

Accuracy of Center of Rotation Determination for SPECT Imaging

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The center of rotation (COR) determination used in a commercially available software package for SPECT imaging is shown to be significantly inaccurate. The effects of inaccurate COR determinations in several situations are demonstrated. A method to test software COR techniques and to replace them with a more accurate method is described.

There are many factors which contribute to the quality of single-photon emission computed tomography (SPECT) imaging. Of these none is more critical than the accurate determination of the center of rotation (COR) of reconstruction (1-9). Assuming that the gamma camera gantry is rotating around 360° and the camera head is directed toward a mechanically fixed axis of rotation (AOR), it is still highly critical that the location of this COR be accurately determined since small changes in COR may cause significant artifacts in the reconstructed images. This paper demonstrates the inaccuracy of one gamma camera-computer system in determining the COR for SPECT imaging and outlines a simple method for accurately determining the COR that can be used by any technologist to determine the accuracy of and/or replace the current method of COR determination being used.

MATERIALS AND METHODS

A clinical digital scintillation camera* interfaced to a nuclear medicine computer system† using currently available SPECT software‡ was evaluated. The COR was determined according to the manufacturer's specifications (CORMFG). In order to test the accuracy of the COR determination, the following data were acquired. A hematocrit capillary tube was filled with ~500 μCi (18.5 MBq) of $^{99\text{m}}\text{Tc}$ -sodium pertechnetate and aligned axially (Fig. 1). Thirty views (12° per view) over 360° were acquired. The line source study was then reconstructed repetitively using for the COR, 0.1 pixel increments from 1.5 pixels below to 1.5 pixels above CORMFG (31 reconstructions). A point spread function was calculated for each of the 31 reconstructions, and the COR_{ACTUAL} was defined as the inputted COR of the reconstruction with the smallest full width at half maximum (FWHM) (Fig. 2). For each test, CORMFG was obtained immediately before and after COR_{ACTUAL} to eliminate equipment variation as a possible cause for any difference between CORMFG and COR-

ACTUAL. In order to eliminate collimator hole angle misalignment as a cause of error, the COR_{ACTUAL} had been calculated from 15 different points across the field of view, and COR_{ACTUAL} did not vary by more than 0.1 pixels when calculated from any of these locations (1-3).

The following tests were performed to evaluate the accuracy and reproducibility of COR determination by one gamma camera-computer system and to develop a method that could be used to accurately determine COR for any system.

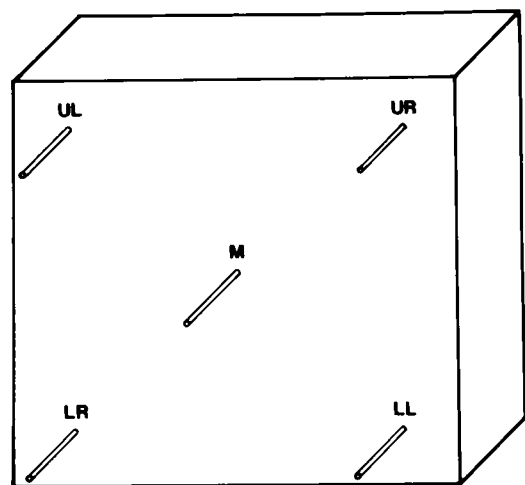
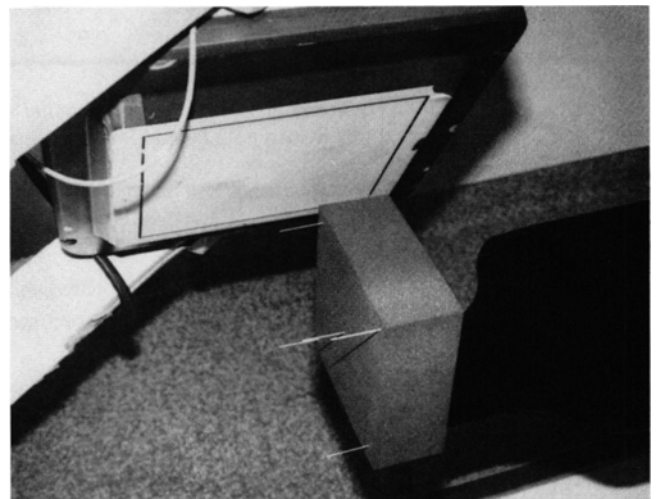


Fig. 1. Five hematocrit capillary tubes are positioned for COR acquisition. For routine daily COR_{ACTUAL} determination the center tube (M) is used. The tubes are aligned approximately parallel to the axis of rotation of the camera gantry. UL = upper left, UR = upper right, LL = lower left, LR = lower right, and M = middle.

