THE PHANTOM STUDY OF SPATIAL REGISTRATION IN PET/CT

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ABSTRACT

Objective: The purpose of this study was to evaluate the spatial registration in terms of the registration difference in PET/CT with the phantom.

Method: Three experiments were performed by using the phantom insert with hollow spheres filled with F-18 and the combined PET/CT system(Siemens, Biograph), including the same offset correction(test 1,2,3) and varied offset correction for the gantry(offset 1,2,3), and the clinical setting. The location of the center of was used for statistical analysis of the location difference. A p-value less than 0.05 was defined to be statistically significant. The acceptable value for the registration difference in the registered image was taken as 1mm or less.

Result: The mean registration difference in the study of same offset correction for the gantry was 0.68$\pm$0.24 mm. The p-values obtained in the first experiment were more than 0.05. There was no statistically significant difference between each test. The average registration difference in the study of varied offset correction for the gantry was 0.51$\pm$0.17 mm. There was a statistically significant difference when the difference in the z-axis was more than 0.05 mm. The average registration difference in the clinical setting was 0.50$\pm$0.28 mm. There was no statistical significance between the clinical setting and the phantom setting.(p-value = 0.764)

Conclusion: In this PET/CT system, the spatial registration was sufficiently accurate in the phantom study and the spatial registration difference in the registered image was less than 1mm.

Key Words: PET/CT; F18; phantom; registration

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INTRODUCTION

Combined PET/CT systems are being used on an increasing scale in nuclear oncology. One important factor for using these systems is the accuracy of spatial registration between the PET and CT images. The accuracy of the registration between PET and CT depends on several factors such as the difference of the patient positioning, internal organ movements, attenuation correction artifacts and errors in the registration procedure.[1] Most studies on this subject have been performed in patients and have focused on internal organ movement especially respiration.[2-6] The lesion mislocalization can occur by the respiratory motion difference between PET and CT. It may be the major cause of the artifacts in PET/CT. This leads to a special breathing protocol in PET/CT study. A spatial registration study in a phantom was performed as part of a lung lesion study by a group of researchers in 2003.[7] The literature contains only a few reports on phantom studies in PET/CT. The purpose of this study was to evaluate the spatial registration difference in the registered image by using the phantom insert with hollow spheres.[8] This study relates to the system itself and to the effect of some parameters on the spatial registration difference between PET and CT in a phantom only.

MATERIALS AND METHODS

PET/CT system

The PET/CT system evaluated in this study was the BGO-based Siemens Biograph (Siemens Medical Systems, Inc). The Biograph combines a PET scanner (ECAT EXACT HR+) and a spiral CT (Somatom Emotion Duo) in a single gantry. The transverse fields of view of the PET and CT were 60 cm and 50 cm, respectively. The axial fields of view of the PET was 15.5 cm with 63 image planes per bed position (2.46 mm slice-to-slice spacing) Gantry offset was performed to ensure that the field of view of the system matches the PET and CT gantries. By acquiring the cross rod phantom, the gantry offset on the x, y and z axes is automatically calculated by the software. The offset in the x and y axes should be less than5 mm. The manufacture recommended that if either the x or y calibration values exceed 5 mm, mechanical re-adjustment of the gantries is required.

Phantom

The NEMA NU 2-2001(8) phantom insert with hollow spheres consists of six different diameters of sphere sizes i.e. 37±1 mm, 28±1 mm, 22±1 mm, 17±0.5 mm, 13±0.5 mm and 10±0.5 mm inserted in the cylinder water filled flood phantom. Each hollow sphere is filled with 0.185 MBq/cc of F-18.

The rod sources were used for gantry offset correction. Two Ge-68 rod sources with a radioactivity of about 148 MBq each were inserted in the box to make a cross rod phantom.

