Multiple Window Spatial Registration: Failure of the NEMA Standard to Adequately Quantitate Image Misregistration with Gallium-67

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Multiple window spatial registration (MWSR) characterizes positional deviations in a gamma camera as a function of gamma ray energy. Good MWSR is important for imaging with gallium-67 (^{67}Ga) and indium-111 (^{111}In). We evaluated the MWSR of three gamma cameras using ^{67}Ga. Measurements were made using the National Electrical Manufacturers Association (NEMA) technique. The MWSR accuracy was measured in multiple locations along the x and y axis of the gamma camera. For all three gamma cameras, the MWSR was within the manufacturer's specification at locations corresponding to 75% of the useful field of view (UFOV). However at other locations, all cameras had misregistration errors outside the manufacturer's specification. The magnitude of these misregistration errors was regional in nature and did not correlate with distance from the center of the field of view. These findings indicate that the current NEMA protocol for measurement of MWSR does not reflect the true degree of misregistration over the UFOV of gamma cameras.

Concurrent with the development of the Anger camera, there has been a proliferation of both techniques and test objects designed to monitor the performance of these cameras. In order to provide uniform criteria for the measurement and testing of gamma camera performance, in 1980, NEMA published a number of standards by which the performance characteristics of gamma cameras could be described (*1*). These standards established both a definition of a standard and exact procedure under which the performance parameters must be measured (*1,2*).

The critical importance of these standards becomes evident when the user performs acceptance testing on a gamma camera (*2,3*). Unless the user adheres strictly to the NEMA Standard technique, discrepancies in camera performance between that measured and that quoted by the manufacturer become difficult to resolve. The occurrence of such a discrepancy has prompted this study, which examines NEMA Standards for measuring the multiple window spatial registration (MWSR) accuracy of a gamma camera. This test characterizes positional deviations in a gamma camera image as a function of gamma ray energy and has particular application for multipeak isotope imaging with ^{67}Ga, ^{111}In, and thallium-201 (^{201}Tl).

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METHODS

A modified NEMA protocol for the measurement of MWSR was used on three commercial gamma cameras.*†‡ Four lead pots were used, each pot had a base and wall thickness of 6 mm. A small 3-mm hole was drilled in the base of each pot to conform to the NEMA protocol (*1*). Four 10-ml saline vials were each filled with ~50 μCi of ^{67}Ga and placed in the lead pots. The four lead pots were positioned on the uncollimated gamma camera along the x-positive, x-negative, y-positive, and y-negative axes at ~95% of the UFOV. Images were then acquired onto a computer (256×256 matrix) for energy windows centered around the 93 keV and 296 keV emissions from ^{67}Ga. A 20% window was used in all cases. The acquisition time was adjusted so that line profiles, taken through the point source images, gave at least 10,000 counts in the peak profile. The differences in peak locations for the 93 keV and 296 keV images were then determined using the linear interpolation technique described in the NEMA Standard publication (*1*). Unlike the NEMA technique, we computed the exact x- and y-differences for each location and calculated the true displacement of the 93 keV and 296 keV images by triangulation. Following analysis ofthe four point sources, the lead pots were each moved 1.5 cm towards the center of the field of view and the above process was repeated. This procedure continued until the center of the field of view was reached.

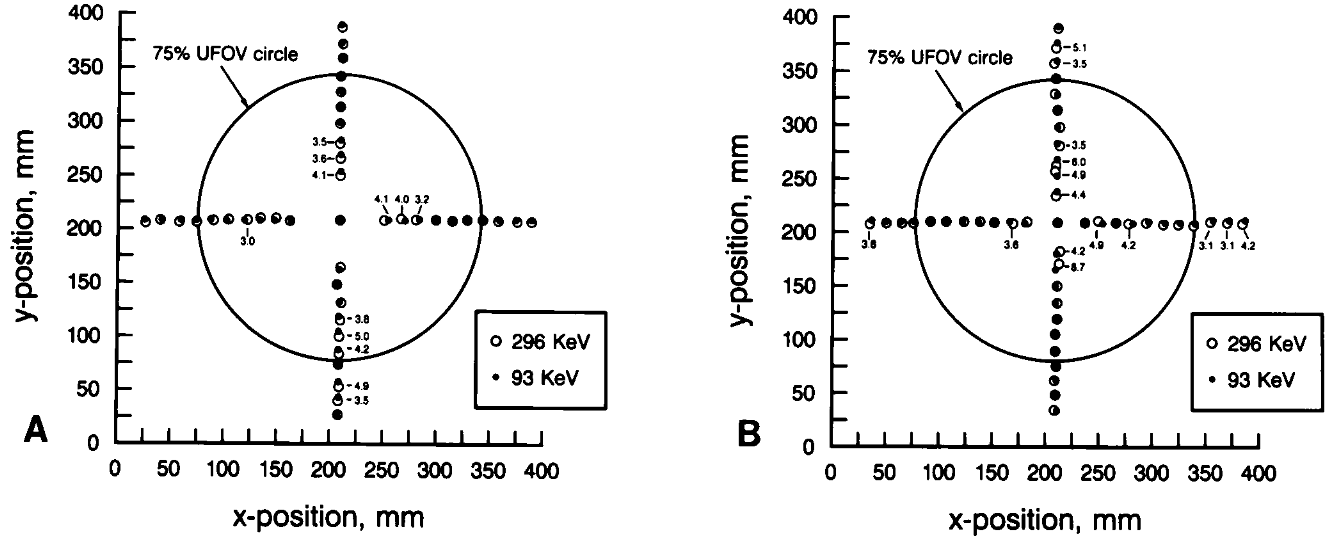
In order to convert the measured values of image position from pixels to millimeters, all three gamma camera systems were calibrated using a 15 cm square test jig containing four cobalt-57 (^{57}Co) point sources. Images of the test jig were acquired on the collimated gamma cameras and stored in a 256×256 matrix size. Line profiles of the point sources were analyzed using a similar technique to that used above to determine the exact x- and y-coordinates of each source. The differences in pixel locations for each source were then used to generate a pixel per centimeter calibration factor for each-system. This calibration factor was used to convert the measured values of MWSR from pixels to millimeters.

