Computerized Monitoring of Scintillation Camera Uniformity

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An efficient and practical procedure is outlined to objectively analyze and monitor scintillation camera uniformity performance on a daily basis using a commercially available nuclear medicine computer system. Our methods are illustrated with the four scintillation cameras currently used in our department. Intrinsic camera uniformity is analized daily according to NEMA specifications, and quantitative results are graphed from the most recent 120 calibration days.

Daily quality assurance is considered indispensable as a stringent *a priori* step to high quality scintigraphic imaging. How stringent the application of a quality contol test can be might depend widely on its content and often seems to be a matter of personal preferences as expressed recently by Murphy (*1*). The most widely accepted set of camera performance tests for scintillation cameras was specified by the National Electrical Manufacturers Association (NEMA) in 1981 (*2*). These performance specifications were updated in 1986 with only minor modifications in the sections pertaining to intrinsic uniformity and count rate sensitivity (*3*). As previously noted, most of NEMA's acceptance testing specifications can be turned into end-user protocols (not their intended purpose) and some are even amenable to quality assurance procedures (*4*). Whether or not NEMA standards are used rigorously for acceptance testing of new equipment (their intended use) or followed loosely, quality assurance performed according to established protocols has been widely accepted within the scope of clinical nuclear medicine imaging. More specifically, intrinsic uniformity properties of scintillation cameras and monitoring of uniformity performance can be efficiently evaluated on a daily basis using NEMA specifications. A qualitative analysis of the most frequent quality control procedure (i.e., evaluation of the daily flood uniformity) should be included in a quality assurance program.

With the availability of programmable mini- and microcomputers, interfaced to scintillation cameras, the quality control workload of many nuclear medicine departments can be improved (*4–7*). What was typically confined to qualitative evaluations can now be achieved quantitatively with minimal user interaction. Uniformity analysis becomes observer independent by following a standard such as the NEMA specification and, therefore, is objectively evaluated. This becomes essential for the increased uniformity requirements of tomographic data acquisition and analysis such as in SPECT where different areas of the camera are used to reconstruct the same spatial volume of a radioactive distribution. The visual evaluation of corrected and uncorrected analog flood images, for example, is too insensitive for tomographic procedures.

This paper will show how digital flood images are acquired and analyzed according to exact NEMA specifications, using a commercially available computer system, and discuss herein our experience based on our four cameras. The quantitative assessment of intrinsic unformity is summarized for the most recent 120 days of camera operation. Lately, various manufacturers have provided the end-user with some type of quantitative uniformity analysis and therefore have improved the monitoring of scintillation camera performance through automation. The "black box" characteristics of these software packages, however, may be unsatisfactory in some circumstances by either not following adequately a standardized protocol (e.g., NEMA) or not showing the desired flexibility.

MATERIALS AND METHODS

The computerized intrinsic NEMA uniformity analysis and monitoring is performed daily on the following four cameras[*†‡§]: three large field-of-view and one portable. Data collection, analysis, and display is performed on standard computer systems[¶].

Following NEMA guidelines, the cameras are flooded with point sources of ^{99m}Tc located at a distance of ~ 5 camera diameters, using a standard 20% window setting. The count rate is limited to 25,000 counts per sec (cps) for the large-field-of-view camera[*] and 30,000 cps for two other cameras[†‡]. Although intrinsic uniformity is dependent on the incident count rate, we allowed 60,000 cps (which is beyond NEMA's recommended threshold value) for the new camera[§]. This time-saving modification seemed warranted by the linear dependence of incident events versus observed counts and independence of uniformity and count rate below 80,000 cps for this particular camera. The total number of counts accumulated in each digital image is ~ 12 million for the round-field-of-view (RFOV) cameras and 16 million for the square camera which ensures the NEMA advocated count density of 4,000 counts per pixel.

