Field Flood Uniformity Correction: Benefits or Pitfalls?

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Strict quality control of scintillation camera images is increasingly recognized as important in a nuclear medicine laboratory. The field flood uniformity of the camera should be tested daily. A variety of commercially available data systems facilitate the above task. Concomitantly, scintigrams are increasingly being corrected for uniformity. This study points out that for the most common source of nonuniformity, namely, unbalanced photomultiplier tubes, uniformity correction can occasionally, depending on the scatter fraction, produce clinically significant artifacts. This effect is due to the application of a linear correction factor to a nonlinear phenomenon.

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The use of field uniformity correction is growing rapidly, as data systems are becoming more and more widespread (*1*). At first sight, uniformity correction appears to be a perfectly reasonable procedure to correct clinical scintigrams for the nonuniform response of the camera. However, in some instances the conventional uniformity correction procedure can aggravate problems and should therefore be used with due caution, if at all.

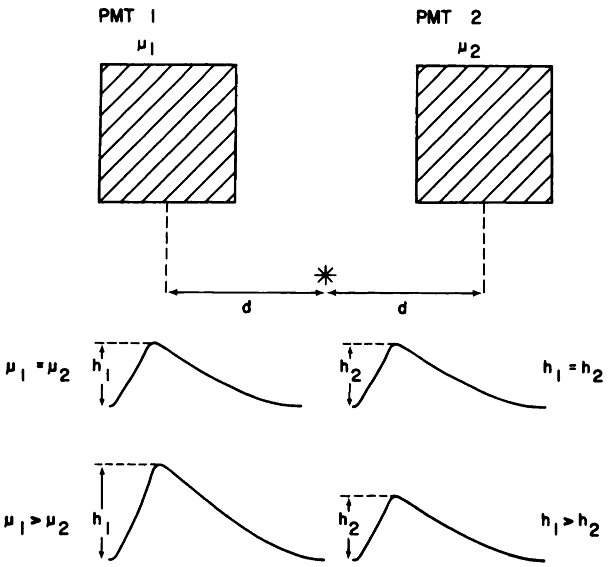

FIG. 1. Schematic of two PM tubes with primary scintillation event occurring between them. When $\mu_1 = \mu_2$, output pulse heights are equal (first row); when $\mu_1 > \mu_2$, pulse heights are not equal (second row).

Uniformity correction is a form of a posteriori image processing. Generally speaking, the processed image, compared with the unprocessed image, can fall into one of the following categories as far as pattern recognition is concerned:

1. The processed image is better than the unprocessed image;
2. the processed image is not substantially better; or
3. the processed image exhibits artifacts.

If the processed image is not better than the unprocessed image, there is no value in performing the operation. If processing yields better images, then the improvement must be judged against the time and effort required to produce it; this question is beyond the scope of this report. Lastly, image-processing

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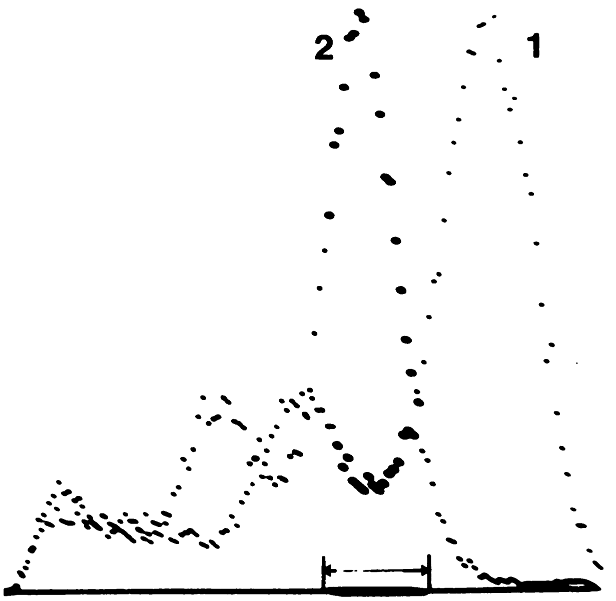

FIG. 2. Example where $\mu_1 > \mu_2$. Pulse-height discriminator set on photopeak of Tube 2 rejects primary photons from Tube 1 but accepts scattered photons. Arrow indicates position of window.

