Evaluating Transmission-Emission Misalignment in Brain PET

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Objective: Proper alignment of the transmission and emission images in PET is crucial for appropriate attenuation correction and other uses, such as registration of the PET emission data with data from another modality. The patient may be removed from the table after the transmission scan and later repositioned for the emission scan using a laser beam projected onto fiducial marks on the patient. Repositioning the patient introduces the possibility of misalignment between the transmission and emission scans. The purpose of this investigation was to determine the magnitude of any transmission-emission scan misalignment.

Methods: An immediate postemission transmission scan was obtained on 17 patients. The usual preinjection transmission image was registered to the postemission transmission image using a surface-matching algorithm. The rotations and translations necessary to register the two data sets are a measure of patient repositioning error.

Results: The average X, Y and Z translations were 2.32 mm (range 0.54–4.66 mm), 1.35 mm (0.11–4.33 mm) and 4.6 mm (0.66–16.61 mm), respectively. The average X, Y and Z rotations were 1.32° (0.07–4.79°), 0.84° (0.10–2.12°) and 2.67° (0.01–13.03°), respectively.

Conclusion: We conclude that while our transmission and emission data are generally repositioned within acceptable limits for the purpose of attenuation correction, significant errors are most likely to occur in the Z axis repositioning. ***Key Words:*** positron emission tomography imaging; repositioning accuracy; transmission-emission misalignment

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PET studies using [^{18}F]-2-fluoro-2-deoxy-D-glucose (FDG) have been useful both in the clinical evaluation of epilepsy and in the investigation of regional cerebral glucose metabolism in a variety of other situations (*1*). To obtain an accurate measure of FDG uptake, it is imperative to correct these studies for attenuation. The use of transmission data has been shown to be an accurate method of attenuation correction (*2*). The transmission images are low-count, low-resolution computed tomography (CT) images. With many scanners the transmission data must be acquired before the patient is injected with radioactivity. After transmission imaging, the patient is removed from the imaging bed for the injection of the FDG and the 45-min uptake period. The patient is then repositioned on the imaging bed and the emission image is acquired. Thus, while the transmission and emission imaging procedures are separated temporally they hopefully are aligned physically.

The transmission data is used to generate an attenuation correction sinogram which is then applied to the emission sinogram during reconstruction resulting in attenuation corrected transaxial images. For this method to work properly, the transmission and the emission data must be spatially aligned. The effect of transmission-emission misalignment is demonstrated in Figure 1. It was discovered that this patient's transmission and emission images were acquired at different z-axis positions in the scanner.

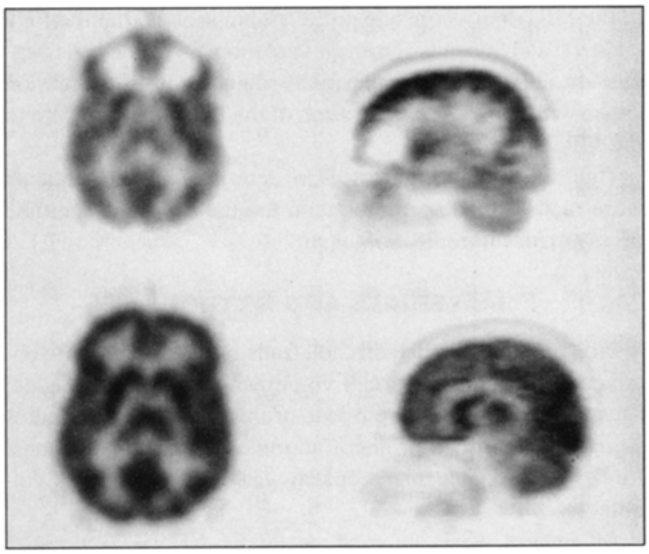

FIGURE 1. Effect of having emission and transmission data not spatially aligned. The top two images show the appearance of hypometabolism in the frontal lobe region due to improper alignment of the transmission and emission sinograms. The misalignment between the sinograms was corrected and the data were reconstructed. Radiotracer uptake distribution is typical of a normal FDG brain image, as seen in the bottom two images.

