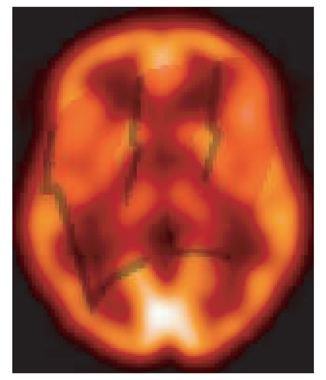
Multi-Scanner PET 2D/3D Comparison with Cerebral FDG.



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Human Subject Data

Methods

Under independent studies [1], human subjects were scanned in 2D and 3D mode on two different scanners [2,3]. The protocols were typical of cerebral FDG studies and were similar enough to warrant the comparisons made in this work. The image pairs were inspected for interscan motion; none could be detected to within half of a reconstructed pixel dimension (0.9 - 2.1 mm).

A modified regression analysis was performed to compare 2D and 3D modes for each scanner. For each subject's rate-constant data, every 3D value was plotted as a function of the corresponding 2D pixel (see example in Figure 1), and the values from each scan pair were placed into 20 bins, with approximately the same number of values in each bin. The division between each bin is perpendicular to the line of identity, and is indicated by a different color. The Center-of-Mass (CoM) of each bin was then calculated. A plot of the regression line for each bin (not shown) would overlay the corresponding CoM, and would be tangent to the line connecting the CoM points. The distance (dCoM) from each CoM point to the line of identity is a measure of the mismatch between the two data sets in that bin (see examples in Figure 2). The CoM is above the line of identity where the 3D pixel values are higher than their corresponding 2D values, and below the line of identity where 3D values are less than corresponding 2D values. The average of each CoM in each bin was then calculated for all 6 (12) scan pairs for the ECAT HR+ (GE/Advance), shown by the heavy black line and squares in Figures 2.

Due to the nature of the human subject data, which was acquired as part of a seperate larger investigation, we were unable to obtain a matching set of 2D/3D human FDG data after the GE Advance's detector modules were refurbished.

Results

It is immediately apparent that the ECAT/HR+ has a very good correlation between 2D and 3D modes through the entire range of values, whereas the GE/Advance has an increasingly worse correlation for higher values. In bins 18-20, which contain most of the pixels of interest for hot-spots or areas of high uptake, there is a 20-25% discrepancy between 2D and 3D modes. We found this effect to be worse for 3D GE/Advance data reconstructed with an axial ramp filter than for an axial Hanning filter [4]. These observations apply to both the rate-constant data as well as to the original concentration data (mCi/cc, not shown)