Two static flood images are acquired into 64×64×16 matrices for each camera. The first image is collected under clinical data collection conditions (i.e., all correction devices being enabled). A second flood image is then collected with all correction devices turned off. In the present case, this means the following: disabling the uniformity correction, high count rate

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mode, energy and linearity correctors, uniformity correction and electronic masking, as appropriate for each camera. Data collection is initiated using predefined acquisition protocols. The only variables required for acquisition are the initials of the operator, activity of the ^{99m}Tc point source in microcuries and the time of its calibration. This allows the software to correct for source decay before data acquisition and, in case of delays, compute the intrinsic sensitivity. Decay corrections for the duration of data collection are neglected.

The analysis of both flood images is started automatically without operator intervention at the completion of data acquisition. The computation of uniformity indices follows the protocol outlined by Raff et al. (*4*). Intrinsic integral uniformity (IU) reflecting the global uniformity property and differential uniformity (DU) reflecting the local uniformity characteristics are calculated for the useful-field-of-view (UFOV) and for the

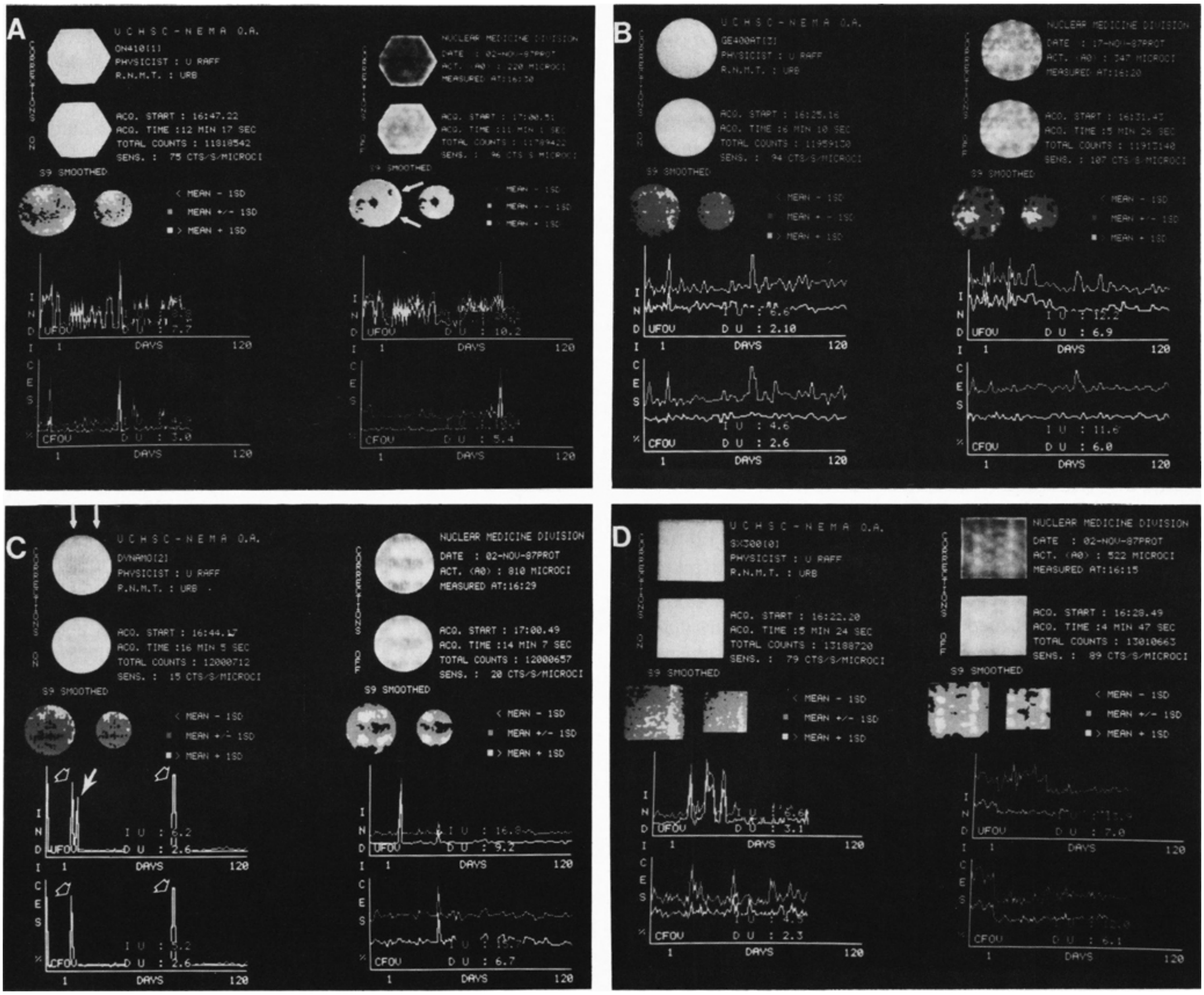

FIG. 1. Results of computerized NEMA uniformity analysis are displayed for our four cameras. Precipitous changes in uniformity performance caused by either camera malfunctions or operator errors can be observed in all four cases. Functional images for flood field matrices clearly show correlated areas of pixels indicating unbalanced gain of PM tubes or other electronic malfunctions resulting in image artifacts. The three grey levels used to display these functional images correspond to an average number of counts below the average −1 standard deviation (s.d.), within the average ±1 s.d. and above the average +1 s.d. Archival of results is performed on one 8 × 10 film. The numerical values on the graphs correspond to the last points of the two curves.

(A) Edge packing effects reflected in the functional UFOV image are indicated with an arrow and can be seen to account for a "worse" uniformity than should be attributed to the camera with correction devices disabled. This is also partially due to the observed offset in X gain influencing the digital masking for the UFOV. (B) Notice the high degree of stability of integral and differential uniformity over the displayed period of time. (C) Uniformity problems are indicated with arrows: the open arrows show interruption of data collection by the operator thereby reducing the number of counts accumulated and demonstrating the necessity of the high-count density required by NEMA. A third peak indicated by the full arrow in the UFOV graph of the corrected flood refers to the malfunction of a PMT located between the UFOV and the CFOV. Hence, it is missing in the CFOV