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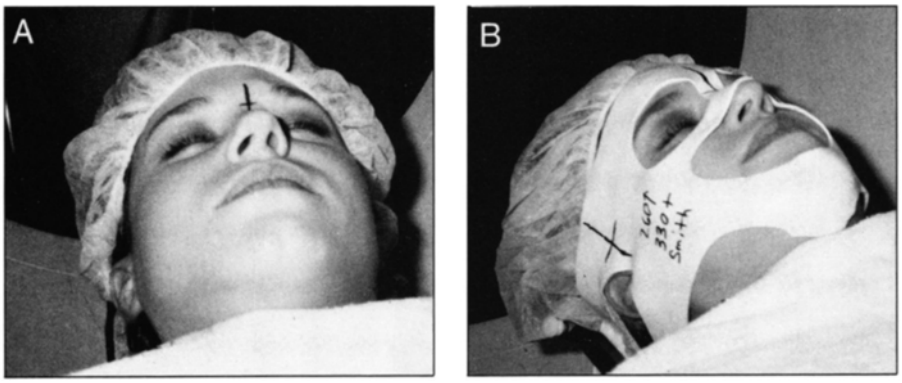

FIGURE 2. Fiducial marks are placed on (A) the patient's face and (B) on the thermoplastic mask. These marks are used for alignment with the laser positioning system in the scanner. The scan table height and translation is also recorded on the mask.

The impact of this misalignment on the final image was significant and can be seen as decreased intensity in the inferior frontal lobe and generalized cortical thinning (Fig. 1, top row). This pattern is the result of the attenuation coefficient that is appropriate for the sinuses (i.e., air) being applied to the brain with a density of 1 g/cm^3. Once the misalignment was identified and corrected, the emission image was reconstructed again. In the corrected image the frontal lobe regions have the appropriate metabolic rates and the apparent cortical thinning is corrected (Fig. 1, bottom row).

The transmission images can also be used for registering PET images to other higher resolution modalities such as CT and magnetic resonance imaging (MRI). Such registration is useful for comparing the anatomical information available from such modalities to the functional information available in the PET data. The transmission images are used to determine the transformation (X, Y and Z translations and rotations) necessary to register to the MRI data because it provides good skull visualization for surface fitting. This transformation is then used to register the PET emission data to the MRI data. Here again, the assumption is that the PET emission and transmission images are properly aligned. A transmission image that is not spatially aligned with the emission image will lead to misregistration of the PET emission data to the MRI images.

This study was conducted to determine if our patients were repositioned accurately and to quantify the magnitude of any errors in repositioning.

MATERIALS AND METHODS

Preinjection and postemission transmission scans were obtained on seventeen normal volunteers (12 male, 4 female; ages 23 to 70 yr) for the purpose of this study. These studies were obtained on a protocol approved by the Institutional Review Board. Informed consent was obtained from all volunteers.

All images were obtained on an ECAT 951/31 scanner (Siemens Medical Systems, Hoffman Estates, IL). This scanner uses ^{68}Ge/^{68}Ga rings as the source for the transmission images. The use of ring sources requires that the transmission data used for attenuation correction be acquired prior to the injection of the radiopharmaceutical. Each patient was positioned on the imaging bed with the canthomeatal line parallel to the image plane. Transparent tape was placed on the anterior and both lateral aspects of the patient's head. The built-in laser cross-hairs in the center of the axial field of view were projected onto the tape and marked accordingly (Fig. 2A). A thermoplastic mask (Tru-Scan, Annapolis, MD) was heated and molded to the patient's face for stabilization during the scans. After the mask was formed and allowed to harden, the laser position was recorded on the mask at the start scan position. The scan table coordinates (i.e., table height, Y position and translation into the scanner, Z position) and the patient's name were recorded on the mask (Fig. 2B). The preinjection transmission scan was then acquired for 15 min per bed position. The patient was removed from the imaging bed and placed in a separate room for the FDG injection and uptake. At the end of the uptake period (approximately 45 min), the patient was returned to the imaging bed and realigned, using the laser realignment system, first with the facial fiducial marks, and then the previously prepared mask was reapplied and realigned in the same way. The emission scans were then acquired.