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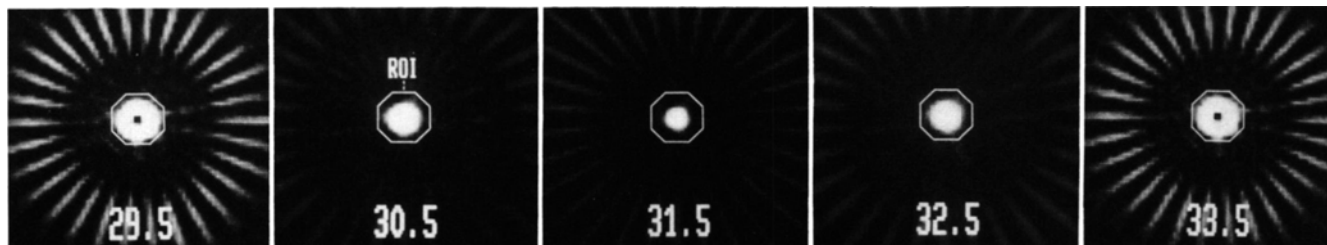


Fig. 2. A method to determine the image with the smallest FWHM. A series of reconstructions in which CORACTUAL was 31.5. The ROI in image 29.5 is used to locate CORACTUAL. The image with the most counts contained in this ROI is the image with the smallest FWHM and represents CORACTUAL (= 31.5).

TABLE 1. Comparison of CORMFG and CORACTUAL

Item	CORMFG		Pixel Size (mm)	Error		
	(Pre)	CORACTUAL (Post)		Pixels	mm	
64 × 64 Word No Zoom	32.1	31.6	32.1	5.99	0.5	3.0
64 × 64 Word 1.48 Zoom	31.3	30.8	31.4	4.05	0.5	2.0
128 × 128 Word No Zoom	63.7	62.6	63.9	3.06	1.2	3.7
128 × 128 Word 1.48 Zoom	62.0	61.1	62.0	1.99	0.9	1.8

Note: Results are the location of the COR in pixels.
 CORMFG = Center of rotation as determined by the manufacturer's specifications. CORMFG was determined both before (Pre) and after (Post) CORACTUAL.
 CORACTUAL = Center of rotation determined using hematocrit capillary tubes (Fig. 1).

1. A one time evaluation of COR for 64 × 64 word, no zoom; 64 × 64 word, 1.48 zoom; 128 × 128 word, no zoom; 128 × 128 word, 1.48 zoom (Table 1).
2. Two weeks (10 work days) of daily evaluation of COR for 64 × 64 word, no zoom (Table 2).
3. A one time evaluation of COR for 128 × 128 word, no zoom, in which five capillary tubes were aligned axially, one centrally, and each of the others 10 cm from the center (Fig. 1 and Table 3).
4. A 128 × 128 word, no zoom, 120 image/360°, 800K/image acquisition of a SPECT phantom§ (hot bars are cold background (BKG) and cold bars are hot BKG) was reconstructed using a series of COR inputs above and below CORACTUAL to evaluate the effect of an erroneous COR determination on resolution (Fig. 3).

A useful acquisition and processing protocol for the determination of CORACTUAL is presented in the Appendix.

RESULTS

Test results indicated that location of the capillary tube was not critical for CORACTUAL determination as long as the collimator had been pretested and was acceptable for uniformity of COR measurements over the entire field of view (1) (Table 3). It has been suggested that the capillary tube should not be placed exactly at the axis of rotation (AOR) as depicted

TABLE 2. Daily COR Testing 64 × 64 Word, No Zoom

Day	CORMFG	CORACTUAL	Error	
			Pixels	mm
1	32.1	31.5	0.6	3.6
2	31.9	31.5	0.4	2.4
3	31.5	31.6	0.1	0.6
4	32.0	31.4	0.6	3.6
5	31.5	31.5	0	0
8	31.4	31.4	0	0
9	31.4	31.6	0.2	1.2
10	31.5	31.3	0.2	1.2
11	32.4	31.4	1.0	6.0
12	31.4	31.5	0.1	0.6

Note: Pixel size each day was 5.99 mm.

