
Evaluation of Emission-Transmission Registration in Thoracic PET

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The intent of this investigation was to quantitate the amount of misregistration between PET emission and transmission scans of the thorax that occurs in a normal clinical environment. **Methods:** The data from 17 FDG myocardial studies were evaluated. Prior to injection, a transmission study was acquired for 15 min using a $^{68}\text{Ge}/^{68}\text{Ga}$ ring source. The location of the crosshairs from a laser alignment system was marked on the patient who was then removed from the scanner and injected with 10 mCi of FDG. After 45 min, the patient was placed back on the table and repositioned with the previously placed marks and a 15-min emission scan was acquired. The outline of the lungs on both the transmission and emission images was manually segmented. Both attenuation-corrected and noncorrected emission images were evaluated and the one that provided clearer visualization of the outline of the lungs was chosen for segmentation. The segmented contours of the transmission and emission scans were then registered with the method described by Pelizzari et al. using the transmission image as the "head" and the emission image as the "hat." The allowable transformations were x and y shifts and rotation in the transverse plane. **Results:** Shifts in the x-axis averaged 2.4 mm (range: 0.2–7.3 mm, 80% less than 3.3 mm) with shifts in the y-axis averaging 2.6 mm (range: 0.1–8.7 mm, 80% less than 2.4 mm) and rotations in the transverse plane averaging 1.6 degrees (range: 0.2 to 5.1 degrees, 80% less than 2.4 degrees). A phantom study indicated that the accuracy of this method of evaluating misregistration was 2.35 mm and 1.81 mm in the x and y directions, respectively. **Conclusion:** Our preliminary evaluation indicates that careful application of laser alignment is an adequate method of registration in most cases.

Key Words: thoracic PET; image registration

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Most PET scanners use a measured attenuation correction technique. In this method, a transmission scan of the patient is acquired prior to the administration of the radiopharmaceutical by exposing the patient to a source containing an equilibrium mixture of ^{68}Ge and ^{68}Ga . By taking the ratio of smoothed versions of a blank transmis-

sion scan (one without the patient present) and the patient's transmission scan on a pixel-by-pixel basis, a set of attenuation correction values can be determined. The acquired emission PET scan can then be multiplied by these values to provide data corrected for attenuation. The transmission and emission studies are usually acquired sequentially and for studies with ^{18}F -fluorodeoxyglucose (FDG), the patient is usually removed from the scanner during the uptake period and then repositioned for the emission study.

In the thorax, tissues with vastly different attenuation coefficients (i.e., lung, soft tissue and bone) exist in close proximity. Thus, proper registration of the emission and transmission scans for accurate attenuation correction is especially important in the thorax. Misregistration can lead to over- or undercorrections that can severely compromise the image quality and quantitative accuracy of the resulting images. McCord et al. have determined that translations greater than 10 mm and rotations greater than 8 degrees between emission and transmission scans in the thorax can lead to visible artifacts that might affect interpretation (1). A question remains as to whether misregistrations of this magnitude occur in a typical myocardial PET study using good technique. This study sought to evaluate the magnitude of such misregistration errors in routine, clinical PET imaging of the myocardium.

METHODS

All of the PET scans performed in this study were performed on a Siemens ECAT 951/31 (Hoffman Estates, IL). This device images 31 contiguous slices with a 3.3-mm center-to-center spacing (axial field of view of 10.4 mm). The spatial resolution of this device is approximately 6–7 mm in all three dimensions.

A phantom study was performed to evaluate the accuracy of the surface-fitting algorithm developed by Pelizzari et al. as a measure of misregistration. The Alderson thorax phantom was used. The lungs were filled with air and all other organs (thyroid, both chambers of the heart and the general soft tissue) were filled with water. Nine markers were placed on the phantom. The markers consisted of nonmetallic electrocardiogram (ECG) leads fitted with syringe caps. The ECG leads were placed on the phantom, and the syringe caps were snapped on when necessary. For the emission markers, the ends of the syringe caps were filled with a small amount of ^{18}F . For the transmission markers, lead pellets were taped to the end of the syringe markers. In both cases, the markers were less than 3 mm in diameter.