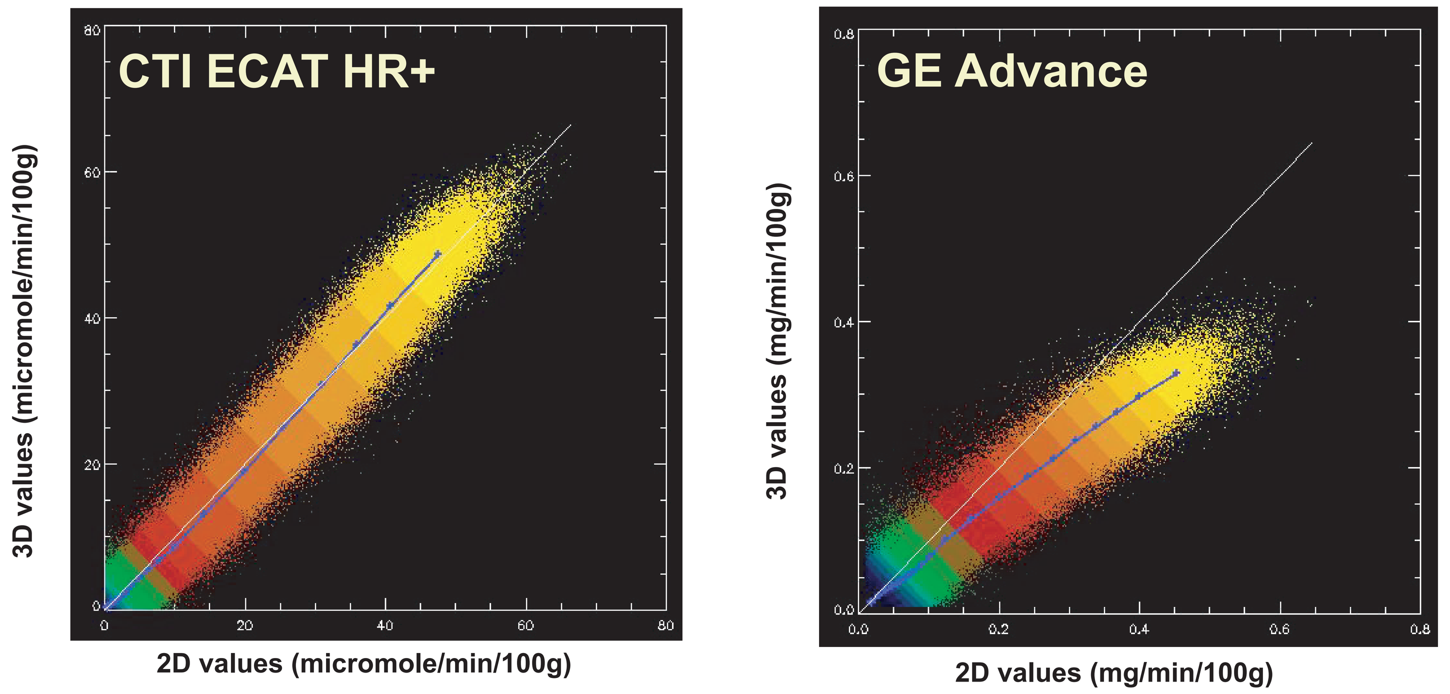


Figure 1. Scatter-plots of 2D vs. 3D values for the CTI ECAT HR+ (left) and the GE Advance (right). These images show typical plots for a single subject acquired under the respective human FDG protocol for each scanner. The GE Advance data were acquired prior to refurbishing the scanner with new detector modules; the comparison improved markedly after this upgrade (see Phantom Results). In the example shown above, hotspots on the GE Advance would tend to have a value that is too low by as much as 20%.

