Improved Performance from Modifications to the Multidetector SPECT Brain Scanner

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A multidetector single photon emission computerized tomographic brain scanner was modified to improve the angular sampling. The detector plate was rotated such that 12, 24, or 36 angular projections could be acquired. Phantom experiments demonstrated that the angular aliasing artifacts seen in images obtained with 12 detectors were eliminated with 36 effective detectors. In addition, the reconstructed image noise in a uniform source was decreased by a factor of 1.7 by the use of 36 instead of 12 angular projections, as predicted by computer simulation.

J Nucl Med 25: 688–691, 1984

Interest in single photon emission computerized tomography (SPECT) of the brain has recently been stimulated by the apparent ability to image regional cerebral blood flow using radiopharmaceuticals labeled with I-123 (*1–6*). This work has also revived considerable debate concerning the relative merits of different instruments for SPECT imaging (*7–9*). The multidetector SPECT brain machine is a high-sensitivity scanner originally conceived of by Stoddart (*10*). Each detector scans both tangentially and radially to the field of view, resulting in uniform spatial resolution, sensitivity, and slice thickness throughout the field of view (*11,12*). The instrument's 10-mm spatial resolution within the transverse slice (*11–13*), 15-mm slice thickness (*12,13*), and single-slice sensitivity of 14000 sec^{-1} μCi^{-1} ml for a cylindrical source of Tc-99m 20 cm in diameter (*11*) are well suited for transaxial imaging of the brain using I-123-labeled compounds.

Images obtained with this scanner have appeared noiser than might be expected, and a nonstochastic noise component has been observed, described as a "Hong Kong dollar" artifact. As an attempted solution, the manufacturer originally used an automatic background subtraction as part of the image reconstruction, but this is undesirable for quantitative analysis.

A recent simulation (*14*) showed that the observed artifacts and excessive noise amplification of this scanner were due to inadequate angular sampling. We decided that the entire array of detectors could be rotated two times between complete detector raster scans so that 36 effective angular projections would be acquired at 10° intervals instead of 12 projections 30° apart. With this modification, calculations showed that the structured noise could be eliminated and the random noise reduced by a factor of 1.7* for the same total number of detected photons.

METHODS

The modified machine is shown in Fig. 1, with the detectors in their starting position. The large plate which holds the 12 detectors was mounted on a fixed back-plate, which contains a large ring bearing (not shown). A new stepping motor and drive screw were mounted on the back to rotate the entire detector plate under computer control. The location of the centers of rotation of the detector plate and the ring bearing coincide within 0.2 mm. The plates can be tilted up to 16° to acquire oblique cross-sectional scans of the brain. The angular-drive stepping motor, as well as the tangential and radial-drive motors, were replaced with five-phase stepping motors. The scanning speed, number of radial steps taken during raster scans, and the number of detector-plate rotations and their angular range are programmable using a microprocessor development system.

To compare the new instrument's performance with that of the old system, we scanned the following phantoms: an axial line source of Tc-99m, centered in the machine; an annular "ring" source of Tc-99m with inner and outer radii of 4.4 cm and 5.6 cm, respectively; and a uniform cylindrical "flood" phantom, 15 cm in diameter, also filled with Tc-99m.

The phantoms were each scanned initially in the unmodified instrument mode. One raster scan was obtained consisting of 12 tangential scan lines per detector at 12 different radial distances from the center. Other scans were performed by rotating the de-

Received Oct. 10, 1983; revision accepted Jan. 5, 1984.