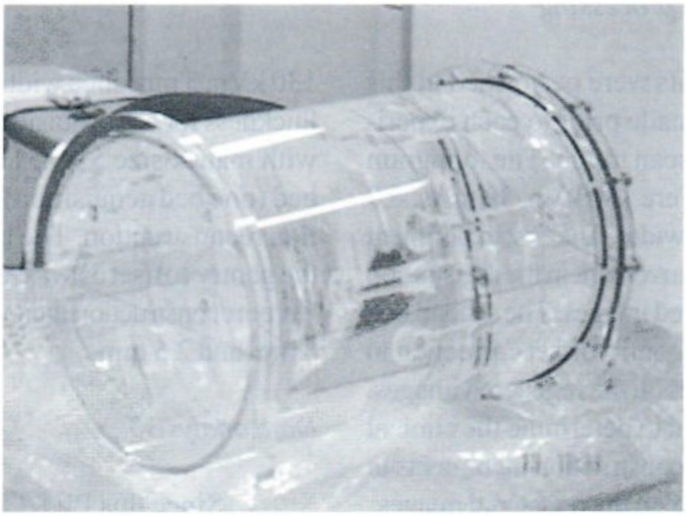

Fig. 1 Setting of NEMA NU 2-2001 phantom, inserting with hollow spheres, inserted in the water filled phantom.

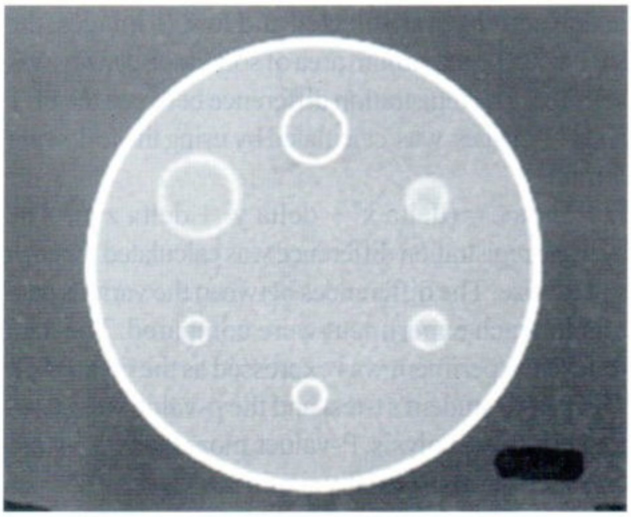

Fig. 2 CT image of the phantom with hollow spheres diameter ranging from 37 mm to 10 mm.

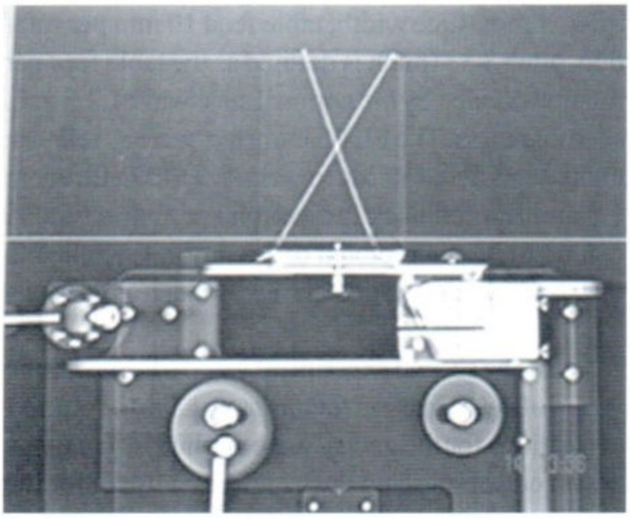

Fig. 3 Topogram of the cross rod phantom for gantry offset correction.

PET/CT acquisition and processing

Three experiments were performed in this study. The topogram is made prior to each experiment to define the axial scan range. The topogram acquisition parameters were 130 kVp, 30 mAs, 5.9 seconds and 1.0 mm slice width. The first experiment studied the effect of bed movement in the registration differences on the registered images. The second one investigated the effect of gantry offset correction in the registration differences on the registered images. The last one was designed to determine the clinical setting and the effect of reconstruction increments in the registration differences on the registered images.

