Analysis of Gamma Camera Detector Stability and Its Effect on Uniformity Correction For SPECT

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A critical analysis of regional changes of detector uniformity over time on uniformity correction and its effect on single photon emission computed tomography (SPECT) imaging was performed. Three tomographic imaging systems were tested using a sequential imaging technique and computer analysis of the change of regional uniformity in all images. Our study revealed a direct correlation between the accuracy of uniformity correction and the introduction of uniformity related artifacts after image reconstruction. Each gamma camera detector demonstrated a unique period of stability for accurate uniformity correction and artifact-free reconstructed images. Periods of acceptable uniformity stability ranged from 6 hr to 10 days.

Requirements of detector uniformity for tomographic application are currently available (*1*) and are generally accepted to be within $\pm$ 1%. To achieve this recommended level of uniformity in clinical practice, a uniformity correction process is required which uses a high count reference (flood) image that is stored on computer in order to correct subsequent incoming data prior to reconstruction. A new reference flood for this process must be acquired periodically to reflect current detector uniformity. The rationale for this procedure is that nonuniformities can be corrected if the nonuniformities are known and constant. However, if the regional uniformity of the detector changes after the reference flood is stored, this correction technique is no longer valid and improper uniformity correction will occur.

Most equipment manufacturers recommend that a new reference flood be stored on a weekly basis. This period may be selected due to the inconvenience of the procedure and not due to information regarding detector stability and performance. We have developed a method to simulate and analyze the uniformity correction process over various time intervals in order to determine the adequacy of uniformity correction over time. The results of this analysis will determine the frequency at which reference floods must be acquired for proper nonuniformity correction.

MATERIALS AND METHODS

The primary requirements to perform our analysis are: a) an accurate and reproducible method of acquiring sequential flood images. Any one of the popular methods is acceptable, but the technique must be reproducible over a long period of time; and, b) an algorithm for image nonuniformity correction and uniformity analysis. Some computer manufacturers support these algorithms in one fashion or another.

Data acquisition from three cameras* consists of acquiring an initial high count reference image (10,000 cts/pixel) and then acquiring identical sequential images at any frequency desired over the time span of interest in order to compare uniformity to the reference image. For example, identical sequential images may be acquired hourly, daily, weekly or in any combination of intervals after the initial reference image has been acquired.

Analysis of the adequacy of nonuniformity correction is performed in two parts. First, the reference flood image is used to correct any one or all of the sequential flood images. Second, a functional image is created which demonstrates the accuracy of the correction process. As each sequential image is processed, it is automatically displayed.

The correction procedure is performed by surveying the central field of view of the reference image in order to obtain the average pixel value.

Each pixel of the entire reference image is then compared to the average pixel value to calculate individual correction factors for each pixel:

$$CF_i = P_x/P_i$$

In the above equation, CF_i is the correction factor for each pixel (i). P_x represents each pixel in the reference image and P_i is the mean pixel value of the central field of view of the

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sequential image. Once the correction factor is determined, the image is corrected by multiplying each pixel of the sequential image by the corresponding correction factor.

The second phase of the process is a computer analysis of the previously created uniformity corrected flood image. The purpose of this procedure is to create a functional image of nonuniformities of the corrected image. The procedure is performed by first surveying 75% of the central field of view of the corrected image to calculate the mean pixel value. Next, each pixel of the corrected image is compared to the mean pixel value and sorted in regard to its percent deviation from the mean value. Typical categories of the sorting process are $\pm 0.5\%$, $\pm 1\%$, $\pm 2\%$ and $\geq \pm 4\%$ deviation from the mean value. Each category is assigned a relative intensity that is in proportion to the absolute magnitude of deviation from the mean value. As each pixel is sorted, a functional image is created by assigning the pixel to its corresponding coordinate, but with a new intensity. The standard data display is shown in Fig. 1.

RESULTS AND DISCUSSION

Three tomographic gamma cameras were evaluated using our analysis procedure. The stability of the detectors were tested at various intervals over a period from 1 hr to 14 days. The results of the analysis at each time interval were evaluated and compared to tomographic quality control images of uniform cylinder phantoms that were acquired during the same time period.

Two basic patterns of uniformity correction were recognized from the functional images. The first pattern demonstrated several pixels, which, when corrected, exceeded (worse than) $\pm 1\%$ uniformity, but were distributed randomly over the field of view (Fig. 2). The second pattern was similar to the first, except that the pixels which exceeded $\pm 1\%$ uniformity were grouped together or localized. When these two patterns were compared to transaxial images of a uniform cylinder phantom, no artifacts were detectable when the analysis of the uniform correction pattern demonstrated nonlocalized pixels that exceeded $\pm 1\%$ uniformity. On the other hand, "bull's-eye" artifacts were readily noticeable in the transaxial images when the analysis of the uniformity pattern showed a localized grouping of corrected pixels that exceeded $\pm 1\%$ uniformity as in Fig. 3.