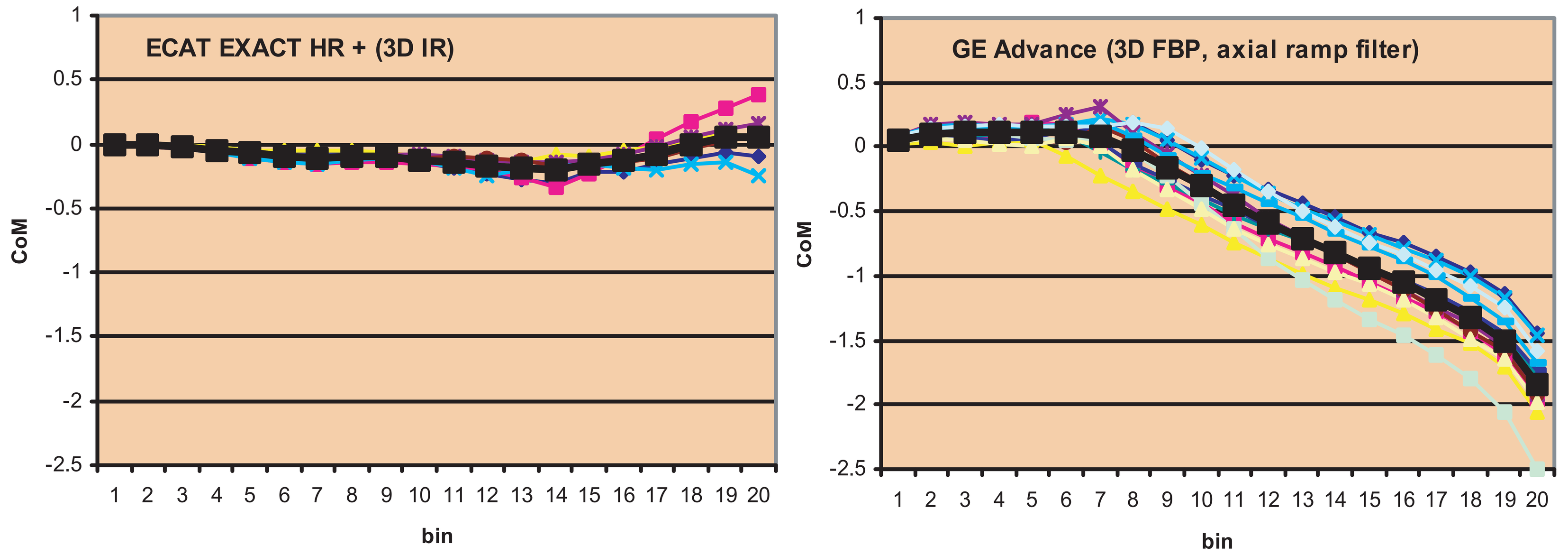


Figure 2. Plots of Center-of-Mass (CoM) for each subject for ECAT HR+ (6 subjects, left) and GE Advance (12 subjects, right) both in units of mg/min/100g. The dark black line and squares show the average of all subjects for each scanner.

Abstract

A comparison was made of 2D and 3D FDG cerebral PET scans acquired on human subjects on two different PET scanners, a CTI ECAT HR+ and a GE Advance. The two scan protocols were part of independent studies and involved a 30 (20) minute 2D scan, a 10 (5) minute transmission scan after (before) injection, and a 10 (10) minute 3D scan for the Advance (HR+). Image reconstruction used each vendor's standard recommendations. The HR+ showed good correlation between 2D and 3D modes, whereas the Advance systematically showed up to a 20% difference between modes, with larger discrepencies for higher pixel values. However, after a major upgrade to the GE/Advance that included replacing all of the detector units, a marked improvement in the 3D quantitative accuracy was noted.

A head-sized phantom containing a warm background and various sizes of hot and cool spheres (9, 17, 22mm) was scanned in both scanners. The concentration (0.5 - 0.8 microCi/ml) and volume (~3 liters) were designed to mimic a typical cerebral FDG scan, and a range of scan durations (1-30 minutes) were acquired to span the range of most FDG protocols. The correlation between 2D and 3D modes showed a similar pattern for each scanner as for the human data. However, the Advance showed somewhat better reliability and slightly better accuracy for recovering activity within the small spheres in 3D mode.

The GE/Advance was recently refurbished with new detector modules and reinstalled at a new location. Phantom work performed after the reinstallation indicates a markedly better correlation between 2D and 3D values, and supports most (but not all) of the earlier results obtained with the human subject data. These human and phantom data suggest that 3D mode can yield similar activation patterns to 2D with a shorter imaging time, but investigation of the results obtained for any specific scanner and task are needed.

Discussion

The human subject data show the state-of-the-art for cerebral FDG scans in the mid-late 1990's. The CTI ECAT HR+, acquired in 1999, shows a relatively small discrepency between 2D and 3D modes. Phantom tests show demonstrate little or no change since then.

The GE Advance data, acquired in 1996, shows a larger discrepency. Some of the difference is due to the choice of reconstruction algorithm and parameters; there is a factor of ~2 difference in 3D hotspot values depending on whether an axial Hanning or ramp filter is used. Since the detectors were replaced, there has been a noticeable improvement in congruency between 2D and 3D values, although there is still a significant difference especially for higher values. The standard manufacturer's software does not support an iterative 3D reconstruction on the GE Advance; when this is implemented, there may be better congruence between 2D and 3D modes.

Conclusions

The ECAT EXACT HR+ showed good correlation between 2D and 3D modes for human cerebral FDG data, whereas we found differences as great as 20% in the GE Advance, especially for higher values or hot-spots. Hardware and software upgrades to the Advance after the FDG data were acquired have reduced this discrepancy, as evidenced by recent phantom work. Furthermore, 3D data acquired on a GE Advance prior to the detector block replacement should be interpreted with some caution, particularly where using precise quantitative values is important.

References

[1] Hochachka PW, et al., Am. J. Physiol., 46:R314-319, 1999.
[2] Lewellen T, et al., IEEE Trans. Nucl. Sci., 42:1051-1057, 1995.
[3] Brix et al., J. Nucl. Med., 38:1614-1623, 1997.
[4] Oakes TR et al., IEEE TNS 47(3):1233-1241, 2000.

Phantom data

Methods

We scanned the same phantom under similar conditions in each of the two scanners in 2D and 3D mode. The phantom contained cool and hot spheres of various sizes in a warm background, as indicated in the image at right (Figure 3).

