The Line Resolution Pattern: A New Intrinsic Resolution Test Pattern for Nuclear Medicine

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Routine measurement of spatial resolution of a gamma camera is normally performed through the use of a four-quadrant bar phantom or one of several commercially available resolution phantoms. These phantoms all provide a qualitative index of system resolution with the inherent assumption that any change in intrinsic resolution would be apparent in the bar/hole pattern image. However on nine gamma cameras, comparison of intrinsic resolution determined from the line spread function by NEMA standards and from visual estimation of a four-quadrant bar phantom image showed poor correlation. The purpose of this study was to design and evaluate a new test pattern which would provide a more accurate estimate of resolution. We developed a line resolution phantom (LRP) which consisted of a 16-cm-diameter lead disk with a series of horizontal and vertical slits. This phantom permits a quantitative estimate of intrinsic resolution (to within 0.5 mm) from a visual examination of the LRP image. Evaluation on nine gamma cameras showed good agreement between results obtained with the LRP and measurement of resolution from the line spread function. The LRP is a simple and inexpensive test phantom which should find applications in quality control and acceptance testing.

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The spatial resolution of a gamma camera can be measured using either intrinsic or extrinsic techniques, each with its own advantages and disadvantages. Intrinsic measurement involves the removal of the collimator with the attendant risk to the sodium iodide crystal. Extrinsic measurement may show Moire patterns due to interplay of the bar or hole pattern and the lead septa of the collimator (*1,2*). This has always been a problem with medium or high energy collimators and, with the improvements in camera intrinsic resolution, it can also be a problem with low-energy collimators (*3*). Hence, under most circumstances, intrinsic measurement of resolution is preferrable to extrinsic measurement.

To evaluate the spatial resolution of a gamma camera, a wide variety of test patterns has been developed over the years. The most common test pattern is the four-quadrant bar phantom which accounts for over 80% of all resolution phantoms used in nuclear medicine (*4*). The concept inherent in the use of this or any bar or hole pattern is that at least one element produces a pattern that is just barely resolvable (*5*). Only under this condition can subtle changes in resolution be detected. Although this concept is inherent in the use of most resolution test patterns in nuclear medicine, to the best of our knowledge the correlation between the bar pattern image and system resolution as described by the full width half maximum (FWHM) has never been documented, other than in an anecdotal manner (*5,6*).

The purpose of this study was twofold: (a) to examine the relationship between a four-quadrant bar pattern image and system intrinsic resolution and (b) to design and evaluate a resolution test pattern that would permit rapid and easy quantitative assessment of intrinsic resolution without the need for computer analysis or comparison with previous test pattern images.

METHODS

Phantom Design and Evaluation

The design considerations for the line resolution phantom (LRP) were that it should (a) allow visual determination of intrinsic resolution to an accuracy of 0.5 mm in both x and y directions, (b) it should permit measurements of line spread function to allow determination of FWHM and FWTM, and (c) it should be usable on any type of gamma camera from the modern 50-60 cm field-of-view jumbo gamma cameras down to the 20-30 cm field-of-view mobile gamma cameras.

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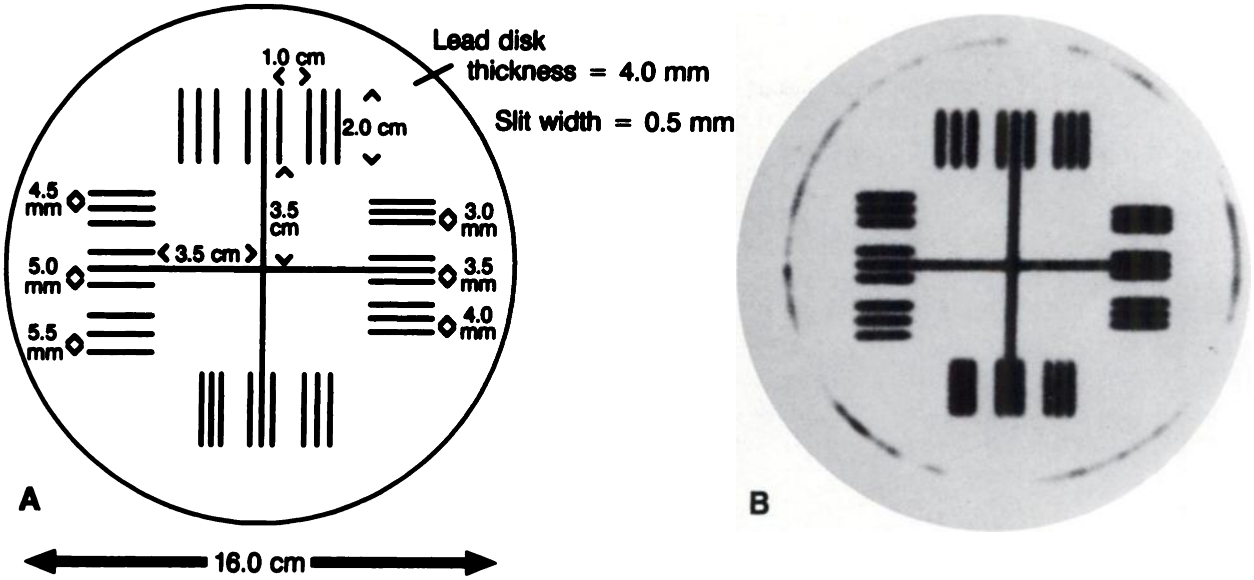