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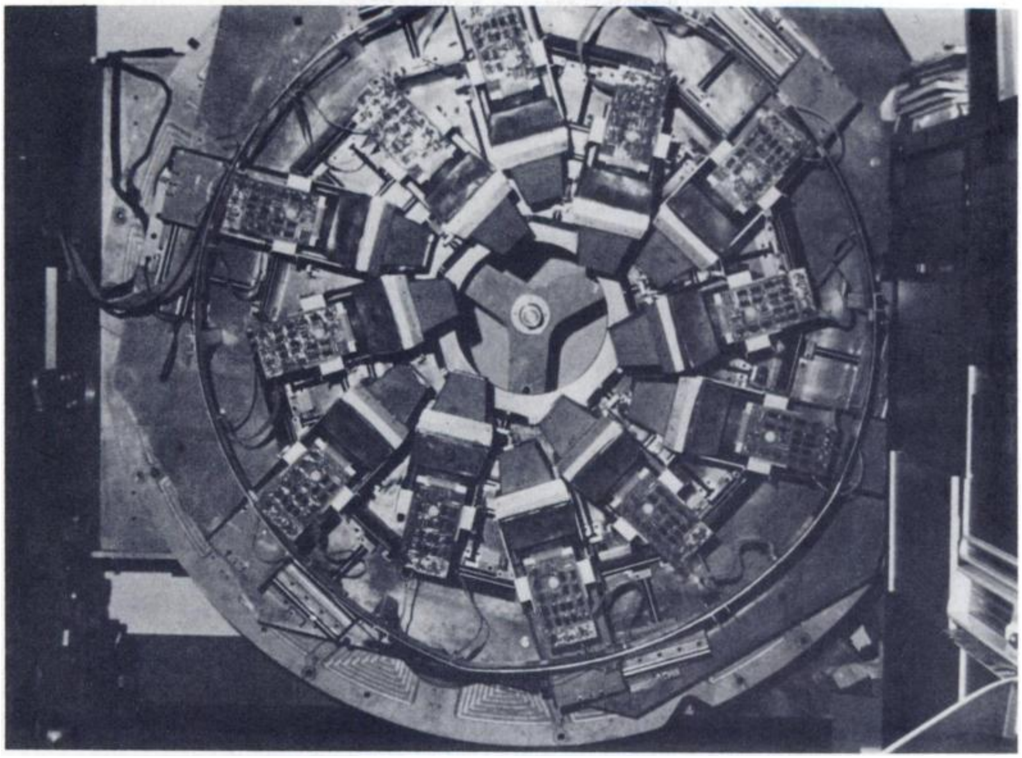

FIG. 1. Rebuilt multidetector SPECT brain scanner showing 12 detectors with focussed collimators in their initial positions before scan begins. After all detectors perform raster scan tangentially and radially to circular scan field, entire plate rotates about large ring bearing (not shown). Second raster scan is then performed, followed by another rotation if desired. Removable line-source alignment fixture is shown in center of scan field.

tector plate through an angle of 15° between raster scans, acquiring 24 effective angular projections. Finally, scanning was performed with two rotations of 10° resulting in three raster scans, or 36 effective projections. Because of limited data storage, the number of tangential lines scanned by each detector was limited to an even number equal to ten or less when using 24 effective detectors, and six or less when using 36 effective detectors. The radial distance between adjacent tangential line scans is given by:

$$10.5\ \text{cm}/(N_{tan} - 1)$$

where N_{tan} is the number of tangential lines scanned by each detector. Scan times and/or activity concentrations were adjusted so that approximately the same total number of counts was obtained when scanning a given phantom using the different scan patterns.

RESULTS

Figure 2 shows reconstructions of the centered, axial line source, scanned using (left) 12 detectors with 12 tangential scan lines each, and (right) 36 effective detectors with six tangential scan lines. The gray scale was windowed from 0% to 16% of the maximum count in the image. Therefore, the angular aliasing streaks in (a) are at a level of ~8% of the maximum count, whereas the lack of streaks in (b) means that the improved angular sampling has reduced the artifacts to <1% of the maximum count. The image with 24 effective detectors (not shown) is improved over the 12-detector result (Fig. 2, left), but it shows a few small streaks at a level of 1-2% of the maximum count.

The "wobbly" ring-source reconstruction in Fig. 3 (left), which results from a 12-detector scan is another manifestation of limited angular sampling. This "Hong Kong dollar" artifact can also be eliminated by scanning with 36 effective detectors (Fig. 3, right).

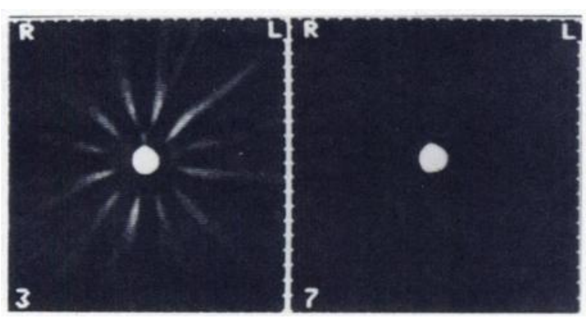

FIG. 2. Reconstructions of centered, axial line source of Tc-99m scanned using (left) 12 detectors with 12 tangential scan lines each, and (right) 36 effective detectors with 6 tangential scan lines each. Gray scale was windowed from 0% to 16% of maximum count in each image to enhance visibility of any aliasing streaks.

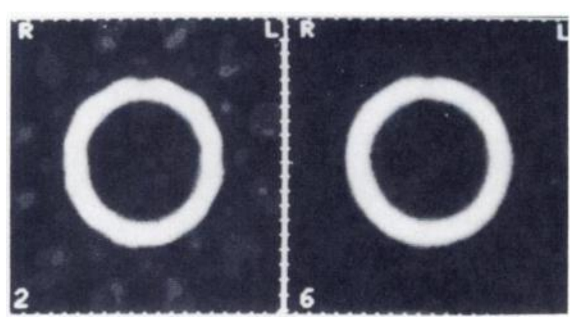

FIG. 3. Reconstructions of hollow ring source of Tc-99m scanned using (left) 12 detectors and 12 tangential scan lines, and (right) 36 effective detectors and 6 tangential scan lines. Top of ring shows air bubble. Background in center of ring is due to improper correction for attenuation.

