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High-resolution and high-sensitivity SPECT imaging of breast phantoms

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Abstract

A small field of view gamma camera based on a Position Sensitive Photomultiplier Tube has been used for tomoscintigraphic imaging of breast phantoms. The breast phantoms consist of small hot quantities of ^{99m}Tc placed in a plastic pot filled with a lower concentration ^{99m}Tc solution. The volume of the hot quantities varied from 0.5 to 0.25 ml and the target to background activity ratio varied from 3:1 to 5:1. The impact of the acquisition time per projection and the number of projections on image quality has been investigated.
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1. Introduction

Scintimammography provides functional information on tumor activity that is complementary to the structural information of X-ray mammography [1]. This information can be obtained using PET or SPECT techniques. In the case of PET, FDG is used and in the case of SPECT, Tc-99m Sestamibi has shown very promising results [2]. However, large field of view PET scanners and SPECT systems based on Anger camera suffer from low resolution. In addition, the large distance from the breast decreases sensitivity. Thus these systems are not very efficient for the early detection of small breast tumors. Dedicated

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systems have been developed during the past years, which are based on both technologies and they are used in combination with standard mammography. Position Emission Mammography (PEM) detectors have provided very promising results since they offer high-resolution tomographic information [3]. A number of scintigraphic detectors has been built and evaluated as well [4,5]. However, acquisition time is a limiting factor, thus in clinical practice these systems are used mainly in planar mode.

We have previously shown [6] that a small field of view detector based on a Position Sensitive Photomultiplier Tube (PSPMT) and a pixelized CsI crystal can be used for 2D efficient imaging of breast phantoms in planar mode. In addition, it was shown that SPECT imaging seems to increase system sensitivity, since a spot that was not visible in the acquired projections was visible in the reconstructed slices.

We have used the same system in order to test its performance in SPECT mode. The aim of this study was to investigate the impact of acquisition time, number of projections and type of tomographic acquisition in simple breast phantoms in order to obtain optimal SPECT results in acceptable acquisition time.

2. Methods

2.1. Acquisition system

The gamma camera consists of a R2486 Hamamatsu PSPMT equipped with 8×8 crossed-wire anode wire pairs. A 2.7 cm thick collimator with 1.12 mm diameter hexagonal holes and a 4.6 cm in diameter CsI(Tl) crystal pixelized in $1.13 \times 1.13\,mm^2$ cells are used in conjunction with the PSPMT for photon detection. The analog anode signals are preamplified through 16 preamplifiers (LeCroy TRA1000) and then transferred to a CAMAC system, which hosts an ADC (LeCroy FERA 4300B), a memory (LeCroy FERA 4302), a driver (LeCroy FERA 4301) and a controller (Jorway 73A). The digital signals are transported to a G3 Power Mac via a SCSI bus. Specific software (Kmax 6.4.5—Sparrow Corporation) allows CAMAC programming, data acquisition and signal processing.

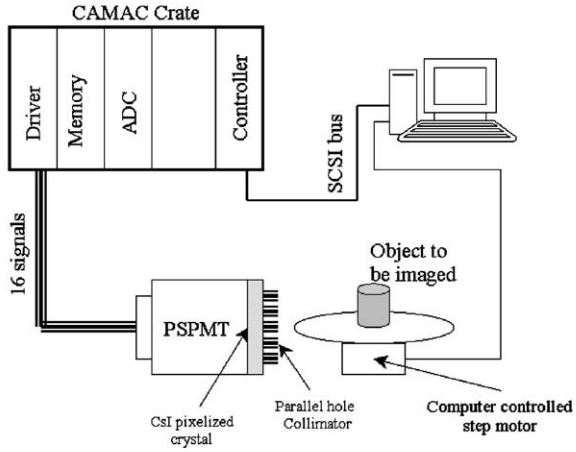

Fig. 1. Schematic diagram of the experimental configuration.

A computer-controlled step motor (MD-2 ARRICK Robotics) allows object rotation, thus, projection data from several angles is acquired. The slices are reconstructed using 30 iterations of a MLEM algorithm. The experimental configuration is shown in Fig. 1.