For this study we acquired a short (2 min per bed position), postemission transmission study at the completion of the emission study. The patient was not moved except to reposition the scan table in the axial direction to the start Z position number. This image was likely to be correctly aligned with the emission image because the patient had not been removed from the table between the two scan acquisitions. This second transmission study was used only for evaluating the transmission-emission misalignment and not for attenuation correction since emission data is simultaneously being counted with the transmission data. The preinjection and postemission transmission images were reconstructed using filtered backprojection (Hann filter with a cutoff of 0.4 cycles/pixel).

An edge detection algorithm was applied to each transaxial image of both the reconstructed preinjection and postemission transmission image files to define the skull surfaces. The headholder for our system and the skull have similar attenuation characteristics and are in close proximity which made defining the skull boundaries difficult. This problem was corrected by subtracting the headholder from

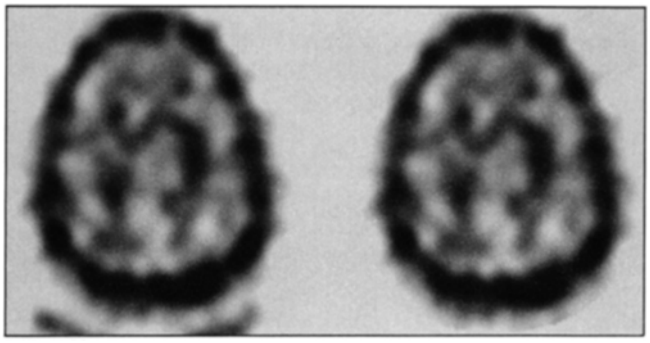

FIGURE 3. The image on the left shows the effect of the attenuation characteristics of the headholder which are similar to those of the patient's skull. This necessitated subtraction of the headholder from the transmission images. The image on the right is the transmission image after the headholder was subtracted from each image.

TABLE 2
17 Pre-Injection and Postemission Transmission Scan Pairs

	Rotations (degrees)		
	X	Y	Z
Absolute mean	1.320	0.840	2.672
Standard deviation	1.477	0.684	3.798
80%*	2.640	1.660	2.480
	Translations (mm)		
Absolute mean	2.325	1.349	4.637
Standard deviation	1.027	1.280	4.513
80%*	3.020	2.600	7.440

*80% of the observations fall below this point.

the images. A region of interest was traced around the headholder in the transverse image and the pixel values inside the region were set to zero. This technique was applied to all planes in both transmission image data sets to erase the headholder from the images. This left us with only head surfaces with which to fit the desired contours (Fig. 3). The edge detection algorithm used a threshold based on a percentage of the maximum pixel value for the study as the boundary criterion. The contours were placed at the 30% isocontour on all images.

The contours were converted to head and hat files to be used with the surface-fitting algorithm described by Pelizzari (*3,4*). This algorithm is an iterative technique that shifts and rotates the hat file in space until the best fit is achieved with the head file. The best fit is defined by the smallest residual value obtained where the residual value is the sum of the squared distances from the points of the hat to the surfaces of the head. This program also generates a parameters file that contains the X, Y and Z translations and rotations necessary to achieve the best registration of the two transmission studies for each of the 17 patients. From these numbers, we were able to calculate the amount of misalignment between the two transmission studies (Table 1).

RESULTS

The results of our investigation are summarized in Table 2 which shows that the means of the absolute value of the rotation around the X, Y and Z axes were all less than 3°, and that the standard deviations for the rotations were also 3° or less. Eighty percent of the images evaluated in this study had rotation misalignments from the preinjection transmission to the postemission transmission study of less than 2.6° in the X axis, 1.6° in the Y axis and 2.5° in the Z axis.

The means of the absolute value of the translations was less than 2.5 mm in the X and Y direction, but in the Z