graph below. Parallel arrows above flood matrix point out a regular grid pattern reported as A/D converter problem in the camera by the manufacturer (This artifact has been observed only in a 0- and 180-degree orientation). Notice how this affects the pattern of the corresponding UFOV functional image. (D) Periods of great uniformity variations followed by stable uniformity performance after corrective intervention can be observed for corrected and uncorrected flood images.

central-field-of-view (CFOV) of each camera. NEMA standards for uniformity evaluation do not include definitions of UFOV and CFOV for square-field-of-view cameras. The UFOV of our square detector camera was defined as a square with a side length equal to 95% of the original length after eliminating a 2-pixel wide frame around the flood matrix. The CFOV square was then obtained by reducing further the UFOV square side length to 75% of its value. A FORTRAN program performs the computation of uniformity indices and the display of results and graphs.

RESULTS

The results obtained from our four-camera department are summarized in figure 1. Each of the four quadrants, corresponding to one camera, can be zoomed individually to the full screen display. The quality assurance protocol contains the following information: camera identification, the operator's initials, time of acquisition start, total data collection time per frame, total number of counts accumulated, point source activity in microcuries, and the time at which this activity was measured. In addition, the intrinsic sensitivity in counts/seconds/microcurie is calculated for the constant distance of point source to camera and displayed. The digital flood images and the nine-point smoothed matrices are shown for an additional visual appreciation of nonuniformities in corrected and uncorrected flood images.

Functional images for UFOV and CFOV are displayed below the flood matrices *(4)*. These functional images are particularly useful to emphasize areas of nonuniformities (i.e., areas of pixel correlations). Three grey level ranges corresponding to pixel values within the average pixel value $\pm$ 1 standard deviation (s.d.), less than average -1 s.d., and greater than the average $+1$ s.d. are used. Cold and hot areas are identified by the lightest and darkest grey levels, respectively. Some manufacturers have adopted this idea and provided a display of a functional uniformity image[¶].

Daily uniformity index variations are displayed below the corresponding flood matrix. Integral and differential uniformity values are kept in a uniformity index file and selected for display only for a fixed period of 120 days. After this interval, the (color coded) graphs move to the left dropping the first values while adding new index values for display purposes. The camera's performance is always displayed for the most recent 120 days of clinical operations. The current IU and DU values (color coded for easy identification) are also shown to demonstrate the considerable range of variations of uniformity over short periods of time.