TABLE 3. CORACTUAL Determination from Five Different Locations

CORMFG	59.2
CORACTUAL Center	59.6
Quadrant	
1 (UL)	59.6
2 (UR)	59.6
3 (LL)	59.6
4 (LR)	59.6

UL = upper left; UR = upper right; LL = lower left; and LR = lower right.

in Fig. 4 but somewhat off center for CORACTUAL determination (5). The comparison of CORMFG and CORACTUAL for a variety of acquisition matrices and zooms resulted in a deviation of CORMFG from CORACTUAL of as much as 3.7 mm (Table 1), and during the daily testing at 64 × 64 word, no zoom (commonly used setup parameters), the variance was as great as 6.0 mm (Table 2).

When a SPECT phantom was reconstructed using various CORs above and below CORACTUAL (Fig. 3), loss of resolution was most noted at depth (near the center of the phantom) with significant degradation noted even when the inputted COR was only 0.5 pixels (128 × 128 word) (1.5 mm) from CORACTUAL. The reconstructions using inputted CORs of pixels 60.5 and 64.5 each represent a deviation 6.1 mm from CORACTUAL, and the loss of resolution in these images was severe (Fig. 3).

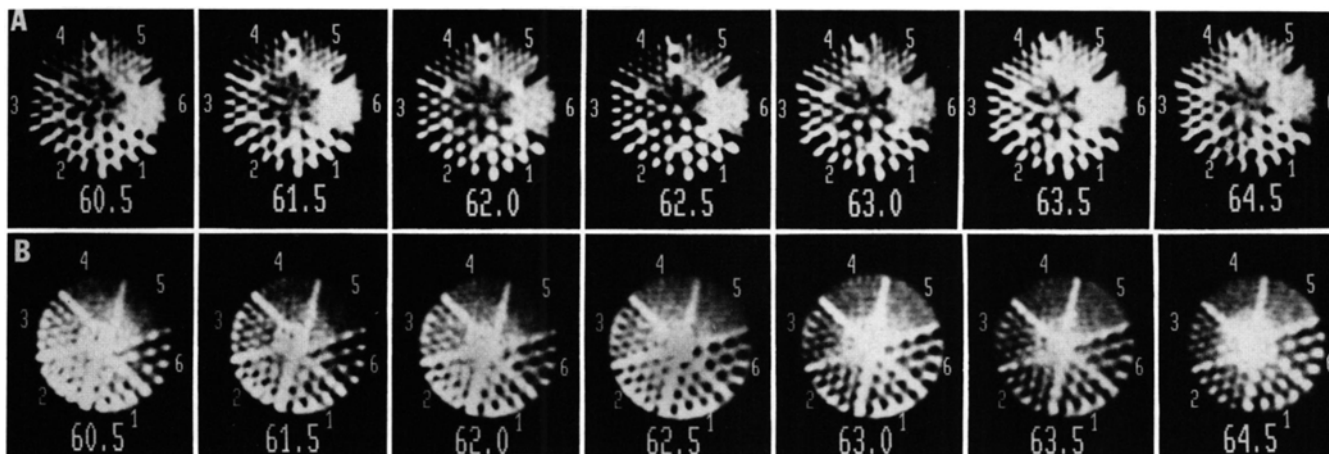


Fig. 3. SPECT phantoms reconstructed at various CORs above and below COR_{ACTUAL} (= 62.5). Row A represents cylindrical holes (hot) 4.8 to 12.7 mm in diameter, drilled into a lucite block (cold background). Row B represents cylindrical rods (cold) 4.8 to 12.7 mm in diameter suspended in a liquid tank (hot). Resolution is obviously sharpest at COR_{ACTUAL} (62.5) and drops off rapidly as the inputted COR varies farther from 62.5. Each slice contains 30 million counts. 1 = 4.8 mm rods or holes; 2 = 6.4 mm; 3 = 7.9 mm; 4 = 9.5 mm; 5 = 11.1 mm; and 6 = 12.7 mm.