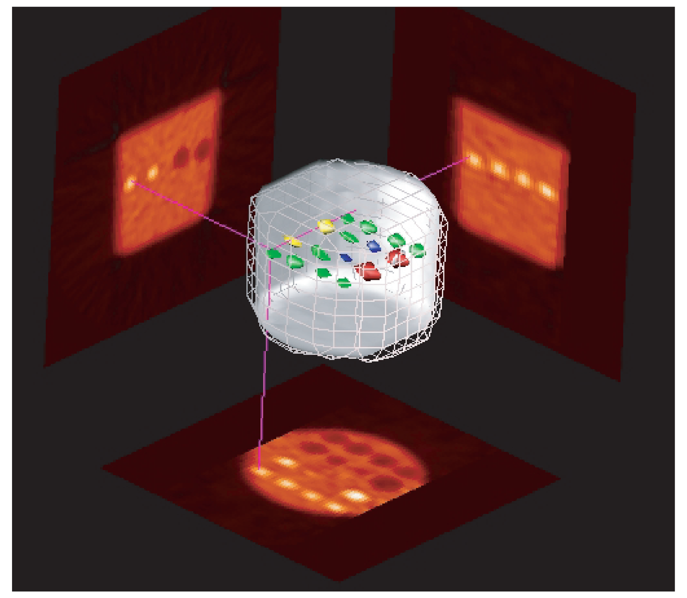
The phantom's radioactive concentration (0.5 to 0.8 mCi/ml) and volume (2950 ml) were designed to simulate a [^{18}F]-FDG PET scan of a human head. The phantom was a slightly tapered cylinder (15.0 cm diameter in the center, 15.5 cm height) resting on one of its flat sides. It contained 8 pairs of hollow plastic spheres. Four pairs (22, 17, 9, 17 mm ID) were mounted on thin wire 2cm from the midline; one sphere in each pair was injected with a nominal concentration of half of the warm background (cool-spots), and the other sphere in the pair contained twice the warm background (hot-spots). Four additional pairs of spheres (all 17 mm ID) were positioned lateral to these spheres and away from the walls.

A 2D dynamic series of 5 scans was acquired with time durations of 30, 15, 5, 2, and 1 minutes, followed by the same series in 3D, followed by a 20 minute transmission scan. The objective was to cover the range of total counts typical of most cerebral FDG protocols; the lower duration frames were included to yield information about lower count rate situations.

The vendors' approaches were used for calibration, except on the GE Advance a solid ^{68}Ge phantom was used instead of an aqueous ^{18}F phantom. The standard software from each manufacturer was used for the normalization, scatter correction, attenuation correction, and for reconstruction, as follows:

2D GE Advance: FBP, 20cm FOV, 128x128, 4.6 mm Hanning filter
2D ECAT HR+: FBP, 20cm FOV, 128x128, 4.0 mm Hanning filter
3D GE Advance: Kinahan-Rogers FBP, 20cm FOV, 128x128, radial 4.6mm Hanning filter, axial 8.5 mm ramp filter
3D ECAT HR+: IR, 20cm FOV, 128x128, 3 iterations, 8 subsets, no axial filter.

Figure 3.



Results

The CoM for each bin, derived identically as for the human data, is shown in Figure 4. The ECAT/HR+ shows a good correlation across most of the bins, while the GE/Advance shows a poorer correlation for larger values, especially for scans performed prior to the Novenber 2000 detector upgrade. This upgrade to the Advance involved a complete refurbishment of all detector crystals, and the scanner was then reinstalled in a new location; there is now a markedly better correlation between 2D and 3D values for the spherical phantom. Interestingly, a 3D axial ramp filter improves the correlation in the pre-upgrade data, which is in contrast to the human data where an axial Hanning filter yielded a better correlation.

ROIs were drawn in each plane containing a sphere, and each ROI volume matched the true volume of its sphere. The GE/Advance showed a slightly better recovery of activity levels in the spheres (not shown), and also showed a lower standard deviation across the 6 pairs of 17mm spheres as demonstrated in Figures 5. The GE/Advance shows a similar standard deviation between 2D and 3D for time frames from 5-30 minutes, corresponding to typical FDG acquisition times. For very short frames, the standard deviation for 2D mode rises sharply. The ECAT HR+ shows a similar standard deviation for all time frames within each ROI, but there is a difference between modes as well as sphere type. Part of this discrepancy may be due to errors in placing the rather small number (6) of volumetric ROIs.

