map yielded similar results. Process of elimination pointed in the direction of the linearity correction map.

To determine if the linearity map was the problem source, bar pattern images in the X and Y direction were acquired (Fig. 1B and C). These images demonstrated marked nonlinearities. The observation that lines in the image appeared to jump over unit distances suggested the problem lay with the inability of the manufacturer's software to accurately track along a given bar pattern line. This makes logical sense: if a camera/crystal has poor intrinsic linearity, it is possible through a barrel/pincushion distortion to shift one line into close proximity with another. It is even possible to shift it into another line. If the software used to track the line source is relatively unsophisticated, the tracking routine may venture back and forth between adjacent physical lines. This would result in unit shift vectors that would give an image consistent with that seen in Figures 1B and 1C.

If the problem stemmed from an inability of the correction software to accurately track line source projections, the image acquisition must somehow separate further the line sources to yield an unequivocal tracking path. This can be done by either: (a) using a higher activity source and increasing the distance between the source and the camera face; or (b) tilting the camera head so that it is not perpendicular to the source. This will have the effect of lengthening the apparent width of the bars comprising the bar pattern, and shrinking the width of the openings. Such an effect is analogous to grid cutoff in diagnostic radiology exams. Tilting the camera head 5° from the perpendicular connecting the point source to the camera face resulted in linearity correction maps that imaged the bar patterns without distortion. Subsequent uniformity images had no artifacts (Fig. 1D).

The artifact's appearance on the flood image (Fig. 1A) occurs only at those points where the linearity algorithm fails to track correction in *both* X and Y directions. Such an observation may require some explanation. From Figure 1B, it is apparent that vertical nonlinearities exist in X across the entire right half of the image. Similarly, from Figure 1C, a horizontal nonlinearity exists in Y across the upper portion of the image. The artifact, however, manifests itself only in the upper right hand quadrant where X and Y nonlinearities coincide. Because adjacent areas of a flood image are equivalent to within Poisson counting statistics, the shifting of counts from one region to an adjacent region will not, in-and-of itself, result in the artifact's appearance. The Harlequin artifact will appear only at those points where counts are added/subtracted in tandem, allowing for a net gain/deficit. These points occur only where the tracking algorithm breaks down in both the X and Y directions. These images point up the need for performing bar pattern images in addition to field floods if linearity correction devices (hardware or software) can be updated in the field.

In summary, the "Harlequin" linearity artifact appears to be the result of software unable to track line activity projections under all conditions. Note that the software and hardware necessarily maintain a complicated symbiotic relationship. When the camera was initially set up, linearity and uniformity images were artifact free and met the manufacturer's specifications. The linearity correction algorithm could correctly track bar pattern projections. In the 6-mo interim, X and Y gains may have drifted. This could effectively shrink the apparent image in memory such that the linearity correction algorithm would no longer track: individual lines would be run together so as to confuse the correction algorithm. Thus a hardware problem might manifest itself as a software problem. The fact that these conditions arose within the boundaries of the manufacturer's own written protocol for reloading correction maps is of some concern.

Software by its nature is designed for a certain operating range. A programmer must make some assumptions about the input data set. This effectively defines the limits over which an algorithm will function correctly. The programmer usually has an idea of the range of input data sets that the algorithm must be able to follow. If this range proves to be too limited to encompass the input data sets generated in the field, then the software must necessarily fail to accomplish its purpose.

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

TO THE EDITOR: I was interested to read the paper by O'Connor and Oswald (*1*) but I would like to make one correction. Contrary to what they say, in 1985 Mr. Kasals and myself published a paper showing how bar pattern detectability was dependent upon the full width at half maximum height (FWHM) (*2*). For the range of values of FWHM that we studied, from 8mm to 18mm, there was a linear relationship of the form:

$$\text{FWHM} = 1.42\ (\text{bar width}) + 1.65.$$

The value for slope and intercept are for 4-mm-thick bars, a count density of 2270 cm^{-2} and images presented on transparency film. These values varied slightly with choice of recording medium and bar thickness.