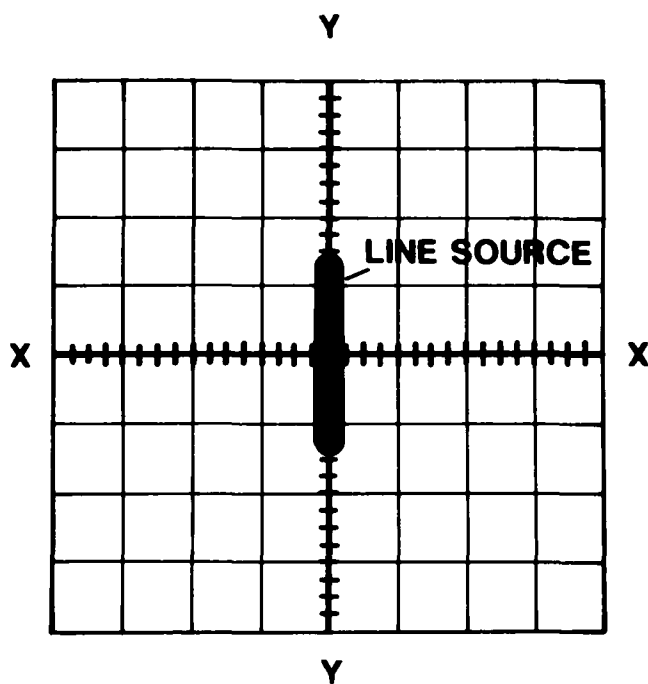


Fig. 4. A schematic representation of proper positioning of the line source on the camera scope for COR_{ACTUAL} acquisition. Y-Y is parallel to the axis of rotation of the camera gantry. X-X is parallel to the direction of rotation.

The reconstruction of a line source with an inputted COR different from COR_{ACTUAL} results in a circle of activity whose diameter is twice the difference between the inputted COR and COR_{ACTUAL} (4-7). The example (Fig. 5) demonstrates how any error of COR determination degrades the resultant image. Each point in a clinical image would be represented as a circle of activity and the image would be severely blurred.

A capillary tube was attached to the positioning table of a clinical study to aid in the clinical evaluation of COR determination (Fig. 6). The small size of the reconstructed point attests to the accuracy of the inputted COR (COR_{ACTUAL})

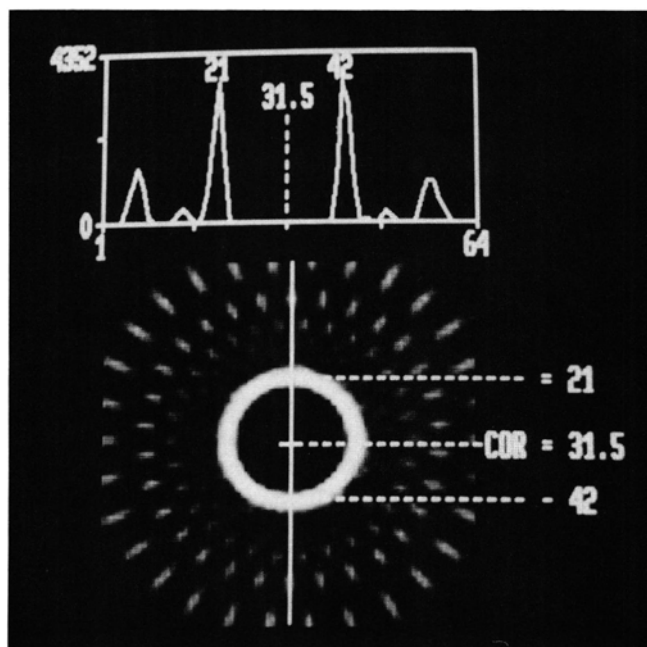


Fig. 5. A reconstruction of a line source is depicted in which the inputted COR (21.0) is 10.5 pixels from COR_{ACTUAL} (31.5). The resultant reconstruction is a circle of diameter of 21 pixels.

used to reconstruct these images. Since we determine COR_{ACTUAL} daily, we do not routinely use a line source during patient study acquisitions.

DISCUSSION

This paper is presented to alert physicians and technologists performing SPECT studies that the COR determination calculated by their software packages (COR_{MFG}) may not be accurate, and that what appear to be small errors in COR determination may significantly degrade the SPECT images. Any error in determining the COR, results in each point being represented as a circle whose diameter equals twice the error

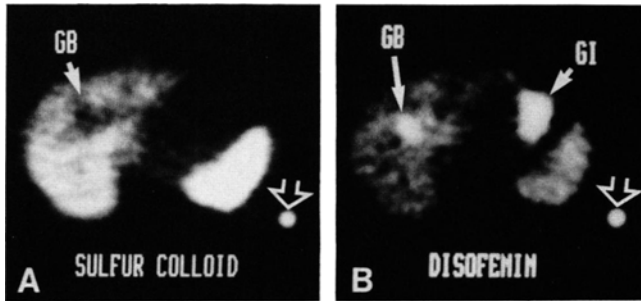


Fig. 6. A line source was attached to the positioning table (rather than the patient to avoid patient motion error) and reconstructed with the clinical study. (A) Transaxial SPECT slice using ^{99m}Tc sulfur colloid reveals a photopenic lesion. (B) Same transaxial slice using ^{99m}Tc disofenin depicting the lesion as an intrahepatic gallbladder. GB = gallbladder, GI = gastrointestinal activity excreted during the biliary study, open arrows = reconstruction of line source.