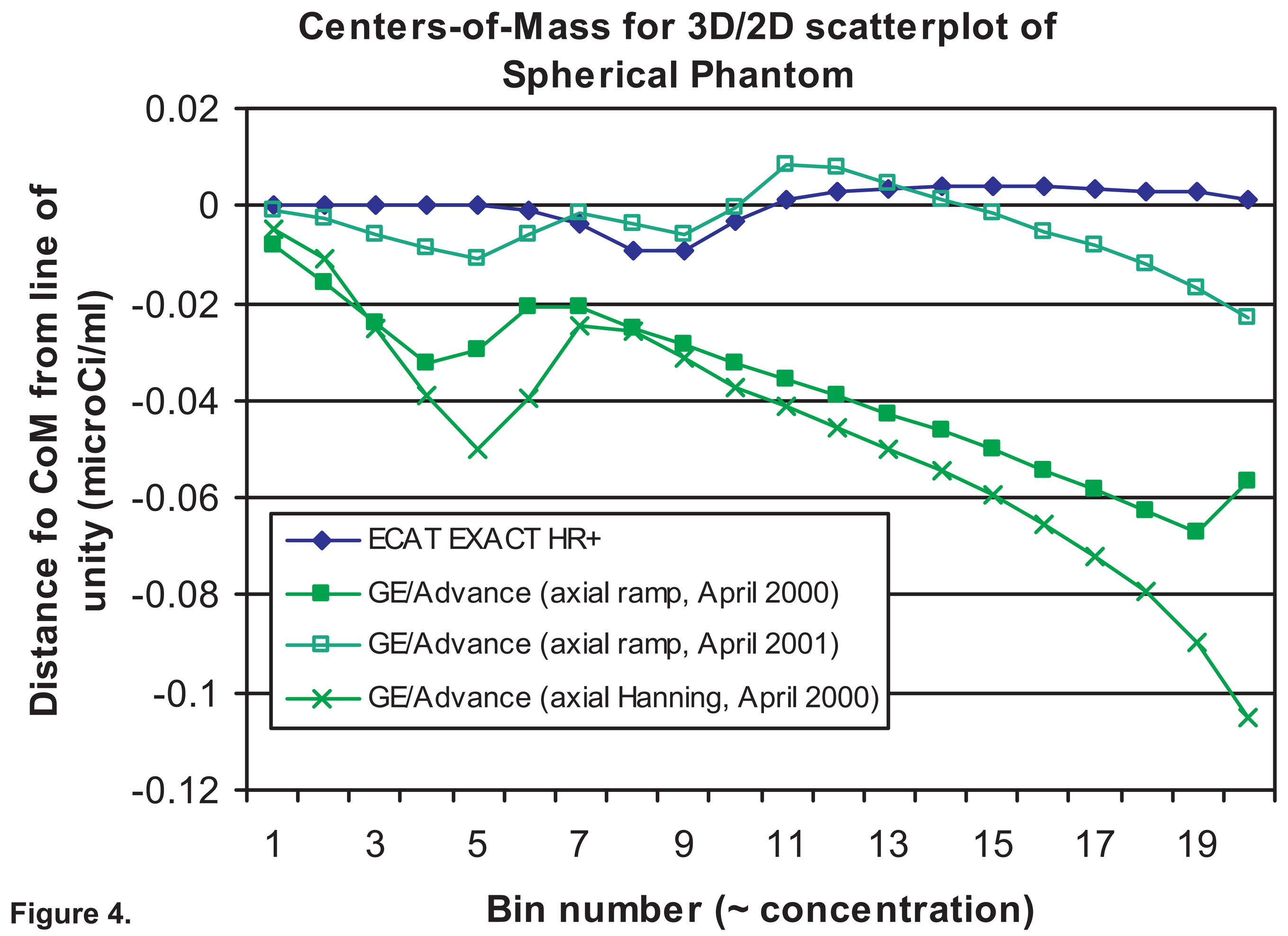


Figure 4.