FIGURE 1
A: Schematic drawing of line resolution phantom. B: One million count image of line resolution phantom obtained using a large field-of-view gamma camera with a zoom factor of 2.0.

A schematic of the prototype LRP is shown in Figure 1A. The phantom was constructed from a 4-mm-thick lead disk on which a number of very fine slits were cut. These slits were 0.5 mm wide and were cut using a computer controlled high speed water jet to an accuracy of 0.1 mm (Jet Edge Ltd., Minneapolis, MN). The finished lead disk was then encased in two sheets of lucite (3 mm thick each) to protect the slits. The size of the spacing between slits (3.0 to 5.5 mm) was designed to encompass the range of intrinsic resolution available on the current and previous generation of gamma cameras (i.e., cameras 5-10 yr old). Future generations of gamma cameras may achieve intrinsic resolutions of 2-3 mm. In such cases, the phantom can be produced with 2.0 to 4.5 mm spacing between slits. The cost of producing this prototype was ~$200. The LRP had a weight of 2 kg, making it three to four times lighter than a standard four-quadrant bar phantom. The light weight of the LRP facilitates positioning and reduces the risk of damage to the crystal. The purpose of the two main cross-lines was to allow estimation of the line profile FWHM from an image stored on computer. These cross-lines were designed so that they each had two sections of length 3.5 cm which were free of interference from adjacent lines. This permitted the placement of 3-cm-wide profiles across the lines allowing estimation of the line profile FWHM according to NEMA protocol (*7*).

Evaluation of the LRP was performed on nine gamma cameras. The gamma camera collimator was removed and the LRP placed in the center of the field-of-view. A lead cape (1-mm lead equivalent) was placed around the pattern to shield the exposed crystal. A 2 mCi (74 MBq) technetium-99m point source was placed 100-200 cm from the camera face to give a count rate of ~10k cps. In all cases, images were acquired on computer into a 256 × 256 matrix with a zoom factor of 1.5-3.0 (depending upon field-of-view of the gamma camera) for a total of 1 million counts per image. On systems with analog formatters, images were simultaneously acquired on the formatter using a comparable zoom factor for 1 million counts per image. The intrinsic resolution of the gamma camera was determined from the computer image by taking profiles in the x and y direction through the cross lines. Profile width was 3.0 cm and the line profile FWHM in the x and y direction was calculated by linear interpolation of nearest neighboring pixels according to the NEMA protocol (*7*). The above acquisition parameters gave an effective pixel size of 0.6–0.7 mm and gave between 5–8 pixels over the profile FWHM. Previous investigators have shown that this is adequate for accurate measurement of FWHM using the NEMA method (*8*). Visual determination of resolution was obtained from the analog images (or from the computer image of digital systems) by noting the minimal resolvable line spacing in both the x and y directions.

For comparison with existing resolution test patterns, images were acquired of a four-quadrant bar phantom on all of the above systems. The bar phantom had line spacings of 4.0, 3.0, 2.5, and 2.0 mm. The bar phantom was imaged intrinsically using a 18.5 MBq (0.5 mCi) point source of ^{99m}Tc placed at four times the useful field-of-view diameter from the camera face. The bar phantom was imaged twice with the second image being obtained at an angle of 90° relative to the first image, thereby providing an indication of resolution in the x and y direction. It is generally agreed that the line profile FWHM is equal to approximately twice the minimal resolvable bar spacing (*5,6*). The bar phantom results were multiplied by this factor to allow comparison with the line profile FWHM.

RESULTS

Figure 1B shows an image of the LRP obtained with a zoom factor of 2.0 on a 40 cm field-of-view gamma camera. The 3.5-mm slots are visible in both directions, but are better seen in the x direction compared to the y direction. These results are in good agreement with the line profile FWHM values of 3.3 mm and 3.7 mm in the x and y direction, respectively.