The performance of the system has been assessed both in planar and tomographic mode using capillary phantoms and small animals [7]. In Fig. 2 the images of 1.1 mm i.d. capillaries filled with a ^{99m}Tc solution and placed in 2 mm distances as well as the comparative image of a small mouse with the used system and a clinical gamma camera (ECAT, Siemens) are shown.

As it can be seen, the system offers a 2 mm resolution in planar imaging and is very sensitive to activity variations. Comparative small animal imaging with the clinical system has shown the improved performance of the PSPMT camera, which makes it suitable for the evaluation of radiopharmaceuticals in small animals.

2.2. Phantoms

In order to simulate a small tumor in the breast tissue, small spots of ^{99m}Tc were placed properly under (or in) a pot filled with 300 ml of a ^{99m}Tc solution of 7 mCi activity. The volume of these spots varied from 2 to 0.25 ml and the spot to the

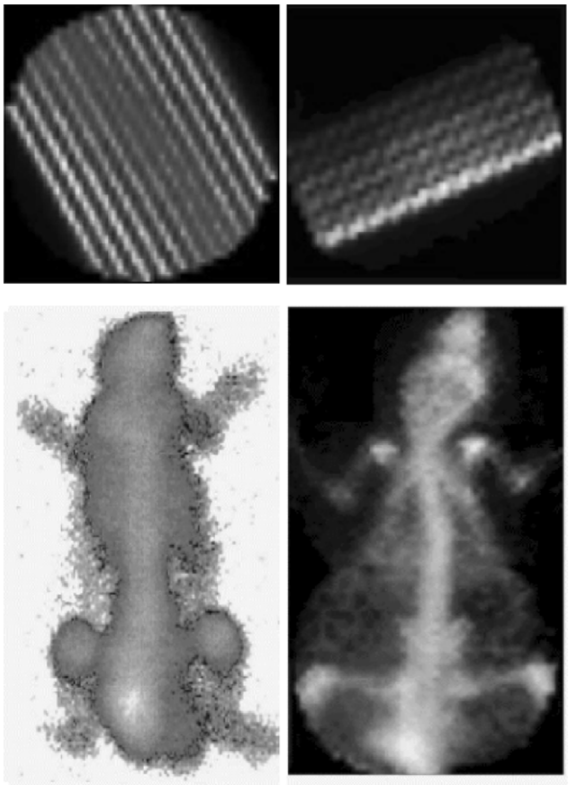

Fig. 2. Top left: Twelve capillaries filled with ^{99m}Tc solution in 2 mm distances. Top right: Six capillaries filled with ^{99m}Tc solution of different concentrations in 2 mm distances. Bottom left: A mouse injected with ^{99cm}Tc-MDP, imaged with an ECAT, Siemens gamma camera. Bottom right: The same mouse imaged with the used PSPMT system.

background activity ratio varied from 5:1 to 3:1. The spots to detector distance was 10 cm. In the SPECT study, the pot was filled with 500 ml of a ^{99m}Tc solution and the spot volume was 0.25 ml and the activity ratio 5:1.

3. Results

3.1. Planar results

In Fig. 3 the image of three spots with activity ratio 3:1 and volumes 0.5 ml (A), 0.375 ml (B) and 0.25 ml (C), placed under the 300 ml pot are shown. On Fig. 3a a 20% energy window has been used and on Fig. 3b a dual-energy window

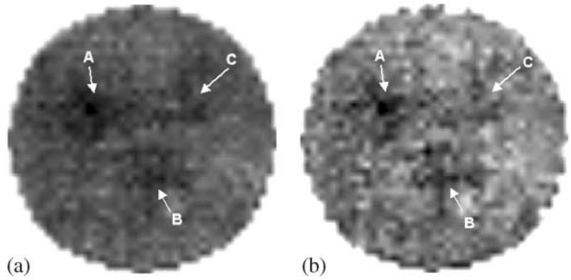

Fig. 3. Image of three spots with activity ratio 3:1 and volumes 0.5 ml (A), 0.375 ml (B) and 0.25 ml (C), placed under the 300 ml pot with the use of (a) a 20% energy window and (b) a dual energy windows subtraction technique.

subtraction technique (DEWST) [8,9] has been used in order to improve image contrast.

