Point-Source Scanner for Assessment of Gamma Camera Performance

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A point-source scanner was made from a mechanically modified x-y plotter. The pen carriage was stabilized so that it could carry a lead can with a radiation source. It was also made longer so that the scanner would see the whole field of view of a rectangular scintillation camera. The movements of the scanner were controlled by a computer. The statistical uncertainty in the scanning movement, including speed, angle, and distance variations, was less than 1% (1 s.d.). The point-source scanner was used to acquire uniformity matrices for different radiation sources and to generate different kinds of line-source and resolution phantoms.

Periodic checks of the performance of the gamma camera are necessary to ensure good image quality. When the camera is used for SPECT imaging, the uniformity of the camera is of utmost importance (*1*). In order to perform a comprehensive quality control procedure, a variety of phantoms are needed, such as bar phantoms, uniformity phantoms, line sources, and point sources. These phantoms often need to be filled with aqueous radioactive solutions, which poses a risk of high absorbed dose and contamination to the personnel (*2*).

In an attempt to lessen the number of phantoms needed, a dynamic line phantom (DLP 101, Veenstra Instruments, Eext, The Netherlands) was designed by Deconinck and Verzelen (*3,4*). It consists of a line source mounted on a movable carriage, which is mounted on a base. The movement of the line source is controlled by a microprocessor, and it is possible to simulate a number of different line, bar, and uniformity phantoms. However, this apparatus has a drawback: the line source has to be filled with radioactivity and it may introduce nonuniformity, due to count-rate losses (*5*). These losses are caused by the variation in the length of the line source, which is exposed to a circular detector as the source is scanned across the camera face.

In order to overcome the difficulties of using a line source, but still benefit from the advantages of a scanning source, we have developed a point-source scanner. This scanner could replace several of the commonly used phantoms for quality control of gamma cameras.

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MATERIALS AND METHODS

The plotter used was a standard A3 (420x297 mm) x-y plotter (Watanabe Digi Plot, Watanabe Instruments Corp., Tokyo, Japan). The original pen-slider shafts with gear-belts and pen holder were replaced by two long shafts of stainless steel and a carriage holder made of perspex for a lead can. The lead can was the same type used to deliver radiation sources to the department from the isotope supplier.

The movement in both the x and y direction was made longer from the original 420x297 mm (A3) to 430x381 mm. This was done by changing the gearing of the step motors and by making the slider shafts longer.

The original plotter table was replaced by a larger table made of perspex with a thickness of 16 mm. The table was mounted with fast lockers on a carriage (Fig. 1).

The scanner can be connected through an IEEE 488 interface either to a minicomputer, for collection of uniformity matrices on a routine basis, or to a personal computer (MS-DOS compatible) for collection of line-source and contrast phantoms. A program was developed in order to control the point-source movement in different applications.

Uniformity Matrices

When collecting uniformity matrices to monitor lack of uniformity, the canister with the isotope was placed in the lead holder, and the count rate was determined centrally over the camera crystal. The speed with which the scanner could collect 20 million counts was determined from this count rate. For this application, the point source was equipped with a collimator that had an opening diameter of 3 mm and scanning paths separated by 3 mm. The speed of the scanner was corrected for the half-life of the radionuclide in use.

Correction matrices can in this way be collected with or without a collimator on the camera and the intrinsic uniformity and uniformity of the collimator determined. If scattered radiation needs to be included in the uniformity matrix, a scatter block of appropriate thickness can be mounted in front of the collimator opening on the lead canister. When using thallium-201 (^{201}Tl) with an activity of 600 MBq and a dynamic collimator on the camera, the collection took ~1 hr.

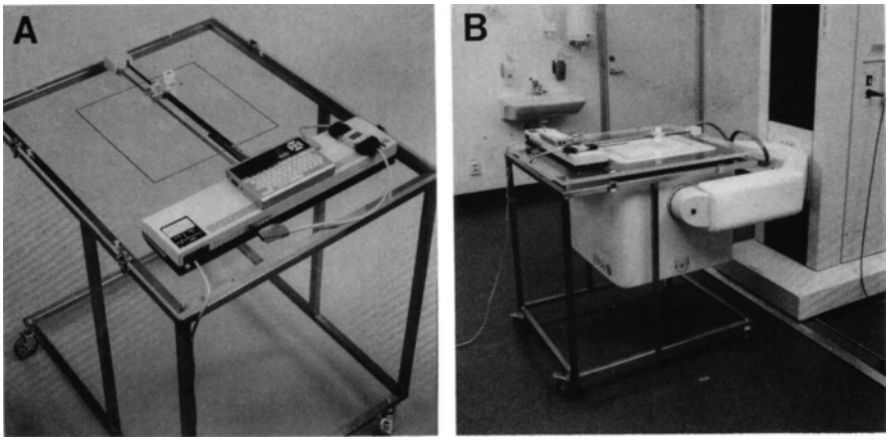

FIG. 1. (A) the point-source scanner; (B) the scanner in position over the gamma camera head.