For the transmission scan, no activity was placed in the phan-

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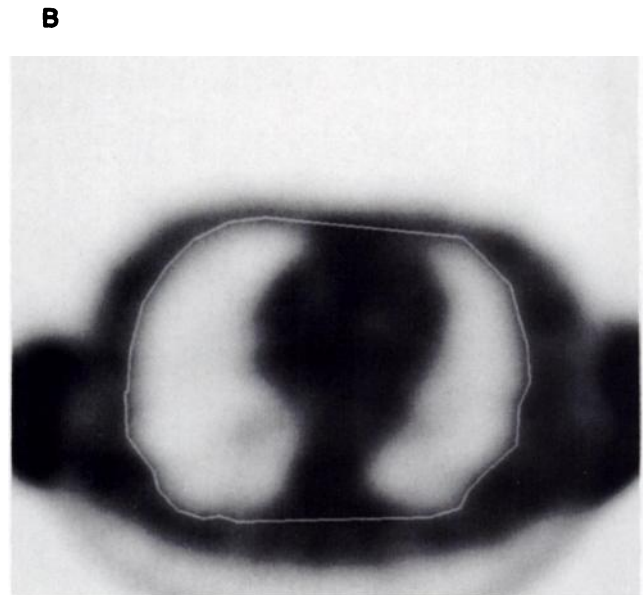
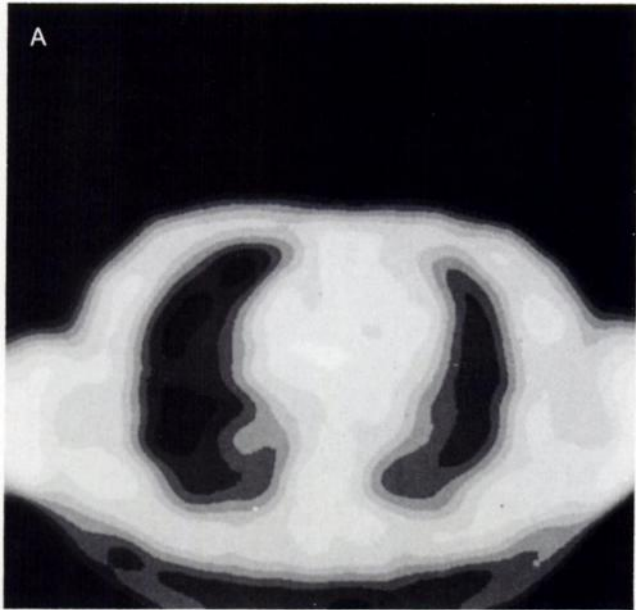


FIGURE 1. (A) Typical thoracic transmission study from an FDG heart study shown in a gray isocontour scale. The lungs and mediastinum can be clearly distinguished in this slice due to the inherent differences in attenuation coefficients between lung and soft tissue. (B) The transmission image in Figure 2 in grey scale overlaid with the ROI generated by tracing around the 60% isocontour. This contour combined with others generated from other thoracic slices form the "head."

tom and a transmission scan (10 min per bed position) was acquired and processed. Four separate transmission scans were acquired with the phantom translated and rotated between each scan. For the emission scan, the general soft tissue portion of the phantom was filled with 0.8 mCi of ^{18}F and a study was acquired with 15 min per bed position. Both studies were reconstructed and processed similarly to the clinical studies. The lung boundaries on both the emission scan and the four transmission scans were segmented as described for the clinical studies. Each of the four transmission scans was then registered to the emission scan and four "registered" transmission scans were generated by applying the transformation determined by the fitting algorithm to the data and reslicing the data to match the emission scan. The centroid of each of the nine markers for the emission scan and the four registered transmission scans was determined. From these data, the mean deviations between the marker location in the emission scan and the transmission scans were calculated.

The data from 17 consecutive FDG myocardial studies were evaluated retrospectively. Of the patients, 16 were male and 1 was female ranging in age from 39.6 to 74.7 yr with an average age of 61.5 yr.