In order to determine the period of time in which a detector maintains acceptable stability for uniformity correction using a single reference flood image, it was ruled that the detector is acceptable until the time that regional, local defects ($\leq 1\%$) appear in the analysis of the uniformity corrected flood images. Using this guideline, acceptable periods of stability were as short as 6 hr and as long as 10 days. Service and repair intervention to the detectors, which demonstrated a very short time period, did not seem to lengthen the interval. The instability appeared to be caused by minute electronic fluctuations below the threshold of observation by trained service engineers.

There have been several discussions on computer analysis of static gamma camera uniformity (*2–5*) and its effect on static

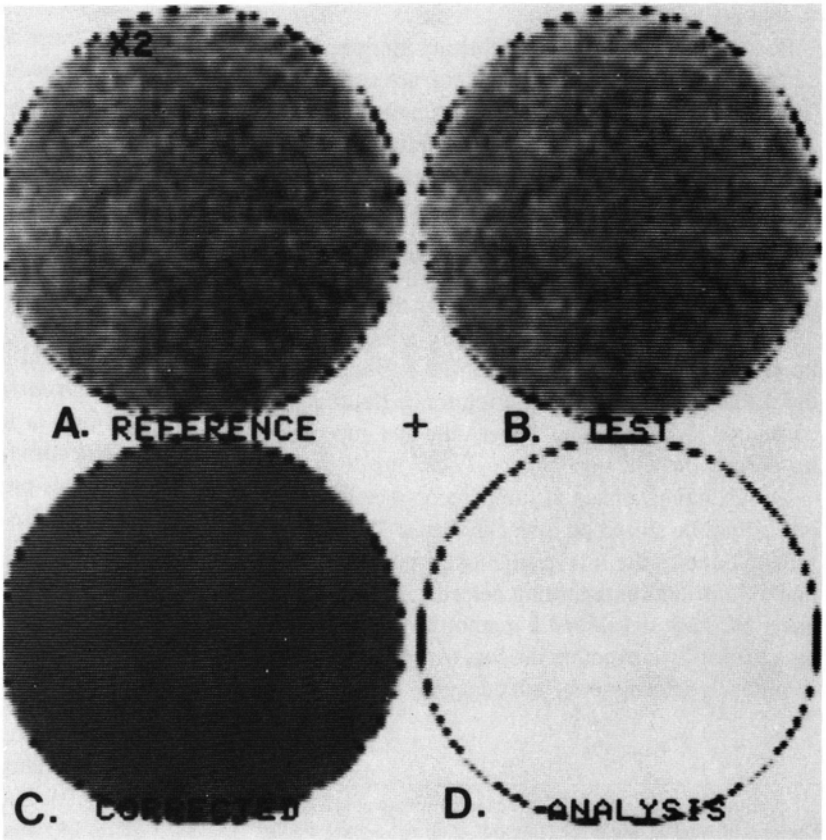

FIG. 1. Standard format of nonuniformity correction and uniformity stability analysis: A) initial reference image; B) sequential image at 72 hr; C) image B is nonuniformity corrected by image A to create image C; D) functional image of nonuniformities in image C. All pixels are within 1% except for edge irregularities.

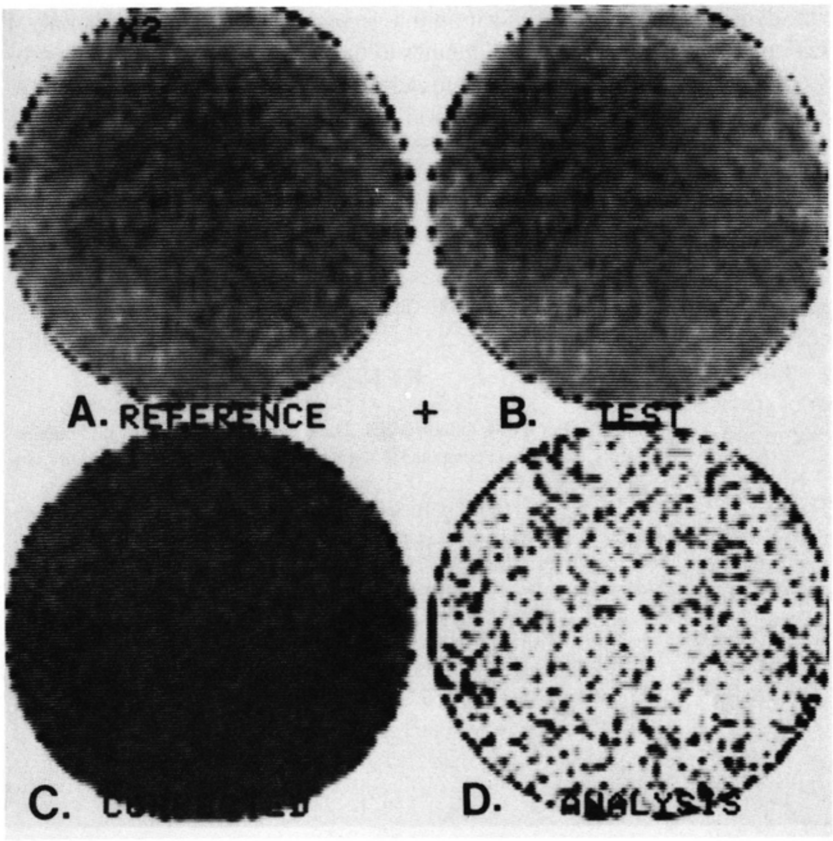

FIG. 2. A) Initial reference image; B) sequential image at 72 hr; C) image B is nonuniformity corrected by image A to create image C; D) functional image of nonuniformities on image C which demonstrate several pixels that exceed 1% uniformity.