of COR determination (Fig. 5) (4–7). The worst error encountered during this study was a 6.0-mm error in COR determination (Table 2). If this error were applied to an image reconstruction, each point in the image would be represented as a circle 1.2 cm in diameter, and resolution would be severely degraded if not ruined. Although deviation from CORACTUAL of not more than 1.5 mm has been considered clinically acceptable (3,4,6), the method presented results in a 0.3-mm maximal error of centering.

Most authors have recommended weekly COR determination (4,5,8,9), but because of the inaccuracy of our CORMFG determination, we have opted to use the CORACTUAL determination daily as outlined in this paper. We have written several macro programs to perform the repetitive reconstructions, and CORACTUAL determination takes no longer than the manufacturer's method. We suggest periodic testing and comparison between the readers' CORMFG and CORACTUAL if CORMFG is to be used. We recommend the use of CORACTUAL for daily use. We use CORMFG (4 point sources) only for pixel sizing and have found biweekly updating sufficient.

A capillary tube may be attached to the patient positioning table and acquired with a clinical study so that CORACTUAL may be determined from this acquisition, or the size of the capillary tube reconstruction may be used as a visual quality control check of the COR used for reconstruction (Fig. 6).

ACKNOWLEDGMENT

The opinions and assertions contained herein are the private views of the author and are not to be construed as reflecting the views of the Army or the Department of Defense.

NOTES

*Digital Dynacamera, Picker International Inc., Cleveland, OH

† A3 Nuclear Medicine Computer System, Medtronic Medical Data Systems, Ann Arbor, MI

‡ A3 Picker Transaxial Tomography MIPS 2.0 software-1986, Medical Image Processing Specialists, Ann Arbor, MI

§ Model 5000 and Model 5001, Data Spectrum Corp., Chapel Hill, NC

APPENDIX

CORACTUAL Acquisition/Processing Protocol

1. Fill a hematocrit capillary tube with 500 μCi (18.5 MBq) of any ^{99m}Tc radiopharmaceutical solution.
2. Position the tube (line source) parallel to the axis of rotation and near but not at (5) the mechanical COR (AOR). For convenience, position the source so that the midpoint of the line source is at the center of the field of view (Figs. 1 and 4). This approximate positioning should be maintained throughout the acquisition and should be checked at gantry positions 0° (anteriorly or posteriorly) and 90° (laterally) before initiating acquisition. If the line source is to be placed off center from the AOR (5), it should be located to the right or left (+X or -Y) of the central Y-Y line at either or both of the 0° or 90° positions.
3. Acquire a 30 image ($12^\circ/\text{image}$) over 360° —10 sec/image study using the matrix for which quality control is being obtained (e.g., 64×64 , no zoom).
4. Reconstruct the line source repetitively using for the COR, 0.5 pixel increments from 30.0 to 34.0 for 64×64 acquisitions, or from 60.0 to 68.0 for 128×128 acquisitions. A one-pixel thick slice at the center of the line source pixel #32 (64×64) or #64 (128×128) will suffice.
5. From the COR = 30.0 (or 60.0) reconstruction, select the smallest region of interest (ROI) to include the line spread (Fig. 2) and record the total counts within this region in each of the reconstructions. The reconstruction with the most counts in the ROI is the one closest to CORACTUAL (CORNEAR).
6. For 64×64 acquisitions, reconstruct the line source repetitively using for the COR, 0.1 pixel increments from 0.5 pixels below to 0.5 pixels above CORNEAR. For 128×128 , use 0.2 pixel increments from 1.0 pixels below to 1.0 pixels above CORNEAR.
7. From the first reconstruction of the group of 11 reconstructions, select a ROI and as in step 5 above, and determine CORACTUAL.
8. If CORACTUAL is stable from day to day, then only steps 6 and 7 above need be repeated. If CORACTUAL falls outside the series of reconstructions, then CORNEAR needs to be redefined (steps 4 and 5).
9. If the individual reconstructions are assembled into one study, a curve generation program can be used to locate CORNEAR and CORACTUAL from the respective groups of reconstructions. Also, a computer macro program can be written to perform the entire iterative process.

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