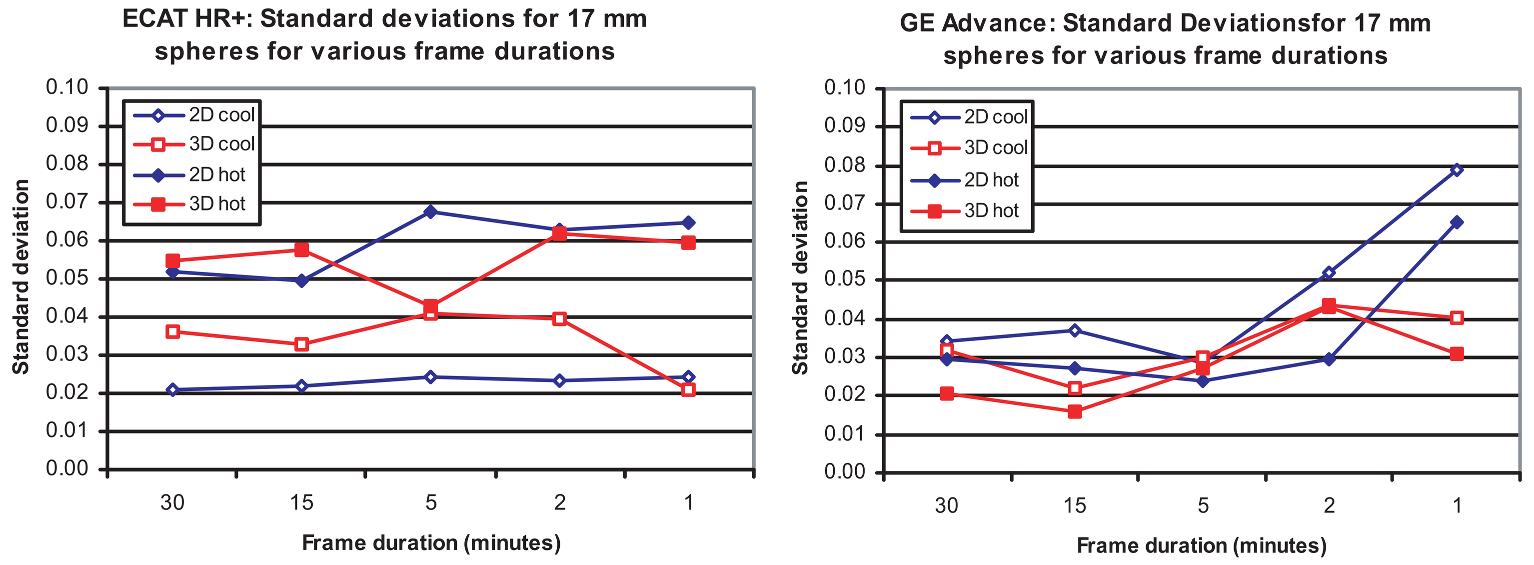
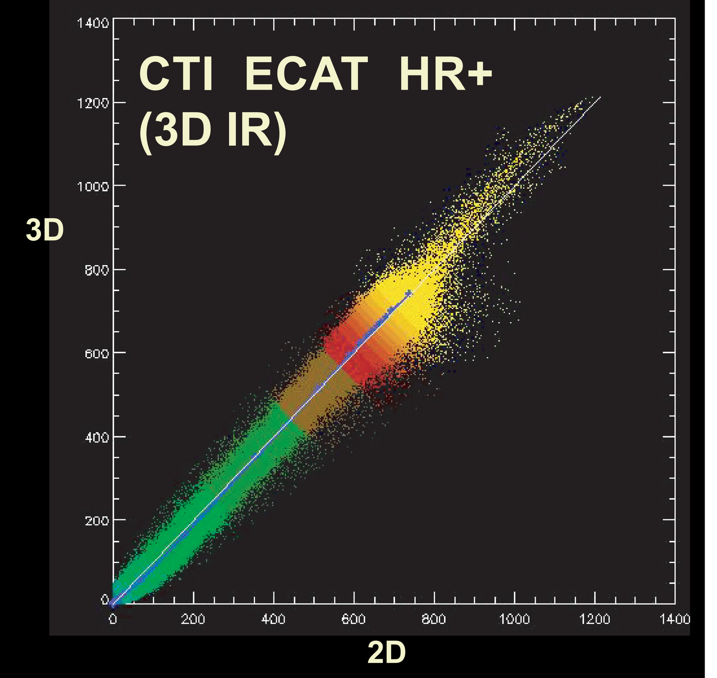


Figure 5.