As it can be seen, the three spots can be imaged successfully and image contrast is enhanced when the DEWST is applied, although the signal-to-noise ratio (SNR) decreases. The obtained images, when spots of the same volume but with higher activity ratios (4:1 and 5:1) were imaged, are significantly improved.

An important parameter in the detection of these spots is the distance between the spot and the detector, which is similar to the depth in normal breast where a small tumor is located. As it is expected the shorter the distance is the clearer the depiction. The 10 cm distance that was used in these corresponds to a tumor located deep inside the breast, thus in a typical clinical case and especially if breast compression is used even better results are expected [10].

3.2. SPECT results

In Fig. 4a slice in the area of the spot is shown. The slice has been reconstructed using the data in the 100% photopeak window (Fig. 4a), in the 20% window (Fig. 4b) and using the DEWST (Fig. 4c). 36 projections from 0° to 350° with a 10° step were acquired and data were collected for 4 min per projection.

An error in the exact determination of the center of rotation was noticed after data collection and was corrected using post processing. However, the resultant images could be qualitatively evaluated

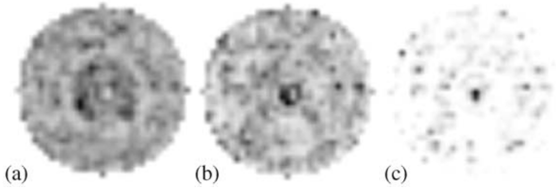

Fig. 4. A slice in the region of the hot spot as it has been reconstructed using the data in (a) the 100% photopeak window, (b) the 20% window and (c) the DEWST.

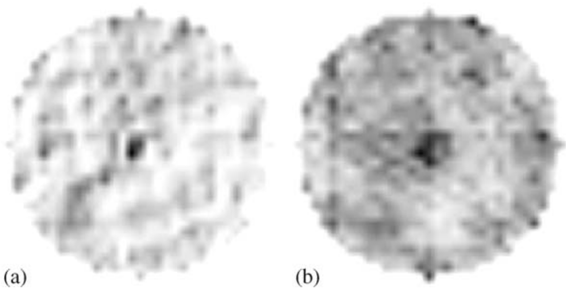

Fig. 5. A slice in the region of the hot spot as it has been reconstructed using (a) 12 projections obtained from 0–360° with a 30° step and (b) 12 projections are obtained from 0–120° with a 10° step (Fig. 5b).

but not quantitatively. As it can be seen, the 100% image is affected by the significant presence of the background whereas the 20% image offers improved contrast. The DEWST seems to significantly improve image quality; however, this technique has to be further investigated.

In order to explore the minimum acquisition time that would be necessary to obtain useful tomographic information, several imaging cases were studied. A number of tests investigated the symmetrical acquisition around the breast (0–360°) using several steps (30°, 60°, 90°), which could lead to a reduced number of projections (12, 6, 4, respectively). A second series of experiments investigated the use of a 10° step and a scan from 0–180°, 0–120°, 0–90° and 0–60°.

Although the presence of the center of rotation error may have partly affected the results, in both cases, it appeared that at least 12 projections are necessary and that the symmetrical acquisition mode is preferable. In Fig. 5 the results when 12 projections are obtained from 0–360° with a 30° step (Fig. 5a) and 12 projections are obtained from 0–120° with a 10° step are shown (Fig. 5b).

As it can be seen the hot spot can be identified in both cases although image contrast is worse when compared to the image of Fig. 4b.

4. Discussion

Scintimammography using dedicated PSPMT detectors can offer useful information since this method can take advantage of the wide range of ^{99m}Tc-based radiopharmaceuticals. Although a PET/PEM system is more efficient for tomographic imaging of the breast, the need for a cyclotron in order to produce PET radiopharmaceuticals is still a practical restriction.