The first experiment was performed using the same offset correction for the gantry. The experiment was repeated three times using the phantom with the bed in the reset position for each repeated experiment. CT acquisition was as followed: 130 kVp, 40 mAs, 3 mm. slice width, table feed 10 mm per rotation, pitch 3.33 (pitch is defined as the table feed per rotation divided by the nominal slice width), 2.5 mm. slice thickness. The PET parameters were as follows: total counts about 77 Mc, matrix size 512x512, zoom 1.0 and filtered back projection reconstruction. A reconstruction increment of 2.5 mm was applied to match the slice thickness of PET as much as possible.

The second experiment was performed using varied offset correction for the gantry. Two new offset corrections for the gantry were applied by using the cross rod sources and the standard protocol for the correction process. The phantom was acquired for each new offset correction for the gantry with the same system conditions. The phantom was acquired and reconstructed with the same parameter as for the first study and same PET scan time per bed. (15 minutes per bed and one bed acquisition) A reconstruction increment of 2.5 mm was used for the phantom data after the gantry offset correction had been applied.

The third experiment was performed with the usual clinical setting used in our institute i.e. 40 mAs, 130 kVp, 5 mm slice width, pitch 1.6 and 4mm slice thickness for CT acquisition. PET data was acquired with matrix size 512x512, zoom 1.92, 15 min per bed (one bed acquisition) and filtered back projection reconstruction. The latest offset correction for the gantry (offset 3) was applied in this experiment. Three reconstruction increments were used i.e. 5 mm, 4 mm and 2.5 mm.

Data analysis

Since this PET/CT was not equipped with software for analyzing the data generated in this study, all data had to be analyzed by using Dr. View/LINUX 1.1.0 software. All registered images were transferred to a snapshot format via CD-R. The sphere center was determined from several registered images. For PET images ,the slice with the maximum area of lesion activity was selected and for CT images, the slice with the maximum area of soft tissue density was selected. The registration difference between the PET and CT images was calculated by using the following formula [7]:

Difference = $(\text{delta } x^2 + \text{delta } y^2 + \text{delta } z^2)^{0.5}$ The average registration difference was calculated for each sphere size. The differences between the various data sets for each experiment were compared. The data for each experiment was expressed as the mean±SD. The paired student's t-test and the p-value were used for statistical analysis. P-values more than 0.05 were considered no statistically significant.

RESULTS

Three tests were done (test 1, 2 and 3) with the same phantom settings and the same offset correction for the gantry. After each test, the bed was reset to the normal position before starting the next test. This was necessary for checking the effect of bed movement on the registration difference in the registered images. The average registration difference for each sphere size was calculated and is shown in table 1.

TABLE 1 Average registration difference with same offset correction for the gantry

Sphere size (mm)	Average registration difference (mean±SD)(mm) test 1	test 2	test 3
37	0.962±0.578	0.759±0.593	1.314±0.426
28	0.975±0.472	1.010±0.690	0.714±0.488
22	0.167±0.408	0.333±0.516	0.833±0.408
17	0.75±0.5	0.25±0.5	0.25±0.5
13	0.75±0.5	0.957±0.667	0.25±0.5
10	0.75±0.5	1.0±0	0.333±0.577

In the second experiment, the new offset correction for gantry was applied for each phantom experiment (offset 1, 2 and 3). Then the same analysis procedure was performed. This experiment was carried out for assessing the effect of gantry offset correction on the registration difference in the registered images. The average registration difference for each sphere size was calculated and is shown in table 2.