TABLE 1
Rotation and Translation Parameters

	Rotation (degrees)			Translation (mm)		
Patient	X	Y	Z	X	Y	Z
1	−0.22	0.68	1.31	2.78	0.18	2.62
2	−2.64	−2.01	0.68	2.54	0.62	−11.52
3	0.54	−0.84	0.76	3.02	−1.14	−0.99
4	−0.44	0.45	−1.50	2.23	−1.35	1.67
5	−3.76	−0.19	−5.53	2.61	−0.18	−3.35
6	−0.40	1.84	1.18	−1.39	−2.07	−7.44
7	−0.58	0.74	1.15	3.16	−3.51	−0.66
8	4.79	−0.11	−11.33	−3.02	−0.83	−7.95
9	1.97	1.24	−0.38	−0.54	0.14	1.62
10	1.41	0.10	−1.01	1.95	−1.05	0.82
11	−0.07	0.81	−2.22	3.35	−4.33	−16.61
12	0.07	−0.26	1.57	−1.56	2.70	−6.52
13	0.39	0.31	−2.48	2.46	2.60	0.94
14	−3.47	−0.31	0.79	4.66	−1.43	−4.74
15	0.27	−0.61	−0.54	−1.75	−0.11	−8.12
16	1.08	−2.12	0.01	−0.57	0.56	−0.76
17	0.34	−1.66	−13.03	1.93	0.14	−2.50

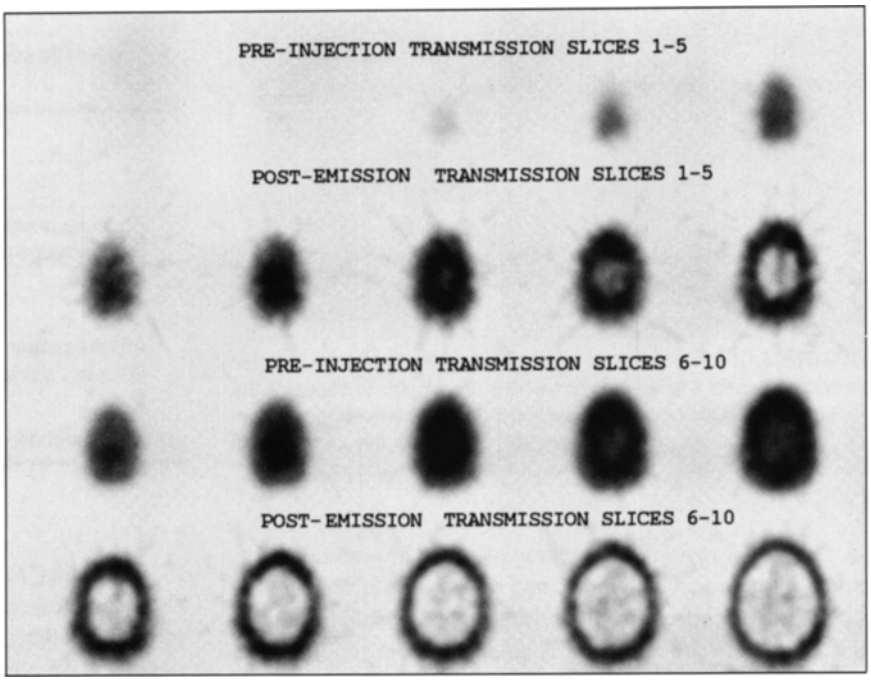

FIGURE 4. Simultaneous display of grossly misaligned preinjection and postemission studies. The offset between the data sets is approximately 4 slices, i.e., the fifth image of the preinjection transmission corresponds with the first image of the postemission study.

direction it was roughly twice that value (4.7 mm). The standard deviations for the necessary shifts were less than 1.5 mm in both the X and Y axes, but in the Z axis, it was 4.5 mm. Eighty percent of the images evaluated in this study had misalignments of less than 3 mm in the X and Y axes. The Z axis variation once again was more than double that of the X and Y axes at 7.44 mm. The Z translation range was from 1 mm to 16 mm which is reflected by the large standard deviation of the Z translation.

Figure 4, shows a pre- and postemission transmission image set of the same patient which demonstrates a large Z axis positioning error. The first slice in which the vertex of the skull is visualized is about 4 slices different on the pre- and postemission transmission images. Registration software was not necessary to determine the gross misalignment between these studies. Based on the number of slices by which these two studies were misregistered, and the thickness and spacing between those slices, this misregistration was estimated to be 12 mm off in the Z direction. The registration software calculated it to be 11.75 mm.

DISCUSSION AND CONCLUSIONS

These data show that patients are generally repositioned adequately for the purpose of attenuation correction. This study did emphasize the need for quality control of the transmission data relative to the emission data. The most significant repositioning errors occurred in the Z axis repositioning. The Z axis corresponds with how far the patient goes into the scanner. Errors in this axis can be a result of not carefully repositioning the patient in the headholder, not realigning the fiducial marks on the patient's head with the laser, or not setting the table back to its original numerical value.

