The "Harlequin" Artifact: Cause and Correction

TO THE EDITOR: Linearity artifacts have primarily been dealt with in the context of their impact on SPECT imaging. Colsher et al. (*1,2*) concluded from simulation data that nonlinearities as small as 0.5 mm could give rise to circular ring artifacts in SPECT reconstructions. Johnson et al. (*3*) documented that changes of this magnitude and greater can occur in scintillation cameras as the camera head is rotated through 180°. Very little has been written, however, concerning the effect of linearity artifacts on planar imaging. This letter documents the occurrence of an artifact arising from an incorrect linearity map. It further presents evidence that the problem lies with the software that analyzes the raw data to arrive at linearity shift vectors.

Manufacturer's recommendations called for updating the linearity correction map at 6-mo intervals. The procedure for doing this involves the acquisition of a parallel bar pattern image from a point source of activity suspended 2.5 m in front of the crystal face. One image is acquired for the X linearity map, the bar pattern then being rotated 90° for the Y map.

After updating the linearity, energy and uniformity maps, acquisition of a uniformity flood resulted in the image pictured in Fig. 1A. The artifact's appearance—regular geometric patterns in the form of diamonds and squares—calls to mind the suit of clothes worn by a Harlequin, hence the appellation for the artifact. Acquisition of a flood image with all correction maps disabled resulted in the appearance of photomultiplier tubes (the consequence of no energy correction); otherwise, the image was unremarkable. Absence of the "Harlequin" artifact indicated its cause was related to one of the correction maps.

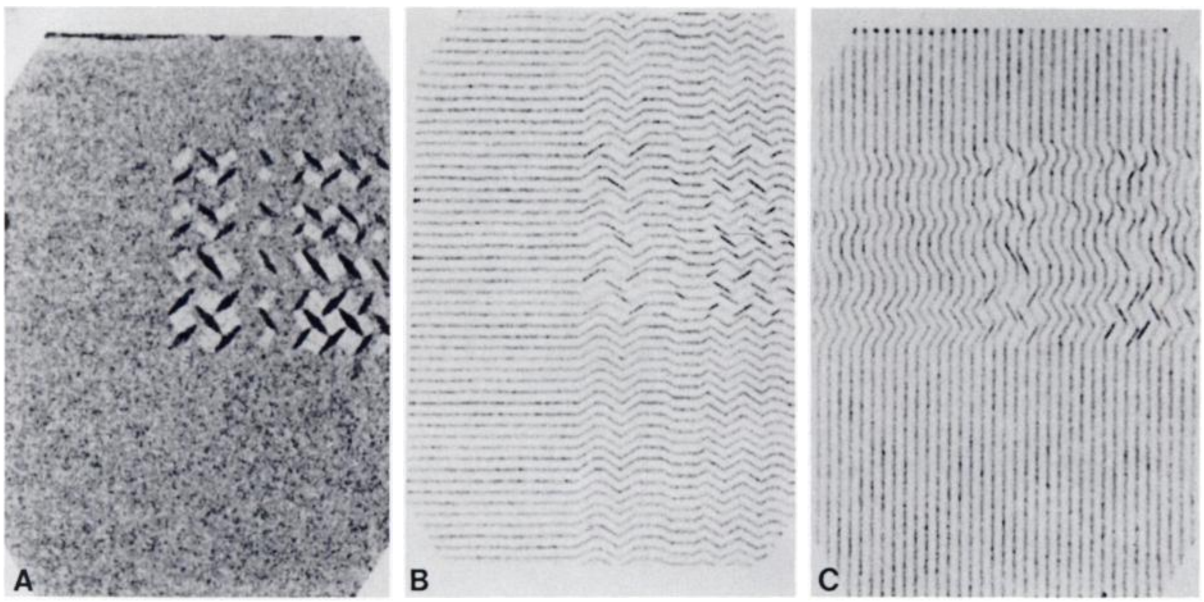

FIGURE 1
A: The "Harlequin" artifact. B: X Linearity image with vertical nonlinearity across the entire right half of the image. C: Y Linearity image with horizontal nonlinearity across the upper portion of the image. D: Uniformity image, after successful tracking of the linearity software.

A new uniformity map was acquired next, followed by a flood image. The image exhibited the Harlequin artifact, and closely resembled Fig. 1A. This indicates the uniformity map was not the culprit. Acquisition of a new energy correction 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.

References

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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

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