Line Source Phantom

The point-source scanner was programmed to move in a number of different line source patterns. These can be used to assess the linearity of the gamma camera, the resolution capability, and the modulation transfer function (MTF). When used for collecting the different line source patterns, the point source was equipped with a lead collimator on which the opening diameter varied between 1 and 3 mm. Before the scanning started, the point source was moved to the center of the gamma camera crystal and the count rate was determined. The speed of the scanner was then determined from this count rate.

RESULTS

In order to use the point-source scanner for quality control of the gamma camera, the variations in the number of detected pulses, from malfunctions of the scanner system, must be small. The following errors had the largest effect on the count rate for the gamma camera.

- Variations in the time the point source was situated at a certain point
- Variations in the distance between the point source and the gamma camera crystal
- Variations in the angle between the hole seen by the point source and the collimator holes of the gamma camera
- Statistical variations in the decay of the radiation source

The variations in the stepping times were measured with an accelerometer connected to the point source during scanning. The mean value of the time between the steps, based on 75 measurements, was 0.274 sec, with a standard deviation of 0.0018 sec. When the distance variations were measured, it was assumed that the gamma camera crystal was flat and at a constant distance from the collimator of the camera. The distance variations were measured with a ruler (accuracy 0.1 mm) over the whole field of view of the scanner. The maximum variation was ±0.5 mm.

The angle variations could appear during the scanning movement, if the point source was tilted around the axis to which it was sliding. This tilt, θ, in Figure 2, changes the impinging angle of the radiation beam against the gamma camera collimator so that more or fewer photons can pass through the collimator holes. Twenty measurements of the number of photons passing the collimator septa during 30 sec, with forced random-angle variations (θ) and within the maximum limits of ±0.7°, gave a mean value of 8,570 counted pulses with a s.d. of 240 pulses.

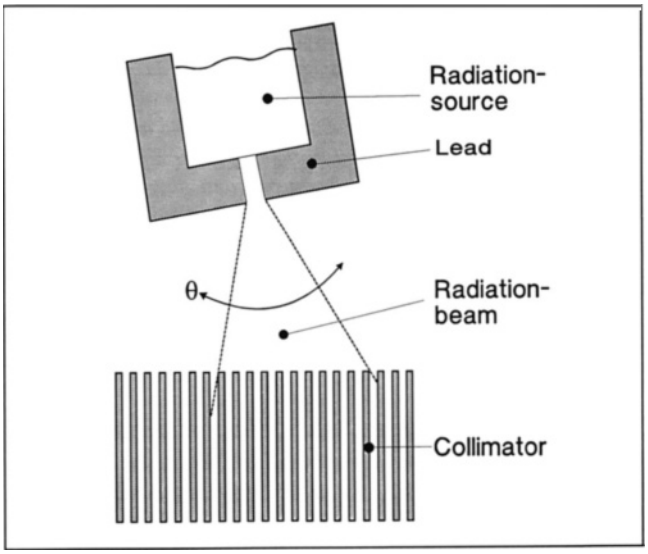

FIG. 2. Angle variations in the tilt of the point-source canister.

The dominating source-to-pulse variation was the variation in the counting statistics, which was caused by the Poisson variation in the decay of the radiation source. For a matrix containing 20 million pulses, the coefficient of variation due to counting statistics was 1.4%. Assuming that the errors were stochastic normally distributed variables, and giving the error limits of 3 s.d., necessary to have 99.7% of the chances within the limits, the errors can be calculated according to the law of propagation of errors (*6*).

The pulse statistical variation was not included in the error calculation, since it was dependent on the total number of counted pulses and not on the construction of the scanner.