During the initial automated uniformity analysis, the cameras' disk file header blocks are marked with a flag allowing multiple repetition of the same analysis without updating the uniformity index file. No curves are displayed in this case. Any file containing two static flood images acquired with the same type of system can be analyzed without generating graphs. As soon as a uniformity index increases beyond a preset threshold, a message is displayed next to the current values indicating that corrective intervention is required. Threshold values for IU and DU indices, for example, were set to the following values for one camera[§]: (a) corrected flood image—8% for IU and 5% for DU; (b) uncorrected flood matrix—15% for IU and 10% for DU.

The complete NEMA uniformity data acquisition and analysis takes ~ 45 min, including the setup times. The analysis, starting automatically at completion of data collection, takes 50 sec on this camera[¶] and 1.25 min with the DEC system[**].

DISCUSSION

Daily analog or digital flood field images are the prerequisite of high quality scintigraphic imaging. Although the quality assurance procedures for scintillation cameras are quite involved and time consuming, intrinsic uniformity performance can be approached efficiently following NEMA specifications. Degradations in intrinsic uniformity depend partially on degradations in intrinsic linearity and can produce, although less dramatic, changes in intrinsic resolution. Since intrinsic resolution depends to a large extent on the number and size of photomultiplier (PM) tubes, an increase in resolution through an increase in the number of PM tubes might affect adversely the uniformity performance of a camera. Therefore large FOV cameras with a high number of PM tubes (e.g., above 60) might require an even closer follow-up of their uniformity performance depending on the involved electronic circuitry to correct for gain shifts.

Following a computerized (NEMA) uniformity protocol has multiple merits. The inspection of digital floods, including the entire imaging chain used in computerized studies, allows for the immediate adjustments of x and y gains and offsets in the present system. Problems arising with Z delays can be identified as shown (Fig. 2) and corrected. Notice the corresponding drastic improvement in uniformity after corrective intervention. Analog-to-digital converter malfunctions can be readily diagnosed as observed in figure 1C with the example of a small field-of-view mobile camera[‡].

Acquisition of analog flood images (1 to 2 million counts per image) are less time consuming and therefore more appealing for those situations where no quantitative data analysis is required. Recently, however, more camera-computer integrated systems, restricted to digital imaging, are indicating a new trend on the market. The advantage of a programmable system or so called "open system" becomes obvious as long as programming expertise is available to the user. The complexity of modern camera-computer systems makes a quantitative uniformity analysis mandatory. Whether or not NEMA specifications are followed is left to the user's discretion. It, however, seems to be the logical approach to the camera-computer uniformity evaluation.

The same analysis presented here can be applied to different situations. Since electronic correction devices can generate astonishing uniform flood images, it seems imperative to collect and analyze flood matrices under the worst conditions (i.e., bypassing all available corrections). Off-peak and high count rate imaging (above 75,000 cps) can also be investigated. Moreover, the angular variation of flood field uniformity required for SPECT imaging can be checked by attaching the ^{57}Co flood disk (NEMA suggestion) to the camera's head. Sys-