Results were obtained from the nine gamma cameras in both x and y directions, giving 18 data points. Figure 2 plots the line profile FWHM against twice the minimal resolvable bar spacing obtained from the four-quadrant bar phantom. The 2.5-mm bar spacing was visible on images from seven of the nine gamma cameras, even though the line profile FWHM ranged from ~4.0-5.5 mm. Figure 3 plots the line profile FWHM against the minimum resolvable line spacing from the LRP. We found good agreement between intrinsic resolution and the visual estimation of minimum resolvable line spacing.

DISCUSSION

At the present time, there are at least six commercially available test phantoms that are designed to measure resolution and in some cases linearity of a gamma camera. The principal ones are the BRH test phantom (*9*), the parallel line equal spacing phantom (*10*), the Orthogonal hole phantom (*11*), the Hine Duley phantom, the Anger pie phantom (*12*), and the four-quadrant bar phantom (*10*). All these patterns provide a qualitative index of resolution. The primary reason for this is, that in all cases, the hole size or the slit width is of the order of 2-5 mm. This is comparable to the intrinsic resolution of a gamma camera. Hence, the image produced is a convolution of the gamma camera intrinsic resolution and the slit width or hole spacing. Small changes in intrinsic resolution would alter the modulation of the light and dark areas in the hole or bar pattern image. The consequence of this is that the same bar or hole spacing may still be discernible over a range of values of intrinsic resolution (Fig. 2). Correct use of these test phantoms then requires that all images be compared with a reference image. This reference image could be obtained during acceptance testing or when quantitative measurements of intrinsic resolution were being performed on the gamma camera.

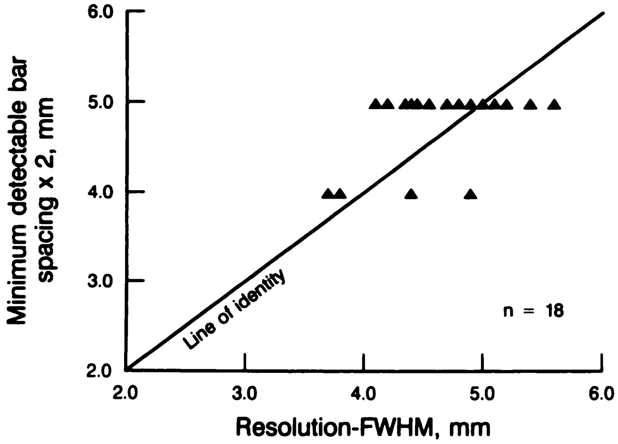

FIGURE 2
Relationship between the minimal detectable bar spacing of a four-quadrant bar phantom (× 2) and intrinsic resolution as determined by the full width half maximum of a line spread function. The line represents the line of identity.

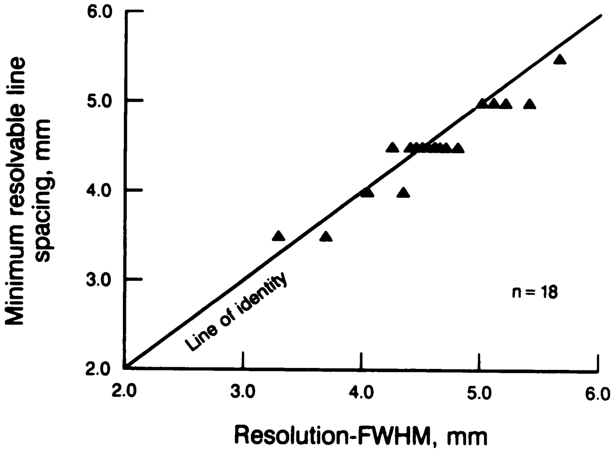

FIGURE 3
Plot of the minimum resolvable line spacing as determined from the line resolution phantom against the intrinsic resolution as determined by the full width half maximum of the line spread function for the nine gamma cameras evaluated. The line represents the line of identity.

In the design of the LRP, the slit width was reduced to 0.5 mm. This is sufficiently small so that the visibility of a series of lines is determined solely by the gamma camera's intrinsic resolution. Under these circumstances two narrow slits will only be visible if they are separated by a distance of at least the line profile FWHM. Hence with this phantom, a quantitative measurement of resolution can be obtained to an accuracy of 0.5 mm from a visual inspection of the image. This is confirmed by Figure 3 which shows good agreement between the line profile FWHM and the minimum resolvable line spacing. A further advantage of the LRP is that a more precise determination of intrinsic resolution can be obtained, if required, by analysis of the two cross slits from the computer image.