Prior to the patient's arrival, a 10-min blank transmission scan (transmission scan without the patient in the scanner) was acquired. A transmission study of the patient was acquired for 15 min. The location of the cross-hairs from the laser alignment system which is built into the scanner was marked on the patient as "+"-shaped markings in the sternal area and on the surface of the patient's upper arms. The patient was then removed from the scanner. The transmission study was reconstructed with a Hann filter with a 0.4-cycles/pixel cutoff. The patient was then injected with 10 mCi of FDG. After 45 min, the patient was placed back on the table and realigned with the previously placed marks. A 15-min emission scan was acquired and reconstructed with a Parzen filter with a 0.3 cycles/pixel cutoff. The pixel size for both of these reconstructed studies was 3.13 mm.

The misregistration between the emission and transmission scans was objectively evaluated by matching the lung surfaces in the two scans. Regions of interest (ROIs) corresponding to the lungs were drawn on both the emission and transmission images in a standardized fashion encompassing both lungs for all slices where the pleural border was clearly distinct. The outer lung borders were followed to the most anterior point. This point was then connected to the most anterior point on the opposing lung. The two most posterior points were connected in the same fashion. The lung borders were determined for the transmission image by displaying the images in an isocontour scale and drawing around the contour that was 60% of the maximum value in the study. On several of the studies, various thresholds were tested with minimal effect on the determination of x and y misregistration.

Figure 1A shows a typical transmission image in an isocontour scale. Figure 1B displays the resulting ROI overlaid upon the same image displayed in gray scale. The lung borders were drawn for the emission images by evaluating both attenuation-corrected and nonattenuation-corrected emission images and choosing the one that provided clearer visualization of the outline of the lungs for manual segmentation. The segmentation of the emission images proceeded in a manner similar to that for the transmission images. The only difference was that the emission images were segmented based upon the lung uptake rather than chest wall attenuation used in the transmission images. Figure 2 is a typical emission study shown in gray scale overlaid with points placed during the segmentation process. For both image sets, points were placed only where the pleural surface could be clearly distinguished from surrounding tissue.

The ROIs from the transmission and emission scans were then converted to two sets of contours. These contours were registered using the method described by Pelizzari et al. (2). This method utilizes one set of contours to generate a surface called the "head" and the second set to generate a series of points called the

“hat.” The algorithm determines the optimum fit between the hat and the head by minimizing the sum of squared differences between the points in the hat to the surface defined by the head. Only points that were clearly distinguishable were incorporated into the contours, particularly for the hat file. The sum of squares, the parameter that is minimized in this fitting procedure, is calculated for all points in the hat file. Thus, by selecting more points in regions of the contours which have a high degree of certainty, the algorithm will be biased to using the data that can be more accurately defined. In this study, the transmission image was the head and the emission image the hat. The transformations allowed were x and y shifts and rotation in the transverse plane. The transformation parameters determined by the fitting program were then analyzed to determine the actual shifts in millimeters and rotations in degrees required to realign the two scans. This transformation thus characterized the amount by which the two scans were misregistered. The results were tabulated and analyzed.

RESULTS

The mean deviation of the markers in the phantom study was determined for each of the four transmission studies. The mean of these four studies was calculated. The mean values were 2.35 mm and 1.81 mm for x and y, respectively.

The experimentally determined extent of misregistration in 17 studies is shown in Table 1. The x and y translation values indicate the magnitude of the shifts necessary to align the emission scans with their respective transmission scans. The rotation angle characterizes how much the emission data needs to be rotated in the transverse plane for proper alignment with the transmission scan. In this manner, the parameters associated with the application of the registration algorithm are utilized as objective and

TABLE 1
Results of the 17 Studies Analyzed

| | x Shift (mm) | y Shift (mm) | x Rotation (deg) |
|---------|---------------|---------------|------------------|
| Average | 2.282 ± 2.068 | 2.346 ± 2.162 | 1.324 ± 1.425 |
| Min | 0.072 | 0.105 | 0.166 |
| Max | 7.348 | 8.686 | 5.135 |

quantitative measures of the magnitude of the misalignment between the two scans.