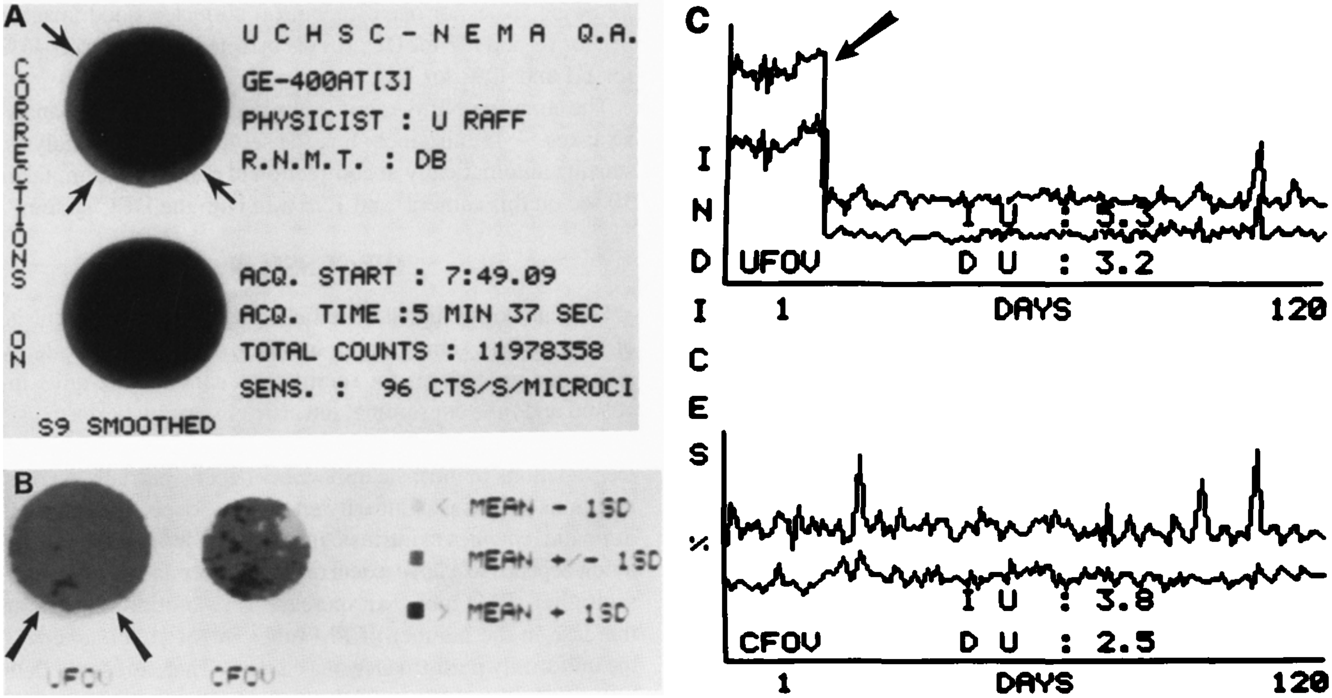

FIG. 2. Example of a malfunction in Z delay that has been observed during acquisition of a flood image, which resulted in a rim of low activity in the digital flood matrix. Arrows indicate the rim of lower activity in the acquired flood (A), reflecting poor UFOV uniformity as observed in the functional image (B) in which arrows point out this artifact. The sudden step function variation of the integral uniformity index indicated with an arrow in (C) shows the considerable improvement in uniformity after corrective action (arrow) has taken place.

tem uniformity for different collimators using solid flood sources or ^{99m}Tc flood tanks can be performed as well using the same type of analysis.

The camera uniformity is known to be energy dependent. Recently camera uniformity and resolution have been inspected for three different radionuclides (^{99m}Tc, ^{201}Tl, and ^{67}Ga) and nine cameras (*8*). Floods were evaluated visually, requiring a group of 10 observers to compare visually the flood images and grade the cameras' uniformity performance. Quantitative analysis, which is an objective approach, and monitoring over time seem to warrant the quality assurance steps chosen here to evaluate slight changes over long time intervals and intermediate global and/or local changes in uniformity that might not be so evident in low-count analog floods (usually 1 to 2 million counts).

CONCLUSION

Efficient and complete daily NEMA uniformity performance testing of each camera in multiple camera departments is feasible with a commercially available nuclear medicine computer system that is programmable and accessible to the end-user who wishes to operate at a high level of flexibility. With a well-coordinated technical routine and a dedicated computer system to each camera, no additional time is required beyond a simple subjective inspection of a photographic flood. The versatility and processing speed of the used system[¶] is emphasized to encourage objective uniformity evaluation of cameras for different imaging situations. This should ultimately be reflected in improved clinical image quality if preventive and corrective actions are taken in response to the observed performance degradations.

NOTES

*Sigma 410, Technicare, Solon, OH

†400 AT (61 tube), General Electric Medical Systems, Milwaukee, WI

‡Dynamo, Picker International, Inc., Highland Heights, OH

§SX300 DDC Square Field, Picker International, Inc, Highland Heights, OH

¶Picker International Inc., Highland Heights, OH

**Gamma-II, Digital Equipment Corp., Marlboro, MA

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