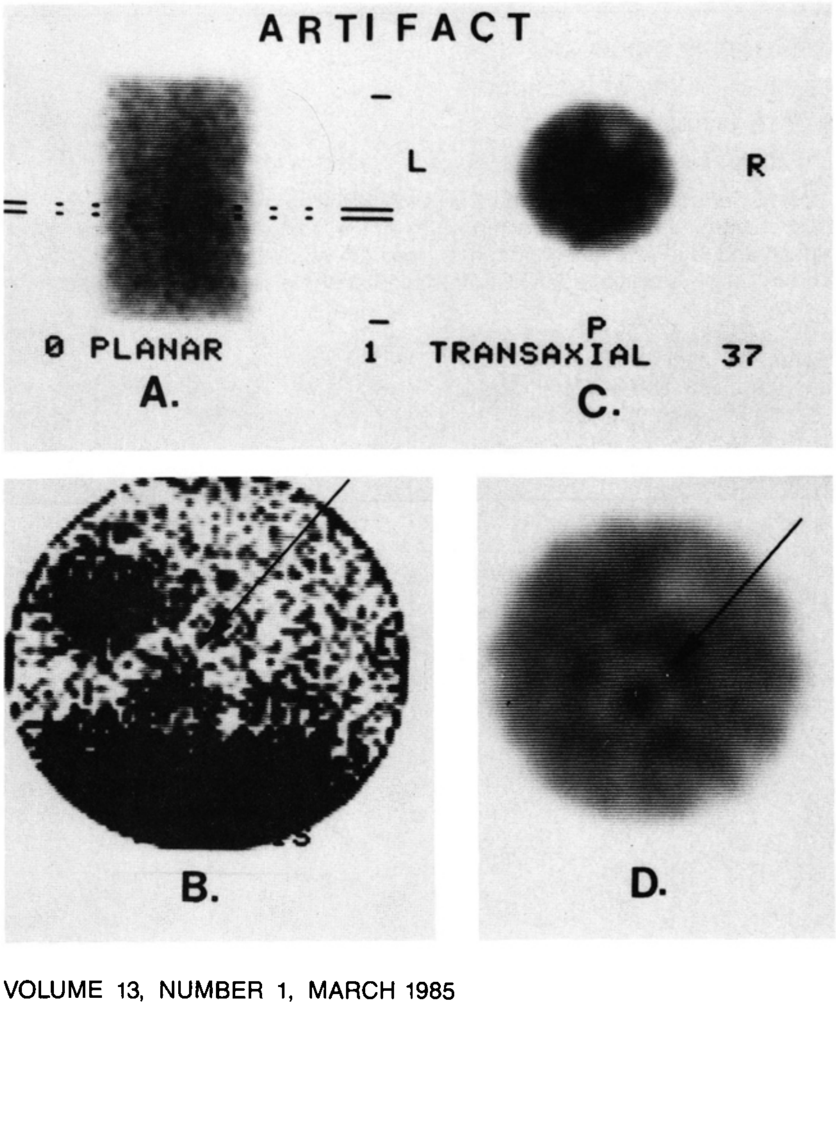

FIG. 3. A) Planar projection of uniform cylinder phantom imaged tomographically. Cursors are placed to correspond to location in detector arrowed in B; B) functional analysis detector regional nonuniformity over 48 hr period; C) cross-sectional image of A at level of cursors; D) magnified image of C to demonstrate "bull's-eye" artifact due to inadequate nonuniformity correction.

imaging; however, little attention has been paid to the dynamic process of nonuniformity correction and its effect on tomographic imaging. Due to the nature of uniformity correction, single static flood analysis is unacceptable for proper quality assurance of dynamic uniformity correction. On the other hand, strict attention must be paid to the change in detector uniformity that takes place over time.

Acquiring high count reference images for uniformity correction is laborious and extremely time consuming. Therefore, most manufacturers recommend that the procedure be performed weekly. Blind acceptance of this recommendation may overlook the likely chance of rapidly changing uniformity, which will clinically manifest in increased number of artifacts the longer the same reference image is used for nonuniformity correction.

In conclusion, we have found this technique extremely valuable for analysis of the uniformity correction process over time and in identifying the period of uniformity stability for individual gamma cameras. This analysis is used on a regular basis to confirm valid uniformity correction, thus eliminating tomographic artifacts due to nonuniformities that are introduced during the uniformity correction process. The analysis is quite useful in initial acceptance testing and adds only a few additional minutes to the routine quality assurance program. The algorithms could easily be integrated into the reconstruction process to give the operator an on-line evaluation of the uniformity correction process during the tomographic imaging process.

FOOTNOTE

*Technicare Omega 500, General Electric 400AT, and Siemens LFOV.

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