With values applied, a variation coefficient of 2.7% was achieved. The variation coefficient in the activity distribution for commercially available flood field phantoms is often stated to be better than 1%; this figure is given for 1 s.d. in the activity distribution. With a s.d. of 1, that is, 67% of the chances within the error limits, the error, expressed as a variation coefficient, was 0.9% for the point-source scanner.

Figure 3 shows an example of a uniformity correction matrix acquired with ^{201}Tl and a dynamic parallel-hole collimator. This matrix was used to correct the tomographic myocardial scintigraphy.

The point-source scanner can be used to assess lack of uniformity for collimators. Figure 4 shows uniformity matrices collected both with and without a low-energy parallel-hole collimator.

For assessing the resolution of the gamma camera, the point-source scanner was programmed to move in a single path in the x or y direction. Thus, the scanner was simulating a line source with a diameter of 1 mm. From the collected line-source matrix, the full width at half maximum (FWHM) and full width at tenth maximum (FWTM) could be determined. This acquisition could also be used for determining the gamma camera's MTF.

A subjective analysis of the linearity of the gamma camera could be achieved by letting the point source move in a number of equally spaced paths over the gamma camera's field of view. The point-source scanner could also be programmed to move with different distances between the paths, in order to obtain a subjective opinion of the resolution. A number of line-source patterns are presented in Figure 5.

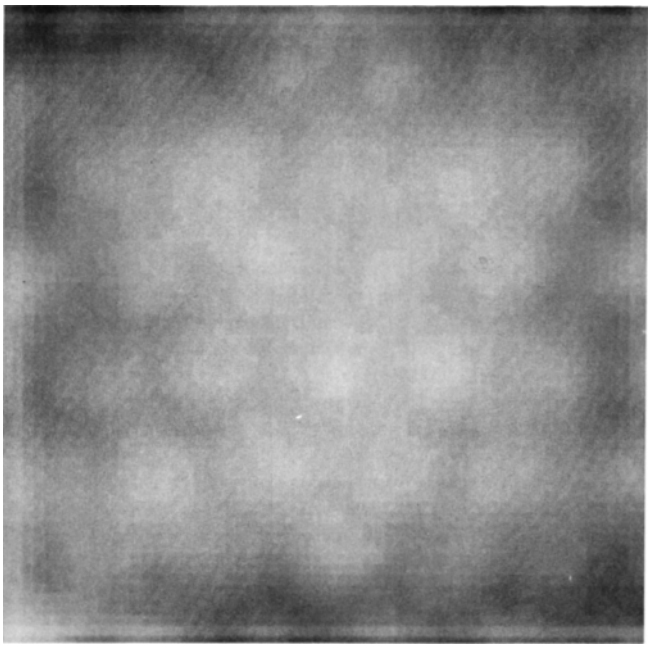

FIG. 3. Uniformity correction matrix acquired with thallium-201 and point-source scanner.

DISCUSSION

The point-source scanner reduces the need for a number of uniformity and bar phantoms to a single point source. The scanner may also reduce the absorbed dose to the personnel involved in filling the different phantoms with activity solutions, since only one point source needs to be handled. No large uniformity phantoms need to be filled or handled. By using the same lead shields and canisters that the radiation sources are shipped in, the handling of the sources is minimized.

The point-source scanner is used in our department for weekly collections of uniformity matrices for ^{201}Tl and with the gamma camera equipped with the low-energy dynamic collimator. This matrix acquisition is started the evening before the tomographic myocardial studies are performed. No activity is lost for phantom preparations, since the canister shipped from the isotope supplier is used for both the scanning and the administration of activity to the patients.

When short-lived radionuclides are used for acquisition of uniformity matrices with high count rates and long collection times, the camera will be exposed to different count rates at the beginning and end of the scan. This could, perhaps, cause a lack of uniformity due to dead-time effects in the electronics of the camera. This phenomenon has earlier been described in connection with the Dynamic Line phantom (*4*). In this case, there was a lack of uniformity because the gamma camera (for round detector heads) was exposed to different lengths of the line source during the scan. When using the