Following a service visit on one of the systems (Camera A),* a new linearity map was loaded on the system and the MWSR was reassessed. The acquisition and analysis was as described above. Two other studies were performed on Camera A. To examine the effect of source position relative to a given photomultiplier tube on MWSR, one of the lead pots containing a 50-μCi source of ^{67}Ga was moved in one-centimeter increments over the face of a photomultiplier tube (PMT) and the exact displacement between the 93 keV and 296 keV images was determined as described above. The relative position of this PMT in the gamma camera field of view is indicated by a circular overlay in Figure 2B.

In order to fully characterize the variation in MWSR over the entire field of view, a simple test phantom was used. This consisted of a lead plate, 3 mm thick and 40 cm in diameter. A series of holes, each 3 mm in diameter, were drilled in the plate in a grid pattern. The lead plate was placed on the uncollimated gamma camera and a 5-mCi point source of ^{67}Ga was placed above the center of the gamma camera at a distance of 200 cm. Images (256×256 matrix) of the test pattern were then acquired at 93 keV and 296 keV. A total of 10,000,000 counts were acquired in each image. Two different methods were used to acquire these images. In the first method, the 93-keV and 296-keV images were acquired using different energy analyzers. In the second method, images of the test pattern were acquired using the same energy analyzer adjusted appropriately for each of the two peaks of ^{67}Ga. After suitable scaling, the 93-keV image was subtracted from the 296-keV image to provide a qualitative estimate of MWSR over the entire field of view of Camera A.

RESULTS

Figures 1A, 1B, and 1C plot the location of the point source images from ^{67}Ga along the x- and y- axis for the three gamma cameras. The misregistration between the 93 keV and 296