Planar images of the breast can be acquired in a short time (<10 min) [11]. However, in the case of SPECT imaging, a number of projections are necessary and as it has been shown in this study, data from at least 12 different views have to be acquired. Since in clinical practice the total acquisition time cannot be more than 20–30 min, acquisition time should be minimized. Weisenberger et al. [11] have shown that a hot spot can be imaged even with 1-min data collection, 2 min after the injection of ^{99m}Tc-Sestamibi. In the case of small tumors in order to have a statistically acceptable number of counts, higher acquisition time would be necessary. A system equipped with more than one gamma cameras could allow simultaneous data collection from different projections [12].

These parameters have to be further investigated using anthropomorphic phantoms in order to determine acquisition protocols that could be applied in clinical practice. Although PET techniques are more promising, a fast SPECT system could offer similar results and be cost efficient.

5. Conclusions

The PSPMT system which has been designed for high-resolution small animal imaging can image small hot spots (down to 0.25 ml), which have spot-to-background activity ratio 3:1 in planar mode. In order to obtain acceptable tomographic images, data from at least 12 projections have to be collected. With the appropriate optimizations such a detector could be a low cost alternative compared to dedicated PET/PEM systems.

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References

[1] J. Maublant, Eur. J. Radiol. 24 (1997) 2.
[2] I. Khalkhali, J.A. Cutrone, I.G. Mena, L.E. Diggles, R.J. Venegas, H.I. Vargas, B.L. Jackson, S. Khalkhali, J.F. Moss, S.R. Klein, Radiology 196 (2) (1995) 421.
[3] R. Raylman, S. Majewski, R. Wojcik, A.G. Weisenberger, B. Kross, H.A. Bishop, Med. Phys. 27 (8) (2000) 1943.
[4] R. Pani, A. Soluri, R. Scaf, R. Pellegrini, A. Tat, F. Scopinaro, G. De Vincentis, T. Gigliotti, A. Festinesi, F. Garibaldi, A. Del Guerra, Nucl. Instr. and Meth. A 477 (2002) 509.
[5] S. Majewski, F. Farzanpay, A. Goode, B. Kross, D. Steinbach, A. Weisenberger, M. Williams, R. Wojcik, Nucl. Instr. and Meth. A 409 (1998) 520.
[6] N.D. Giokaris, G.K. Loudos, D. Maintas, D. Papapanagiotou, K.S. Nikita, N.K. Uzunoglu, A. Karabarbounis, C.N. Papanicolas, E. Stiliaris, S.C. Archimandritis, A.D. Varvarigou, C.N. Stefanis, S. Majewski, R. Pani, F. Scopinaro, Nucl. Instr. and Meth. A 497 (1) (2003) 141.
[7] G.K. Loudos, K.S. Nikita, N.D. Giokaris, E. Styliaris, S.C. Archimandritis, A.D. Varvarigou, C.N. Papanicolas, S. Majewski, D. Weisenberger, R. Pani, F. Scopinaro, N.K. Uzunoglu, D. Maintas, K. Stefanis, Appl. Radiat. Isot. 58 (4) (2003) 501.
[8] R.J. Jaszczak, C.E. Floyd, R.E. Coleman, IEEE Trans. Nucl. Sci. NS-32 (1985) 786.
[9] G. Loudos, N. Sakelios, N. Giokaris, K. Nikita, N. Uzunoglu, D. Maintas, 2nd ITBS Conference, Milos, 26–30 May 2003.
[10] R. Pani, R. Pellegrini, A. Soluri, I.N. Weinberg, G. De Vincentis, R. Scafe, M.N. Cinti, M. Betti, R. Inches, F. Scopinaro, F. Garibaldi, F. Cusanno, A. Del Guerra, I. Khalkhali, IEEE Nuclear Science Symposium and Medical Imaging Conference, Lyon, 2000; Conference Record, 2001, pp. 2696–2698.
[11] A.G. Weisenberger, F. Barbosa, T.D. Green, R. Hoefer, C. Keppel, B. Kross, S. Majewski, V. Popov, R. Wojcik, D.C. Wymer, IEEE Nuclear Science Symposium and Medical Imaging Conference, Lyon, 2000; Conference Record, 2001, pp. 2126–2130.
[12] N. Giokaris, A. Karabarbounis, C. Papanikolas, E. Stiliaris, P. Finou, Greek J. Nucl. Med. 1 (4) (1998) 209.