A simple linear relationship has also been reported for the BRH phantom (*3*) where

$$\text{FWHM} = 1.75\ (\text{minimum resolvable hole spacing}).$$

The criticism that the authors are really making is whether the quadrant phantom is useful for measuring intrinsic resolution; bar phantoms, in general, are useful for giving a quick assessment of spatial resolution.

If it is assumed that the relationship we found between bar spacing and FWHM holds down to the size of bars used in this particular quadrant phantom, then the 3-mm bars would only fail to be seen if the FWHM exceeded 5.9 mm. In other words, for the intrinsic resolution measurements made in the reported experiment only the 2- and 2.5-mm-wide bars are of value. Clearly the design of the quadrant bar phantom is not satisfactory.

The advantage of the line resolution pattern (LRP) over a bar pattern is that as FWHM is equal to minimum resolvable line separation then a quantitative measure of spatial resolution can be made easily. If that is indeed the case, and one is always concerned that other factors such as the way in which the image is displayed might have an effect, then the LRP would be useful for centers that do not have access to data processing facilities.

The place of such measurements of intrinsic spatial resolution in a regular quality control procedure should be addressed rather more closely than has been done by O'Connor and Oswald. As changes in intrinsic resolution are likely to be local, the LRP is not going to be an effective way of detecting them. The small size of the phantom and the even smaller area over which measurements are made, make measurements of resolution at many points in the camera's field of view impractical. Indeed there may be a case for making the pattern larger and the lines longer, although it will then be heavier than a similar size of bar phantom.

In our experience the flood images is probably the most useful Q.C. measurement and while the cause of nonuniformaties may be nonspecific, including changes in intrinsic resolution, it can provide a simple, sensitive and global measure of detector performance (*4*).

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REPLY: We read with interest the paper of Kasal and Sharp (*1*) and noted the excellent correlation they obtained between gamma camera resolution as measured by the full width at half maximum (FWHM) and the minimum resolvable bar width of a bar phantom. While these results appear at odds with those obtained in our paper (*2*), a closer examination of both papers shows no discrepancy. The study of Kasal and Sharp was performed extrinsically with varying thickness of scattering medium (5–20 cm) placed between the collimator and the bar pattern. They evaluated resolution over a range of FWHM of 8–18 mm. Their equation, quoted above, indicates that a change of ~3 mm in extrinsic FWHM is required before there is a discernible change (>1 mm) in the minimum resolvable bar width. In our opinion, this insensitivity to changes in system FWHM is unacceptably large. Intrinsically we found a smaller but similar insensitivity of the bar pattern to changes in resolution. Thus while the bar pattern is adequate for very coarse measurements of extrinsic resolution, it is clearly unsuitable for the detection of smaller (<2 mm) but highly significant changes in intrinsic resolution.

With regard to their comments vis-a-vis the design of the line resolution pattern (LRP), we would like to point out that the LRP is not a bar phantom. It was designed to take advantage of the fact that two Gaussian profiles can only be resolved if they are separated by a distance greater than their FWHM. To achieve such profiles, the slit width of the LRP was set to 0.5 mm, which effectively makes it mathematically equivalent to an infintely narrow slit when compared with the FWHM of modern gamma cameras (>3 mm). Hence, with regard to the LRP, the equation and comments of Kasal and Sharp are not applicable.

As we stated in our paper, the main disadvantage of the LRP is that it only measures resolution over a small portion of the field of view. However, we believe that one quantitative measurement of resolution over a limited area is better than an insensitive measurement technique over the entire detector area. As to the place of measurement of intrinsic resolution in routine quality control, we would agree with Dr. Sharp that measurement of uniformity is clearly the most sensitive indicator of detector performance. In our Institution, measurement of intrinsic resolution has been relegated to third place after measurement of image uniformity and image linearity as a useful indicator of gamma camera performance.

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