An Iterative Method for Verifying Systematic Nonuniformities in Refillable Flood Sources

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Accurate tomographic reconstruction of data acquired from rotating scintillation cameras requires strict control of camera field uniformity. Commercially available refillable flood phantoms may develop significant bulging, producing substantial uniformity deviations that may be mistaken for camera nonuniformities, and result in artifacts on reconstructed images. We have developed an iterative method for determining the correct volume of the source, and we have studied the effects of overfilling and underfilling the flood source.

The importance of scintillation camera uniformity is well accepted and documented (1-3). With the advent of scintillation cameras with larger fields of view and increased numbers of photomultiplier tubes, achievement and maintenance of field uniformity become a substantial challenge. Uniformity correction methods and their effects on image quality have been previously described (4-6). More recently, the importance of camera uniformity in regard to emission computed tomography was reported by Rogers et al. (7). They concluded that the stringent requirements of tomography require a well-mixed flood source with random variations of less than ±1%. They recommended that a Tc-99m liquid-filled source be used rather than a solid Co-57 source, because the latter is only guaranteed to be uniform to within ±4% for regions 2.5 cm in diameter. They also emphasized that extreme care should be taken to remove any existing bulges due to overfilling of the phantom.

We describe an accurate method for achieving a truly uniform transmission source. Commercially available software (Star, General Electric Corp., Milwaukee, WI) was used to measure the effects of overfilling and underfilling the phantom, and then to determine its ideal volume.

Methods

We used a transmission source with an internal diameter of 17 in., a thickness of 0.5 in., and a theoretical volume of 1,860 ml (Fig. 1). As a result of age (approximately 5 years), the phantom lost its rigidity and, at the time of the study, had a volume of 2,050 ml, or a 9.3% variance, when filled to capacity. The resultant convex geometry produces a Gaussian distribution of counts (Fig. 2).

To overcome this problem and to obtain a satisfactorily uniform distribution, the flood source was filled with 1,725 ml of liquid Tc-99m, and imaged in the middle of, and with 5-cm lateral displacement from, the center of the camera crystal. The centered static image was collected in a 128 x 128 matrix, for 500 K counts, and the laterally displaced image was collected for decay-corrected equal time.

A difference image was obtained by first adding a constant of 300 to the shifted image, and then subtracting the centered image from this enhanced shifted matrix. Profile histograms of the difference image were plotted, and then the slope of the relevant count distribution was derived. The repeated addition of 25-ml volumes of water, thoroughly mixed with a pre-compression air bubble, allowed this process to be implemented through 1,850 mls. The analysis of a recently purchased phantom, with the same theoretical volume but superior rigidity, was also performed at 50-ml increments, from 1,400-1,750 mls.

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Results

Determination of the phantom's ideal volume was measured from the centered and shifted images. The resultant images demonstrated mapped representation of the overfilled and underfilled sources. Difference images—obtained by subtracting the centered image from the enhanced shifted image—demonstrated a shift of the isotope in the direction of the flood displacement. Figure 3 demonstrates the effects of underfilling and overfilling the transmission source, and an ideally filled source, as well. Cross-sectional profiles through these derived difference images confirm systematic distortion due to inaccurate filling (Fig. 4). The derived profile slope is a quantitative index that can be used to predict the ideal volume (Table 1 and Fig. 5). The aged flood source filled at 1,725, 1,750, 1,775, 1,800, and 1,850 ml and imaged by this technique demonstrates the predicted effect, despite minimal changes in the % rms error of counts taken across the center of the flood source. Thus, minimal variations in the % rms error do not permit us to assess whether the flood source is properly filled or not.

The newer, rigid transmission flood source was also evaluated and a graph of the quantitative index derived (Fig. 5). The effects of age on a transmission source are evident when plots of the two source slopes versus volume are compared (Figs. 5 and 6).

Discussion

Volume variations of as little as 25 ml in refillable flood sources produce artifacts with both quantitative and subjective data analysis. We have described a simple method for determining the ideal volume that enables the technologist to exclude any systematic nonuniformity introduced by the deformation of a refillable flood source. With the refillable flood field

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>% RMS (expected)</th>
<th>% RMS (measured)</th>
<th>Slope of profile histogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1725</td>
<td>2.6%</td>
<td>3.1%</td>
<td>+ 3.93</td>
</tr>
<tr>
<td>1750</td>
<td>2.2%</td>
<td>2.4%</td>
<td>+ 2.47</td>
</tr>
<tr>
<td>1755*</td>
<td>2.7%</td>
<td>2.5%</td>
<td>- 1.30</td>
</tr>
<tr>
<td>1800</td>
<td>2.2%</td>
<td>2.6%</td>
<td>- 7.81</td>
</tr>
<tr>
<td>1850</td>
<td>2.2%</td>
<td>2.8%</td>
<td>- 8.60</td>
</tr>
</tbody>
</table>

*ideal volume

FIG. 2. Overfilled, refillable flood source with histogram demonstrates concave distribution of counts.

FIG. 3. Difference images demonstrate effects of underfilled, ideally filled, and overfilled transmission sources.

FIG. 4. Histograms demonstrate changes in slope of derived images as a function of source volume.

FIG. 5. Aged transmission sources results in severe volume variances.

TABLE 1. Refillable Transmission Source Quantitative Index
Recently purchased transmission source presents less but still demonstrable distortion.

phantom, simple corrections may be achieved without resorting to the production of unique individual refillable sources (7). The use of image subtraction and standard software may provide an easy evaluation of refillable flood phantoms.

This technique may be particularly helpful in quality control procedures required with single photon emission tomography, where high statistic, homogeneous, extrinsically collected floods are a necessity. The use of an accurate refillable phantom will increase the integrity of uniformity in SPECT quality control.

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References