Translations between the emission and transmission scans ranged from 0.2 to 7.4 mm (mean 2.4 mm) and from 0.1 to 8.7 mm (mean 2.6 mm) for the x and y directions, respectively. Eighty percent of the translations were less than 3.3 mm and 2.5 for the x and y directions, respectively. The rotation angle necessary to align the two scans ranged from 0.2 to 5.1 degrees (mean 1.6 degrees) with 80% of the rotations less than 2.7 degrees. The magnitude of these misregistrations are slightly larger than the accuracy of the registration technique as determined from the phantom study (2.4 and 2.6 mm compared to 2.3 and 1.8 mm for x and y, respectively). These values consist of both random and systematic errors and, thus, it is impossible to separate that due to the evaluation technique and that due to misregistration. For this reason, the misregistration values can be considered as an upper limit. These values are all within the “safe” range set by McCord et al. (1). Figure 3 is a histogram of the x and y translations, respectively. Figure 4 represents a histogram of the rotations in the transverse plane.

DISCUSSION

There has been much work done to facilitate registration of transmission scans to the corresponding emission scans. Bacharach (3) and Bettinardi (4) have demonstrated two procedures for realignment of emission and transmission images. These techniques can be retrospectively applied to emission and transmission images. The more common approach is the proactive technique of attempting to position the patient accurately in the scanner in the same location for both transmission and emission scans with the use of lasers or other such alignment aids.

The registration algorithm used in this study is purportedly able to register two image sets to within 2 mm (5). The phantom study reported here is consistent with these results. Although this software was actually designed to register and then reslice one image set relative to another, the technique also provides a good means to objectively and quantitatively assess the misregistration between two image sets. We registered the emission and transmission scans and determined the parameters that would transform one of the studies such that it would register with the other. These parameters provide us with an accurate quantitative measurement of the degree of misregistration.

This surface-fitting registration technique requires accurate surface definition in both image sets being registered.

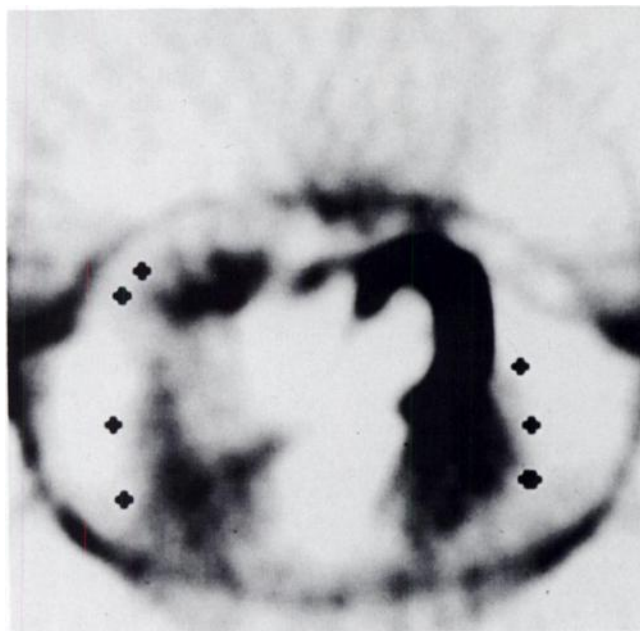


FIGURE 2. Typical thoracic emission image from an FDG heart study shown in gray scale overlaid with points placed during image segmentation. Note that the lungs can be distinguished in this slice due to their uptake of the radioactive FDG tracer.