These images show scatter-plots obtained using the hot/cool spherical phantom. The CTI ECAT HR+ demonstrates a good correlation between 2D and 3D, with only a slight bias toward larger 3D values in the very highest-valued voxels.

The GE/Advance data were acquired after the detector upgrade, and show there is still a fair amount of discrepency between 2D and 3D values. For hot-spots, 3D values are ~10% lower than 2D values.

An axial ramp filter yields moderately better results by the CoM metric, although the variance is higher.



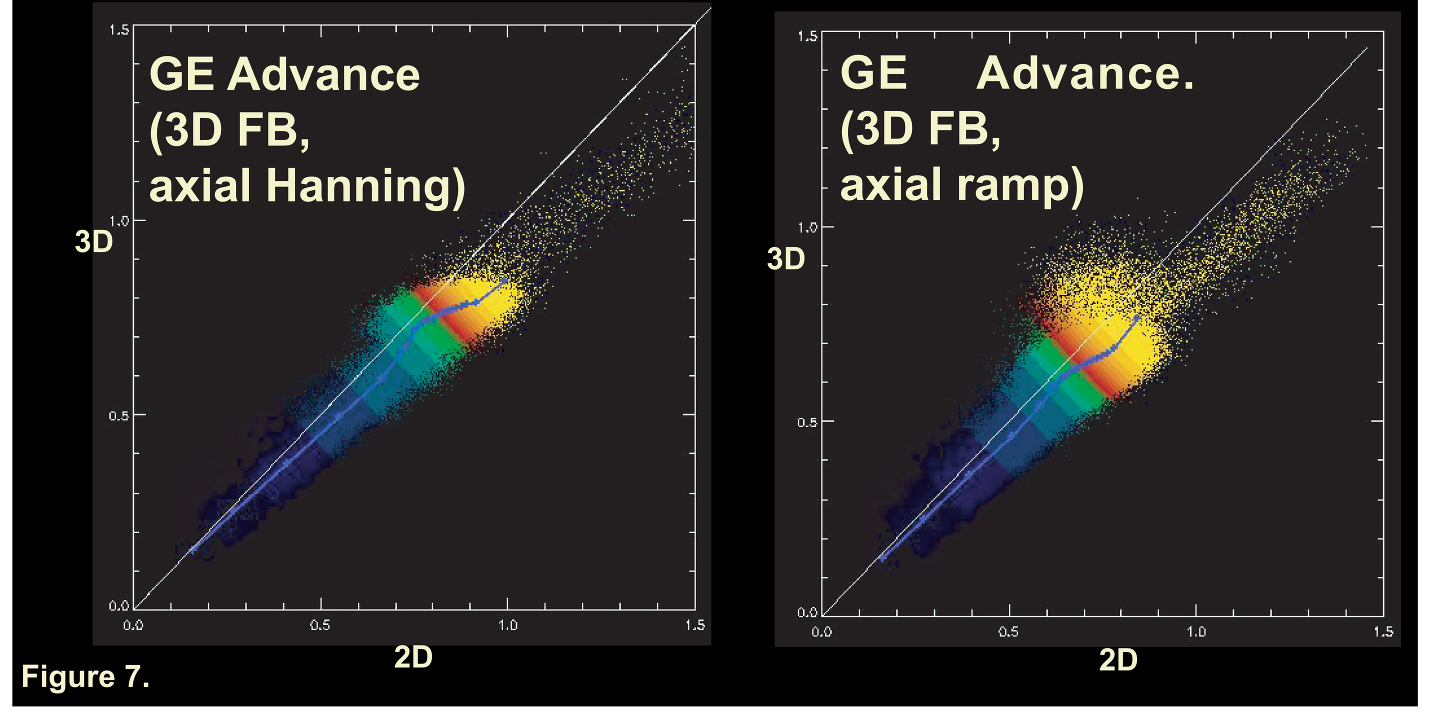


Figure 7.