It should be noted that a lot of useful information can be obtained simply by looking at the spatial relationship between the transmission and the emission images. Simultaneous display of the preinjection and postemission transmission images (Fig. 4) or the preinjection transmission and emission images (Fig. 5) may be used for preliminary quality control of clinical studies. Studies that have gross misalignments would require the use of an analytic attenuation correction rather than the measured attenuation correction. Such comparisons must be made carefully. While it is obvious that the transmission scan in Figure 4 could not be used for attenuation correction or as the basis for image registration, in some cases the misalignment was much more subtle.

While satisfactory for attenuation correction, the alignment between the transmission and the emission studies was not generally accurate enough to use the transmission images to determine the transformation (X, Y and Z translations and rotations) necessary to register the emission images to other modalities. Tests of the accuracy of this image registration algorithm have shown that images can be registered to less than 2 mm for PET to high-resolution data (*5*) and less than 2.3 mm for PET emission-transmission data (*6*). If the pixel size is 3 mm, images could be co-registered with an accuracy of about 2.0 mm or to slightly more than one-half pixel. If the transmission image is used to determine the transformation parameters for the emission image, but the transmission and emission images are not accurately aligned, the error in the registration of the emission to the high-resolution MRI or CT will at least be equal to the magnitude of the misalignment between the transmission and emission images. The magnitude of the translations and rotations needed to coregister our preinjection transmission images with our postemission transmission images, and thus the emission image, is too great to obtain satisfactory

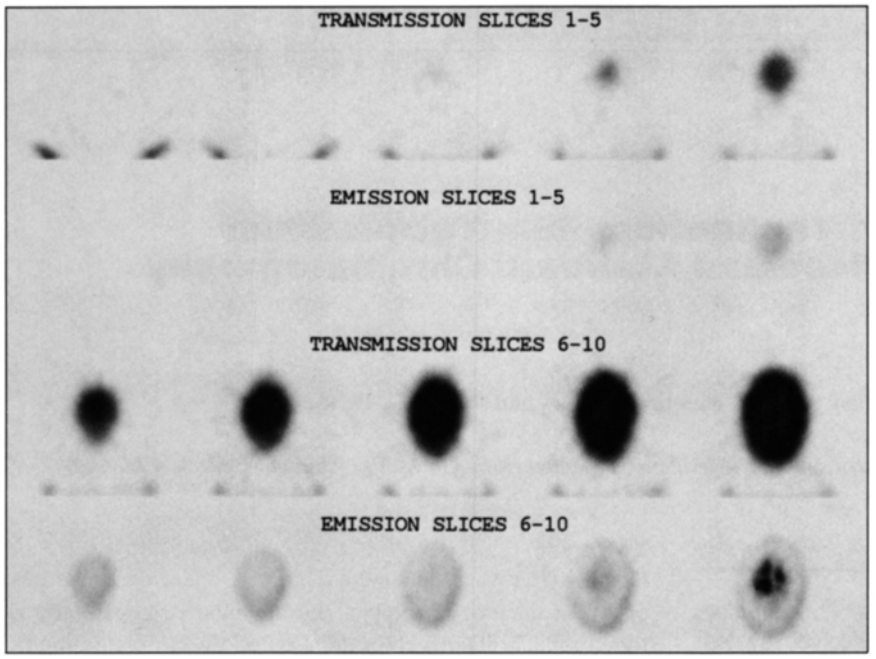

FIGURE 5. Simultaneous display of a closely aligned emission/transmission image set. The difference in the background areas is a result of comparing a transmission to an emission study.

results. The second transmission study would be more satisfactory but has the following disadvantages: it requires the patient to spend more time in the scanner; the radiation dose is slightly increased; and there is the remote but definite possibility that the patient could move or be improperly realigned between the emission and the postemission transmission scans.

In summary, when using PET scanners with ring sources the transmission data must be acquired before the patient is injected with radiotracer. Patients may be removed from the scanner and repositioned at a later time for the emission study. This study found that the patients were generally repositioned adequately for the purpose of attenuation correction but not for using the transmission images to determine the transformations necessary for registration of the PET emission data to other high-resolution modalities.

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