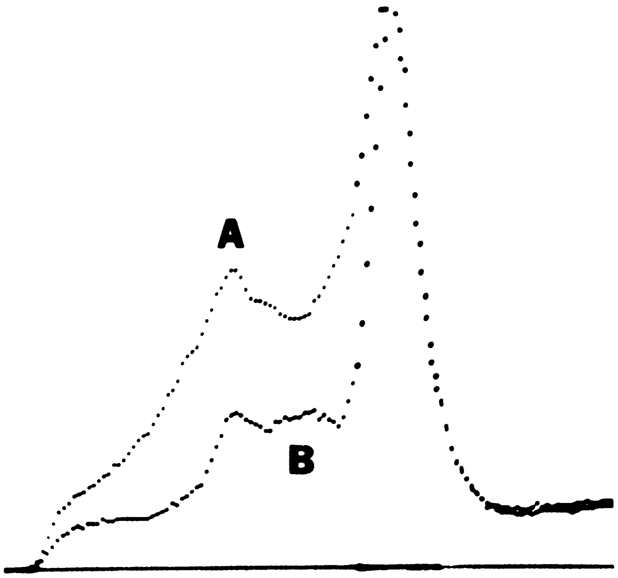

FIG. 3. Cobalt-57 spectra with (A) and without (B) 3 in. of tissue-equivalent scattering medium interposed between detector and flood source.

procedures that introduce artifacts should be carefully avoided in the interest of instrumental integrity.

THEORY

In order to evalute the uniformity correction procedure objectively, one should start with the general equation governing image formation (*2,3*):

$$i(x,y) = \iint o(x',y')\, s(x,x';y,y')\, dx'\, dy'. \qquad (1)$$

This equation indicates that the image i(x,y) is a linear superposition of the source activity o(x',y') through the response function s of the system. In the most general case, the system response s varies across the face of the camera. The procedure for uni-