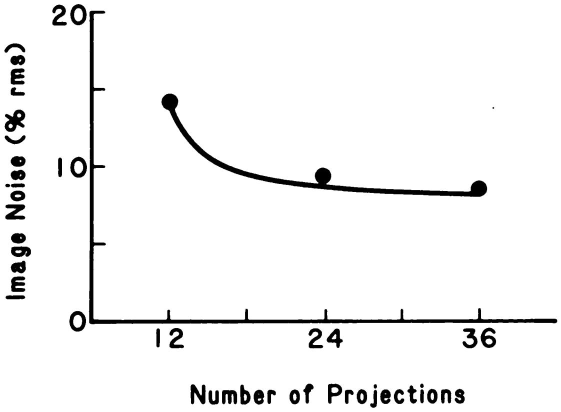

FIG. 4. Image noise in 15-cm cylindrical phantom containing uniform concentration of Tc-99m. Data points were measured on new machine. Solid curve is prediction from computer simulation (*14*). Curve was normalized to first data point, since simulated data were estimated without attenuation and were reconstructed differently from measured data points.

The 24-detector scan (not shown) eliminates this artifact, but there are some background aliasing streaks outside the ring. (The defect at the top of the ring is an air bubble in the phantom.) The residual background appearing in the center of the ring in Fig. 3 (right) is due to an improper correction for attenuation. The algorithm currently used on this machine does not allow for an annulus of attenuating material. A more general method, such as that used for a similar whole-body scanner (*15*), has not yet been implemented.

Finally, in a phantom 15 cm in diameter, containing a uniform concentration of Tc-99m, the %RMS image noise was 14.3% for 12 detectors, 9.3% for 24 detectors, and 8.6% for 36 detectors. Thus, the noise has been reduced by a factor of 1.7 by the change from 12 to 36 effective detectors. Approximately 4 million counts were acquired for each scan. A correction was applied to the measured image noise in each reconstruction to account for the small difference between 4 million and the actual number of counts recorded during each scan, assuming a $\sqrt{N}$ noise dependence. The image noise for these three cases is plotted in Fig. 4, along with the theoretical curve obtained earlier by computer simulation.

For all phantoms scanned there was no observable deterioration in image quality from decreasing the radial sampling of each detector to six tangential scan lines (Figs. 2-3). In addition, the factor of 1.7 improvement in image noise was first obtained by computer simulation of this scanner acquiring 36 effective projections, each with 12 tangential scan lines (*14*). The fact that the modified machine, scanning only six tangential scan lines, performs as well as predicted is further evidence that decreasing the radial sampling to six tangential lines is not adversely affecting the images.

DISCUSSION

By increasing the number of scan angles, the aliasing artifacts seen in images from the multidetector SPECT brain scanner have been eliminated. In addition, the image noise in a uniform source has been decreased by a factor of 1.7, with no loss in sensitivity or spatial resolution. The total scan time for each slice can be preserved by a combination of scanning only six tangential lines with each detector (instead of 12) and scanning each line 50% faster. However, due to the decreased image noise resulting from better angular sampling, a transverse section with the same image quality could be produced in one third the time using the modified machine with 36 rather than 12 discrete angular samplings.

The radial sampling can be reduced to six tangential scan lines without compromising image quality. This result is plausible because scanning six tangential lines corresponds to a sampling frequency in the radial direction that is still consideraly higher than the Nyquist rate. The full width at half maximum (FWHM) of the collimator response along the central axis in the radial direction is 8 cm. Scanning six tangential lines corresponds to 2.1-cm radial sampling.

If 36 angular projections were acquired by a rotating gamma camera system, the reconstructions would be of poor quality. The reason that 36 angular projections work so well for the multidetector SPECT scanner is because of the additional useful information gained by sampling in and out radially with focussed collimators.

ACKNOWLEDGMENTS

The authors thank Dr. Thomas Budinger for helping them to carry out an early experiment that verified computer simulation results indicating problems with angular sampling on this instrument.

This work was supported in part by grant 1-R01-N520847 from the Dept. of Health and Human Services, U.S. Public Health Service, Bethesda, Maryland.

FOOTNOTE

* The noise reduction factor (1.7) is less than the number reported in the proceedings of the Third World Congress of Nuclear Medicine (*14*). This is because of an error in a computer program, which was not discovered until after the proceedings of that conference were printed.

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