the five repeated sets of measurements a FWHM grand mean of 10.03 and a pooled standard deviation of +/−0.28. This confirmed FOV uniformity, and indicated that acquisition of a single set of measurements would be sufficient for further work to obtain detector energy resolution.

The average counts at each window were plotted against the corresponding energy, and Gaussian fitting was used to estimate the full-width-at-half-maximum height, FWHM (Fig. 1). The energy resolution (FWHM%) was calculated as a percentage of the photopeak (140 keV). A comparison between the energy characteristics of two detectors within a dual head gamma camera is tabulated in Table 2 and plotted in Fig. 2.

The counts vs. energy characteristic of a detector using a ^{131}I point source is tabulated in Table 3 and plotted in Fig. 3.

Table 1
Counts acquired at different energy windows using a $^{99}Tc^m$ point source (The resulting FWHM and energy resolution, FWHM%, from Gaussian fitting is also tabulated).

Energy window	Set#1 Counts/minute	Set#2 Counts/minute	Set#3 Counts/minute	Set#4 Counts/minute	Set#5 Counts/minute	Average
115–116	122	110	125	119	121	119.4
120–121	100	112	105	111	129	111.4
125–126	175	180	171	182	178	177.2
130–131	253	276	281	259	249	263.6
135–136	1511	1570	1580	1525	1533	1543.8
140–141	3000	3058	3044	3005	2999	3021.2
145–146	2223	2222	2167	2228	2199	2207.8
150–151	755	721	766	747	750	747.8
155–156	123	125	125	112	126	122.2
160–161	15	17	14	10	12	13.6
165–166	20	22	18	15	14	17.8
FWHM (keV)	9.95 ± 0.26	9.99 ± 0.25	10.10 ± 0.30	10.05 ± 0.28	10.04 ± 0.30	10.04 ± 0.28
XCenter (keV)	141.09 ± 0.11	140.97 ± 0.11	140.93 ± 0.13	141.07 ± 0.12	141.03 ± 0.13	141.02 ± 0.12
Energy Resolution FWHM%	7.1% ± 0.2%	7.1% ± 0.2%	7.2% ± 0.2%	7.1% ± 0.2%	7.1% ± 0.2%	7.1% ± 0.2%