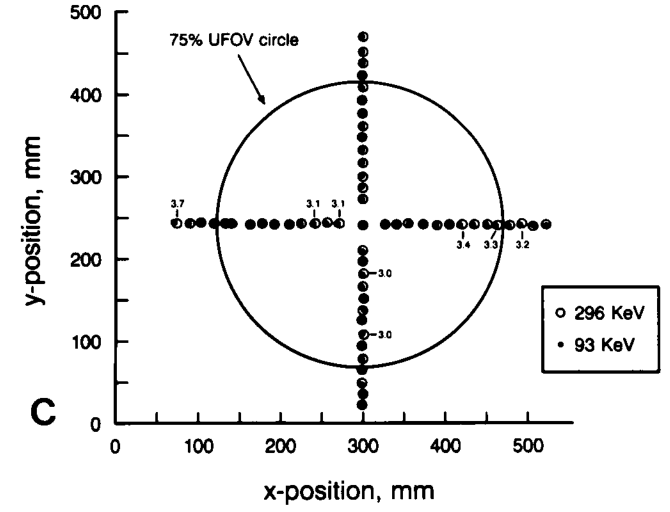
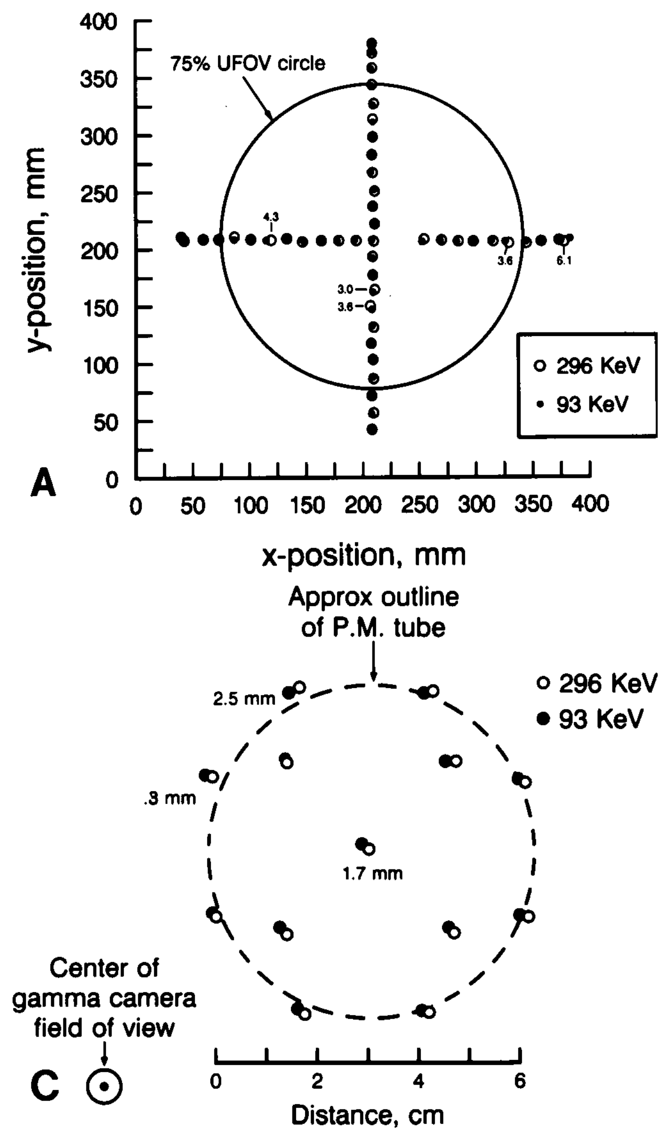


FIG. 1. (A–C) Illustration of the differences in the locations of 93 keV and 296 keV point source images, along the x and y axes of a gamma camera. Results are shown for three different gamma cameras, A, B, and C. Differences of three millimeters or greater are indicated for each camera.

keV images at the 75% UFOV location was close to or within the manufacturer's specified value for all three gamma cameras. However, at other locations, the misregistration appeared to fluctuate randomly over the field of view. On Camera A, the value for MWSR never exceeded 2 mm at the 75% UFOV location. However, closer to the center of the field of view, several locations showed misregistration errors greater than 4 mm (Fig. 1A). On Camera B,+ a similar discrepancy was found with values of MWSR being close to the manufacturer's specified value at the 75% UFOV location, but values closer to the center of the field of view showed larger misregistration errors (Fig. 1B).

Following a service visit and the generation of a new linearity map on Camera A, there was a significant improvement in the MWSR accuracy (Fig. 2A) indicating that variation in MWSR may be dependent on the linearity correction and its variation with energy. Figure 2B shows the 93-296-keV subtraction image obtained with the grid test pattern on Camera A. Misregistration can be qualitatively determined by noting the misalignment between the white (93 keV) and block dots (296 keV) at each location. These results indicate that the variation in MWSR over the field of view is not related to distance from the center of the field of view of the camera but is regional in nature. Large variation in MWSR over a short distance can be seen at the top and bottom of the image (arrows). These locations are close to the 75% UFOV circle. Variations seen in this subtraction image were independent of whether or not the 93-keV and 296-keV images were acquired using the same energy analyzer or different energy analyzers.

To provide a quantitative measurement of the mismatch seen in Figure 2B, and to examine the variation in MWSR over a single PMT, Figure 2C shows the deviation of MWSR in the vicinity of the PMT indicated in Figure 2B (white