TABLE 2 Average registration difference with varied offset corrections for the gantry

Sphere size (mm)	Average registration difference (mean±SD)(mm) offset 1	offset 2	offset 3
37	0.962±0.578	0.555±0.527	0.870±0.523
28	0.975±0.472	0.143±0.378	0.571±0.534
22	0.167±0.408	0.167±0.408	0.736±0.592
17	0.75±0.50	0.25±0.5	0.50±0.577
13	0.75±0.50	0	0.25±0.50
10	0.75±0.50	0.50±0.577	0.333±0.577

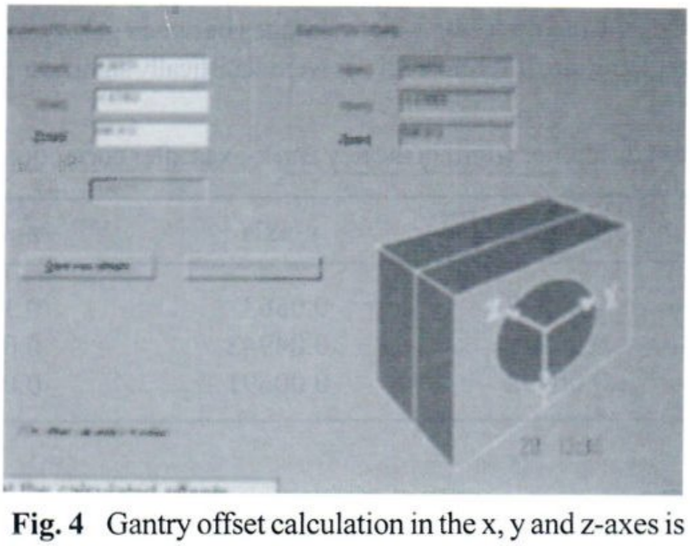

Fig. 4 Gantry offset calculation in the x, y and z-axes is carried out automatically by the software.

For the last experiment, clinical acquisition was performed and the data analyzed using the same procedure. This experiment was done to assess the effect of the reconstruction increment on the registration difference in the registered images when applied to the patient. This test was designed to determine intrinsic difference in PET/CT itself. It was not affected by body weight or internal organ movement. The average registration difference for each sphere size was calculated and is shown in table 3.

TABLE 3 Average registration difference using different reconstruction increments

Sphere size (mm)	Average registration difference (mean±SD) (mm)		
	5mm	4mm	2.5mm
37	0.883±0.525	0.833±0.408	0.667±0.50
28	0.603±0.717	0.25±0.50	0.916±0.432
22	0	0.667±0.577	0.667±0.516
17	0.50±0.707	0	0
13	0.50±0.707	0.333±0.577	0.25±0.50
10	0.50±0.707	0	0

DISCUSSION

In the first experiment the p-value for each test was more than 0.05(0.95 between tests 1and 2, 0.61 between tests 1and3 and 0.67 between tests 2 and 3) Bed movement in the z direction does not have any statistical significance. The variance for each test was calculated to estimate the reproducibility of the operator. The average variance in the PET and CT for the determination of the sphere center was less than 0.5mm. (0.44mm. for PET and 0.32 mm. for CT). The reproducibility of the operator was satisfactory. The average registration difference for all spheres and all tests was 0.686±0.238 mm. (mean±SD). This small number will not have any effect on the spatial registration in clinical practice.

The p-value in the second experiment with varied offset correction for the gantry was as follows: between offsets 1 and 2 it was 0.01, between offsets 1 and 3 it was 0.31 and between offsets 2 and 3 it was 0.04.The registration differences in the registered images between gantry offsets 1 and 2 and 2 and 3 were statistically significant.