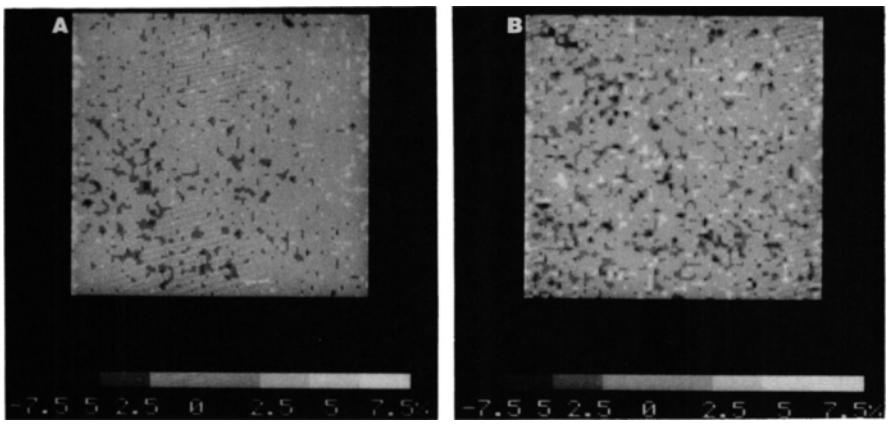

FIG. 4. Uniformity matrices obtained with (A) low-energy high sensitivity collimator and (B) low-energy, general purpose, parallel-hole collimator. These acquisitions were uniformity-corrected with a matrix acquired without collimator.

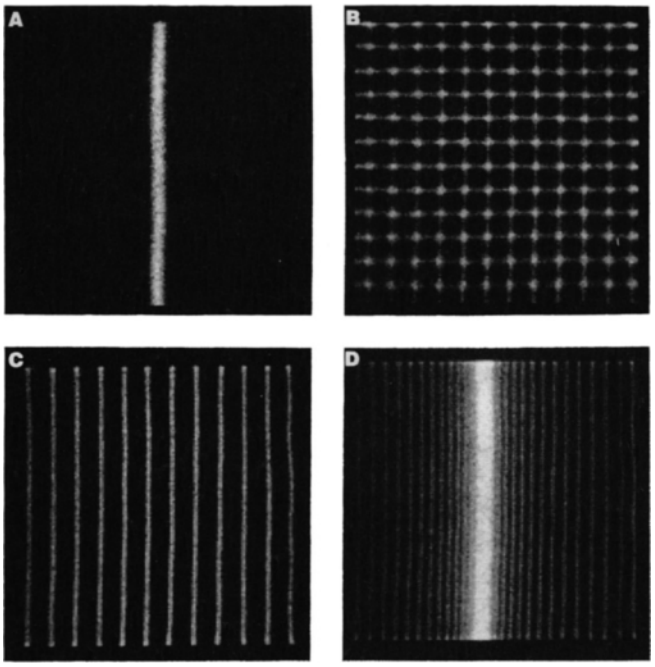

FIG. 5. Images of different line source patterns acquired with technetium-99m and point-source scanner. (A) line source; (B) linearity phantom; (C) parallel line equally spaced; (D) resolution phantom.

point-source scanner, however, collection of a uniformity matrix with 40 million counts takes only about 90 min for a count rate of 10 kcps in the beginning of the scan. This will diminish the effects of differing count rates, even for short-lived isotopes, such as technetium-99m.

One reason for using the point-source scanner to collect uniformity matrices is that the single scan paths do not perform like separable count-rate profiles in the obtained matrix. This could be achieved if each scanning path was separated with a distance much less than the resolution distance for the used point-source collimation and gamma camera. We have chosen a collimation opening of 3 mm at the point source and have chosen to separate the scanning paths by 3 mm.

For a 3 mm collimator, the resolution for a low-energy general purpose collimator and a modern gamma camera was about 7 mm. This showed that the radiation beam was somewhat divergent and that there were some scattered photons present from the perspex table, which worsened the resolution. The diameter of the point source at the place of the gamma camera collimator was also determined by placing an X-ray film in place of the collimator and measuring the blackening area. The diameter of the point source became 30 mm. When collecting uniformity matrices by using the point-source scanner, the errors caused by faults in the scanner are comparable to the faults caused by an uneven activity distribution for commercially available flood-field phantoms.

Parallel-line patterns are useful for judgement of the resolution and linearity of the gamma camera. The point-source scanner could be programmed to have a distance between the scanning paths that suits the particular camera being tested. This distance should be near or equal to the resolution distance of the camera system in order for the test to achieve an optimal sensitivity (*7*).

The point-source scanner may also be used for simulating different radionuclide distributions in various organs. This is possible since the amount of time that the point source is situated in each point can be varied. Thyroid, liver, and theoretically also skeleton activity distributions with different pathological conditions could be simulated by programming the computer. This could be of value when testing detectability or intra-observer variability.

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