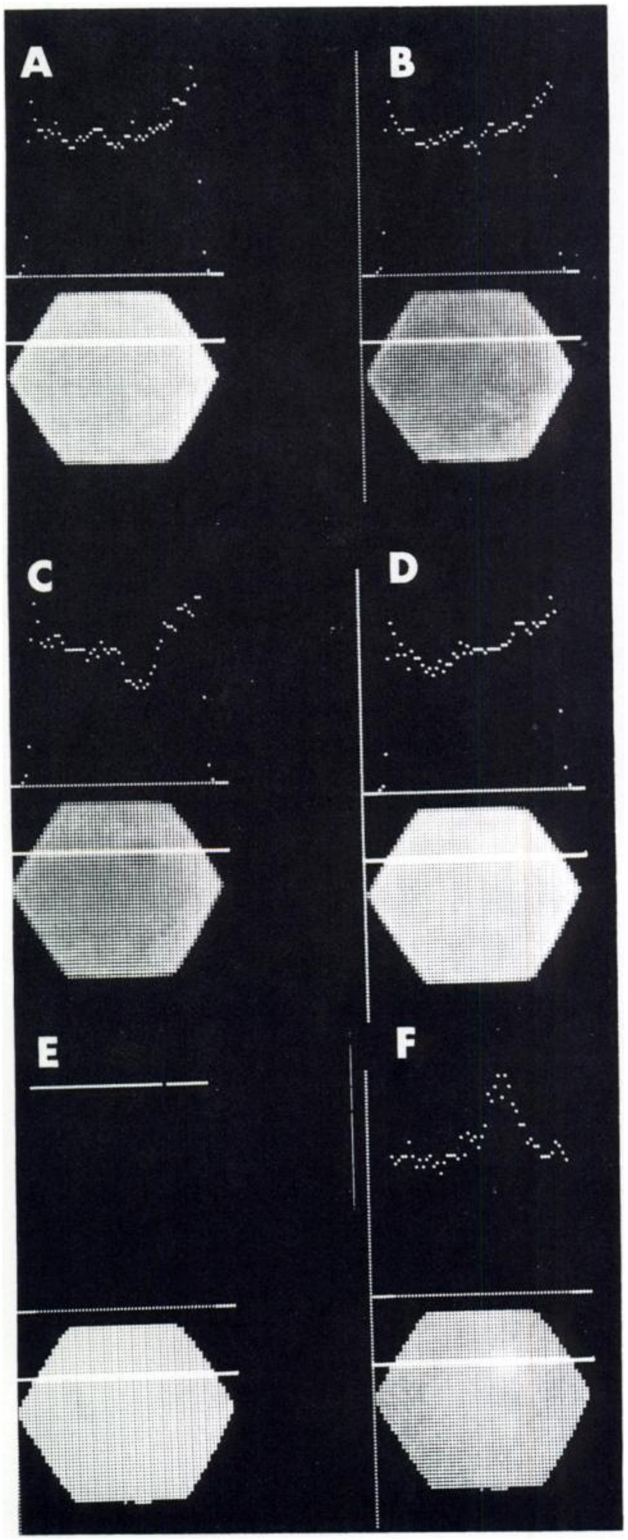

FIG. 4. Images of ^{57}Co flood source. See text for explanation.

formity correction involves obtaining the image of a flood source at the surface of the collimator, digitizing this image, and then constructing an inverse matrix, i.e., one that yields a perfectly uniform image when multiplied with the original digitized image. This matrix is usually said to contain the uniformity correction factors CF_{ij}. These correction factors are then subsequently used to correct the clinical scintigrams.

However, Equation 1 is an integral equation of the first kind and order and must be treated along with its boundary conditions (*4*). In other words, the response of the system, s, will depend upon the distance of the source distribution $o(x',y')$ from the camera and upon the intervening scattering media. This study is directed to the general question: "Do correction factors at the collimator surface apply to areas distant from the collimator, with interspersed scattering media?"

A chief cause of nonuniformity is unbalanced photomultiplier (PM) tubes. To illustrate what happens under this circumstance, consider the simple configuration of two PM tubes with, say, a primary scintillation event occurring midway between them (Fig. 1). If the gains of the tubes are equal, their individual pulse heights will be equal. If, on the other hand, the gain of one PM tube (μ_1) is greater than that of the other (μ_2), then the first tube will deliver a larger pulse height than the second. In this situation, a pulse-height discriminator might conceivably reject primary photons while accepting the less-energetic scattered photons. Such an instance is illustrated in Fig. 2, where, due to the disparity between the gains of the PM tubes, the energy window accepts two different parts of the ^{57}Co energy spectrum. In particular, the detuned tube accepts scattered photons in preference to the primary unscattered photons.

In the presence of a scattering medium, the problem becomes pronounced (Fig. 3). The scatter fraction is considerably increased, and the detuned PM tube accepts more erroneous counts than when the scatter fraction is minimal. Linear correction factors cannot compensate for this nonlinear phenomenon. Thus, according to the above theoretical model, artifacts may be formed when uniformity correction is performed.

MATERIALS AND METHODS

An Ohio-Nuclear Series-100 scintillation camera (equipped with a high-sensitivity parallel-hole collimator), interfaced with a Medical Data System (MDS) Computer, was used to carry out the experiment. Field floods were taken with a solid ^{57}Co source of high uniformity. A 25% symmetric energy window was used to accumulate data. Correction factors were obtained by taking 2 million counts with the ^{57}Co source at the surface of the collimator (*5*).