The LRP measurement is a quick, easy, and convenient test to perform that has several advantages over the NEMA line resolution phantom (*7*). It does not require the computer analysis and the precise alignment with the x and y axis necessary for the NEMA phantom. It is six times lighter than the NEMA phantom and poses less risk of damage to the sodium iodide crystal. Finally, the prototype LRP was 2–3 times less expensive than commercially available NEMA phantoms.

The main disadvantages of the LRP are that it only measures resolution over a small portion of the field of view and clearly provides no indication of system linearity. This problem is common to nearly all resolution test phantoms, with the possible exception of the PLES or Orthogonal hole phantoms. However, the bar and hole spacings of these phantoms must be matched to each gamma camera's intrinsic resolution and, therefore, they have a limited application in a department with multiple gamma cameras. As the field-of-view of modern gamma cameras increases year after year, it becomes more difficult to use one phantom to simultaneously determine resolution and linearity. In the context of quality control, it is probably not necessary to simultaneously measure resolution and linearity. It is generally accepted that intrinsic resolution is a very stable parameter of modern gamma cameras (*12*). When gross localized changes in intrinsic resolution do occur, they are often coupled to degradation in camera uniformity and are more readily detected by the daily flood image than by the measurement of resolution. For quality control purposes, measurement of resolution can be divorced from linearity measurements and performed on a less frequent basis approximately once a month (*13*). Gamma camera linearity, which is more closely linked to uniformity and requires more frequent evaluation than resolution (*14*) can then be measured on a weekly basis using a suitable phantom such as the PLES, BRH, or Orthogonal hole phantoms.

In conclusion, the LRP is a simple and inexpensive test phantom which provides a quantitative measurement of intrinsic resolution without the need for computer analysis or the technical know-how involved in performing line spread function measurements. For quality control, it can be used in place of test patterns that only assess resolution (e.g., four-quadrant bar phantom) and in conjunction with test patterns that primarily measure linearity.

REFERENCES

1. Bonte FJ, Graham KD, Dowdey JE. Image aberrations produced by multi channel collimators for a scintillation camera. *Radiology* 1971; 98:329–334.
2. Yeh EL. Distortion of bar phantom image by collimator. *J Nucl Med* 1979; 20:260–261.
3. Brown PH, Royal HD. Re: Distortion of bar phantom image by collimator [Letter]. *J Nucl Med* 1979; 20:1100–1101.
4. Joint NCDRH and State quality assurance surveys in nuclear medicine: Phase 1 scintillation cameras and dose calibrators. U. S. Dept. of Health and Human Services, HHS Publication FDA 83-8204, 1983.
5. Graham SL. Quality assurance of anger cameras. In: Rao DV, Chandra R, Graham MC, eds. *Physics of nuclear medicine: recent advances.* New York: American Institute of Physics, 1984: 68–82.
6. Computer Aided Scintillation Camera Acceptance Testing, AAPM Report No. 9, New York: American Institute of Physics, 1982: 30–34.
7. Performance measurements of scintillation cameras, Standard Publication/Nu 1-1986. Washington, D. C., National Electrical Manufacturers Association, 1986.
8. Raff U, Spitzer VM, Hendee WR. Practicality of NEMA performance specification measurements for user based acceptance testing and routine quality assurance. *J Nucl Med* 1984; 25:679–687.
9. Paras P, Hine GJ, Adams R. BRH test pattern for the evaluation of gamma camera performance. *J Nucl Med* 1981; 22:468–470.
10. Quality control for scintillation cameras. U. S. Dept. of Health, Education and Welfare, HEW Publications FDA 76-8046, 1976.
11. Hine GJ. An ortho test pattern for quality assurance of gamma cameras. Washington, D. C., Nuclear Associates Pamphlet No. 265K.
12. Anger HO. Testing the performance of scintillation cameras. University of California, Berkeley, Lawrence Berkeley Laboratory Report 2027, 1973.
13. Brookeman VA. Imaging instrumentation quality control. In: Hamilton DR, Herrera NE, Paras P, Rollo FD, MacIntyre WJ, eds. Quality assurance in nuclear medicine. U. S. Dept. of Health and Human Services, HHS Publication FDA 84-8224, 1984: 160–166.
14. Laird EE, Allen W, William ED. Gamma camera computer system quality control for conventional and tomographic use. In: Mould RF, ed. Quality control of nuclear medicine instrumentation. London: Hospital Physicists Association, 1983: 101–110.