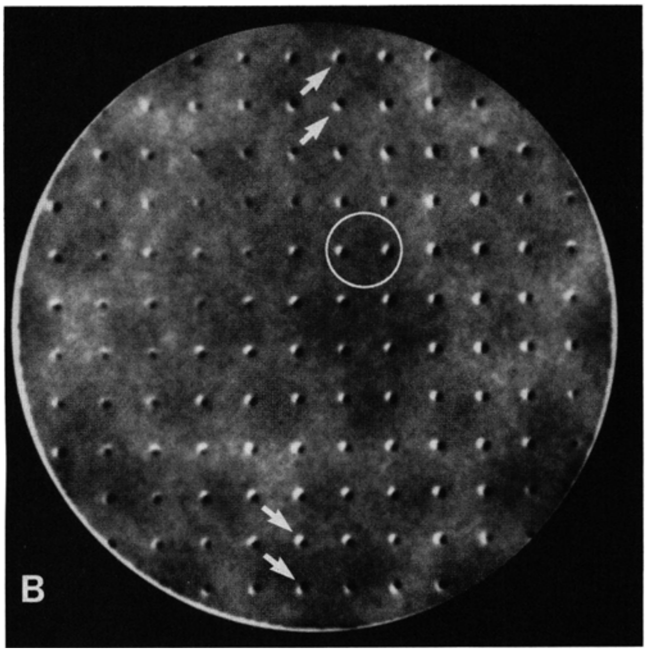


FIG. 2. (A) Measurement of the local differences in 93 and 296 keV point source location were repeated on Camera A following the generation of a new linearity correction map on the system. (B) Subtraction image (296 keV image minus 93 keV image) obtained using grid test pattern on Camera A. Note the relative changes in the 93 keV and 296 keV point source locations at top and bottom of image close to 75% UFOV position (arrows). (C) Representation of the differences in the location of 93 keV and 296 keV point source images over the PM tube indicated by the white circle in Figure 2B. Actual differences in millimeters are shown for three of the locations to indicate the magnitude of the variations seen over the PMT face.

circle). The bull's-eye in the lower left corner of Figure 2C indicates the geometric center of the gamma camera field of view. Deviations in MWSR do not appear to vary significantly over the field of view of a single PMT, nor, in this case, does the direction of the misregistration appear to be correlated with the direction of the PMT relative to the center of the field of view.

DISCUSSION

Most modern gamma cameras have two or three energy analyzers to permit efficient imaging of multipeak isotopes such as ^{67}Ga. In most clinical studies, involving multipeak imaging, the counts from these two or three energy analyzers are summed together to form a composite image. Clearly, it is important that images produced from the different energy analyzers are directly superimposible, to avoid loss of image contrast and resolution.

There are at least two possible mechanisms by which spatial misregistration can occur. Chapman et al. (*3*) have shown that if the x and y gains from each energy analyzer are not identical, it is possible that an image of a source acquired at one energy will not directly superimpose on an image of the same source acquired through a different energy analyzer adjusted for a second energy. Secondly, the intrinsic properties of a gamma camera are such that the calculation of the x and y positional signals for a gamma ray is energy dependent. All gamma cameras employ some type of normalization circuitry to eliminate this energy dependence. Any drift in this normalization circuitry could cause inaccuracies in MWSR. Inaccuracies caused by either of these mechanisms generally manifest themselves as an overall increase or decrease in image size as a function of energy (*3*). While the rationale for the NEMA protocol is not known to us, it appears to be based on the assumption that errors in image registration will be minimal in the center of the field of view and will become larger as one moves toward the edges of the field of view. Hence, the NEMA protocol requires that all measurements be made at locations corresponding to 75% of the UFOV. The results presented in Figure 1 show an apparent random variation in MWSR along the x- and y- axes for all three gamma cameras, strongly suggesting that such an assumption may not be valid.

A third possible mechanism is variation in spatial linearity with energy. Currently, on most modern gamma cameras, one linearity map is used for all gamma ray energies. Variation in spatial linearity with energy could cause regional variations in MWSR. The results presented in Figure 2 show the effects of changes in the spatial linearity correction map on MWSR. This can be best seen in Figure 2B, which shows the regional nature of variations in MWSR over the entire field of view. The cause for these variations may be due to spatial distortion of the camera response when using more than one photopeak analyzer. Chapman et al. (*4*) have demonstrated that this can cause loss of resolution over the entire field of view. However, the generation of the test pattern shown in Figure 2B using both a single and multiple energy analyzer did not show any differences, indicating that this potential mechanism for misregistration was not present in this study.

We were also concerned that measurement of MWSR would be dependent on the exact location of the point source relative to a photomultiplier tube; i.e., whether or not there was a variation in MWSR over the face of a single photomultiplier tube. Figure 2C indicates that under the acquisition conditions used (energy and linearity corrections applied to all images), no significant variations occurred.

Our results have shown that variations of greater than 5 mm in MWSR can occur on what were considered to be well-tuned and clinically acceptable gamma cameras. These cameras all met existing NEMA standards as published by the manufacturers. Neither current quality control procedures nor the NEMA Standards currently evaluate the energy dependence of linearity maps and the effects of these maps on MWSR. Our results indicate that the current NEMA protocol for measuring MWSR is inadequate and we believe that NEMA Standard 2.35 (*1*) should be re-evaluated to provide a more comprehensive measure of MWSR for gamma cameras.

NOTES

* Starcam, General Electric, Milwaukee, WI.

† 3700 Orbiter, Siemens Gammasonics, Des Plaines, IL.

‡ 500A Maxicamera, General Electric, Milwaukee, WI.

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