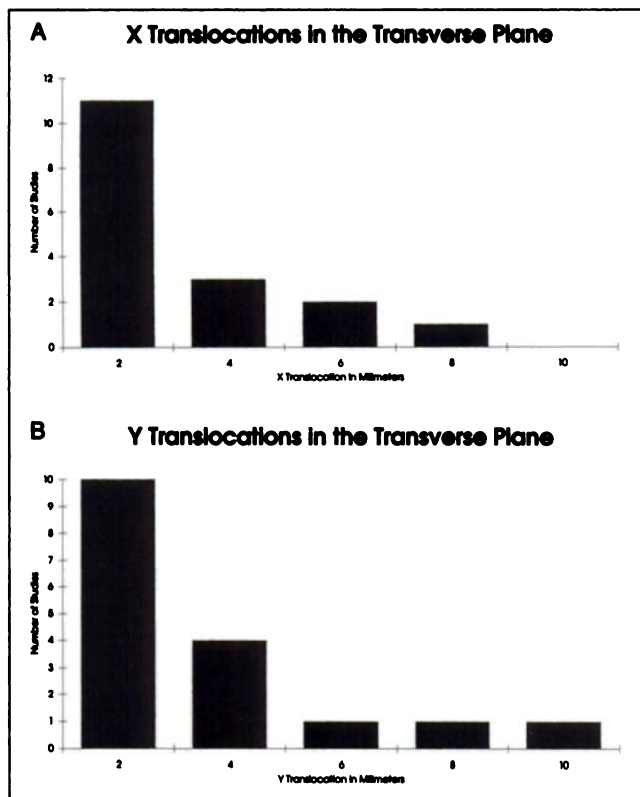


FIGURE 3. Histogram of both the x (A) and y (B) translations required for realignment as a function of the study. Note that in all cases the translations were less than the guideline of 10 mm established by McCord et al.

Understanding the algorithm led to the following set of criteria for a structure in the thorax that could be used for registration: similar appearance in both emission and transmission scans, asymmetry in both the rostral-caudal axis (for accurate z-axis alignment) and the anterior-posterior axis (for accurate y-axis alignment), and sufficient size to change noticeably with small changes in the orientation of the patient.

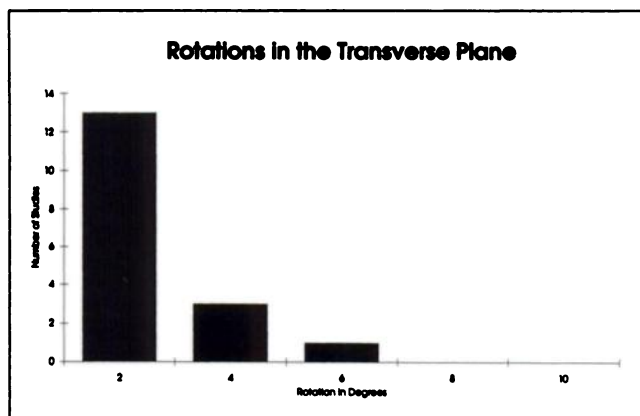


FIGURE 4. Histogram of rotation required for realignment for each study analyzed. Note that in all cases the rotations were within the guideline of 8 degrees set by McCord et al.

Using these criteria, pleural surfaces of the lungs were considered ideal for registration in the thorax. Early experience demonstrated substantial variability in mediastinal structures between emission and transmission scans preventing reliable region definition. Thus, regions were traced around both lungs as a unit ignoring the mediastinum. This method proved to be extremely reliable since the chest wall moves minimally in normal, quiet respiration and thus does not change between or during scans.

The possible sources of error in this method of misregistration evaluation mainly stem from the definition of the lung boundary in the emission and transmission images. In the transmission images the lung boundary determination is based upon the choice of threshold value which was determined by a subjective evaluation. In the emission images, lung boundaries were somewhat inconsistent due to slight nonuniformities in FDG uptake in the lung tissue. In both sets of images, the above effects in combination with limited spatial resolution and the presence of image noise can influence the size of the resulting contours and thereby affect the fitting process.

SUMMARY

We have used the Pelizzari approach to provide an objective evaluation of misregistration between the emission and transmission studies in the heart. This investigation indicated that the extent of misregistration is generally less than 3.5 mm in translation and 3 degrees rotation. These values are substantially lower than the values given by McCord et al. for artifact-free myocardial images (10 mm translation and 8 degrees rotation). Therefore, we conclude that a carefully applied realignment protocol that incorporates the use of lasers and skin markings yields adequate registration between the transmission and emission studies in the thorax.

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