TABLE 4 Gantry offset difference (mm) in the x, y and z-axes after correction

	x-axis	y-axis	z-axis
offset 1, 2	0.09427	0.0563	0.139
offset 1, 3	0.09919	0.04943	0.047
offset 2, 3	0.00492	0.00691	0.092

From table 4, it can be seen that the gantry offset difference between offsets 1 and 2 is smaller than between offsets 1 and 3 in the x-axis but larger in the y and z-axes. The gantry offset difference between offsets 2 and 3 is smaller than between offsets 1 and 3 in both the x and y-axes but larger in the z-axis. This implies that a difference in the z-axis has a greater effect than in the x and y-axes. This calls for caution regarding z-axis gantry offset correction. Though a certain statistically significant difference was found in this experiment, the average registration difference in the registered images for all gantry offsets was still less than 1 mm. (0.512 ± 0.167 mm.) The reproducibility of the operator is satisfactory with a small average variance in the PET and CT for the determination of the sphere center (0.36 mm. for PET and 0.29 mm. for CT)

The third experiment studied the effect of the clinical setting on the registration difference in the registered images as compared with the phantom setting. The p-value for the 5 mm reconstruction increment was 0.76. The different parameters in the clinical setting as compared with the previous data (offset 3) applying the same offset correction for the gantry does not show any effect on the registration difference in the registered images. When comparing the reconstruction increments of 5 mm, 4 mm and 2.5 mm, the p-value shows no statistically significant difference ($p>0.05$). The reconstruction increment does not have any effect on the registration difference in the registered images. Moreover, the average registration difference in the registered images for all three reconstruction increments was less than 0.5 mm. (0.420 ± 0.245 mm.) This means that for clinical acquisition, the reconstruction increment has no effect on spatial registration in the PET/CT as long as the reconstruction increment between PET and CT is numerically the same. The reproducibility of the operator was satisfactory since the average variance for PET and CT in the determination of the center of sphere was less than 0.5 mm.

From the three experiments used in this study, it can be seen that all data show a small spatial registration difference in the registered images in this PET/CT system. The manufacturer indicates that a registration difference in the registered image within 1 mm is acceptable. The results of this study thus substantiate that this system is satisfactory and the values obtained with it are acceptable even though there is a small registration difference in the registered images.

CONCLUSION

There is no statistically significant difference in terms of registration difference associated with bed movement in the z direction, the acquisition parameters such as the pitch number or CT slice thickness and the reconstruction increment. There is a statistically significant difference in the z direction and the gantry correction data and the gantry offset correction data but the difference is numerically less than 1 mm which is within the acceptable value.

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REFERENCES

1. Vogel WV, Oyen WJG, Barentsz JO, Kaanders J H.A.M., Corstens F H.M. PET/CT: Panacea,Redundancy, or Something in Between? J Nucl Med 2004; 45: 15s-24s
2. Goerres GW, Kamel E, Heidelberg TNH, Schwitter MR, Burger C, Schulthess GK. PET-CT image co-registration in the thorax: influence of respiration. Eur J Nucl Med 2002; 29: 351-360

3. Goerres GW, Kamel E, Seifert B, et al. Accuracy of image coregistration of pulmonary lesions in patients with non-small cell lung cancer using an integrated PET/CT system. J Nucl Med 2002; 43: 1469-1475
4. Osman M, Cohade C, Nakamoto Y, Marshall LT, Leal JP, Wahl RL. Clinical significant inaccurate localization of lesions with PET CT: frequency in 300 patients. J Nucl Med 2003; 44: 240-243
5. Beyer T, Antoch G, Blodgett T, Freudenberg LF, Akhurst T, Mueller S. Dual-modality PET/CT imaging: the effect of respiratory motion on combined image quality in clinical oncology. Eur J Nucl Med Mol Imaging 2003; 30: 588-596
6. Nakamoto Y, Tatsumi M, Cohade C Osman M, Marshall LT, Wahl RL. Accuracy of image fusion of normal abdominal organs visualized with PET/CT. Eur J Nucl Med Mol Imaging 2003; 30: 597-602
7. Cohade C, Osman M, Marshall LT, Wahl RL. PET-CT: accuracy of PET and CT spatial registration of lung lesions. Eur J Nucl Med Mol Imaging 2003;30:721-726
8. NEMA. NEMA standards publication NU 2 -2001. Performance measurements of Positron Emission Tomographs. Rosslyn, VA: National Electrical Manufacturers Association; 2001: 30