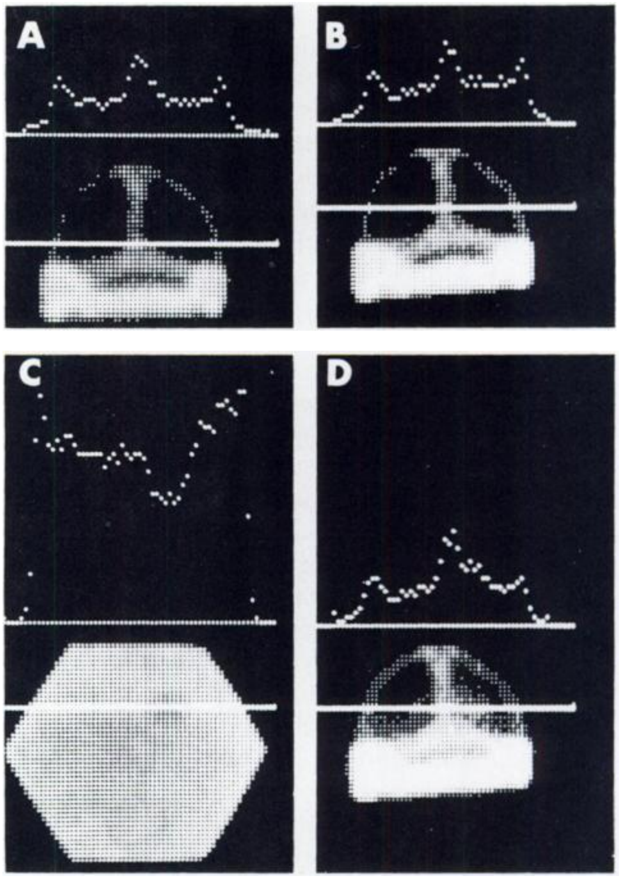

FIG. 5. Images of brain phantom. (A) Image taken at surface of tuned camera; (B) image obtained from detuned camera with 3 in. of scattering medium; (C) flood on detuned camera; (D) "corrected" image. Correction was performed on image B with correction factors obtained from image C.

Images of flood sources and phantoms were taken both at the surface of the collimator and also with 3 in. of tissue-equivalent scattering material interposed. All images were subsequently uniformity-corrected with the correction factors CF_{ij} obtained at the surface.

RESULTS

The results obtained with ^{57}Co are shown in Fig. 4. The flood at the surface, taken with a tuned camera, shows a fairly uniform profile of counts, apart from the edge-packing effect (A). The profile remains essentially unchanged when 3 in. of scattering material is placed between the camera and the flood source (B). When taken with a detuned camera ($\Delta E/E \simeq 20\%$), the flood at the surface exhibits a small area of decreased activity (C). However, on interposing 3 in. of tissue-equivalent scattering medium, the cold spot disappears, due to the corresponding increase in the scatter contribution (D). On applying the uniformity correction, the image at the surface takes on a perfectly uniform appearance, as expected (E). On the other hand, the uniformity correction of the image taken through 3 in. of scattering medium results in an area of increased activity (F). This phenomenon was predicted by the theoretical model we described.

The same results were observed when ^{99m}Tc was used as the source.

Results obtained with a phantom are perhaps more illustrative of a clinical situation. Figure 5 shows that a brain-slice phantom, when uniformity-corrected, produces basically the same kind of locally exaggerated output as was encountered before. In a clinical situation, this may be erroneously interpreted as an abnormality.

We emphasize again that the above study has been carried out for one specific nonuniformity, namely, a detuned ($\Delta E/E \simeq 20\%$) photomultiplier tube. This type of nonuniformity is not uncommon (*6*).

We conclude that uniformity correction may introduce artifacts into a clinical scintigram. *If the field flood nonuniformity is caused by unbalanced PM tubes, we suggest tuning the photomultiplier tubes rather than performing field flood uniformity correction.* This point is worth emphasizing because there may be a "psychological comfort" in hoping to renormalize an image through uniformity correction. Interested readers are encouraged to consult Refs. *7* and *8*, which discuss variation of camera response with energy (^{99m}Tc and ^{57}Co) and count rate.

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