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Development of a Gamma-Camera with a Functional Collimator

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Abstract

We propose the novel gamma-camera with a functional collimator, that has detection ability on the collimator wall surface. The gamma-ray detection sensitivity of the proposed gamma-camera is improved by a factor of 70 compared with a conventional one. Through Monte Carlo simulations, the required gamma-ray emissions for image reconstruction is confirmed to dramatically to be reduced by using the information collected on the collimator wall surface. The spatial resolution is estimated to be 10 mm. In addition, we experimentally demonstrate image reconstruction procedure including reading out the collimator wall surface information. We successfully acquire the reconstructed images of a point-like Am-241 gamma-ray source from the projection image of the prototype gamma-camera with the functional collimator. We conclude that a much larger contribution from the gamma-ray emitters than background results in reduction on the lattice-shaped artifact.

KEYWORDS: *gamma camera, SPECT, functional collimator, image reconstruction*

1. Introduction

A gamma-camera is an imaging device to obtain distribution of gamma-ray emitters [1,2]. The gamma-camera can acquire a functional image of an organ by administering tumor targeting drugs labeled with gamma-ray emitters. When using devices such as the gamma-camera for nuclear medical imaging, medical exposure is a significant problem, because radioisotopes (RIs) must be administered into a patient body in this imaging technique. Medical exposure in nuclear medicine is, of course, desired to be reduced. A typical gamma-camera consists of a position sensitive gamma-ray detector and a collimator such that the gamma-rays emitted from RI sources are collimated to define their position. An incident gamma-ray direction into the position sensitive gamma-ray detector can be restricted by the collimator. The collimator eliminates gamma rays with an undesirable incident direction, which confuse estimation of locations of the gamma-ray emitters. The detection efficiency of the gamma-camera consequently decreases because the collimator completely stops these gamma rays. We, therefore, proposed a novel gamma-camera with a functional collimator, which is used not only to restrict incident gamma-ray directions but also to detect gamma rays that are otherwise eliminated by the conventional collimator. In other words, the functional collimator has the ability of detecting gamma rays on the wall surface of the collimators. This new gamma-camera is expected to improve detection efficiency, because the solid angle viewed from a source position to the detectable area increases. In this paper, we discuss feasibility of the proposed gamma-camera through simulation and experimental studies.

2. Configuration of the Functional Collimator

Figure 1 shows a fundamental configuration of the proposed gamma-camera with the functional collimator. The functional collimator consists of an Imaging Plate(IP) [3,4] and a parallel-hole collimator. The IP is the passive two dimensional imaging sensor plate made from $BaFBr:Eu^{2+}$, and has been developed by Fuji Film Co. Ltd. Latent images on the IP produced by X or gamma rays can be read out by scanning a stimulating laser beam. The IP is a reusable passive imaging sensor. The parallel-hole collimator with square holes is assembled with the comb-shaped wall plates, which are stacks of IPs and tungsten rubber sheets for gamma-ray shielding. The comb-shaped wall plates have the abilities to shield and detect gamma rays. The IP has a photostimulable phosphor layer of 0.115 mm thick and a support layer of 0.3 mm thick made of polyethylene terephthalate. The density and thickness of the tungsten rubber sheets for a gamma-ray sheilding are 11.6 g/cm^3 and 1 mm, respectively. The parallel-hole collimator has 18x18 square holes with 7.1 mm pitch.

3. Simulation Studies

3. 1. Required gamma-ray emissions for image reconstruction

To confirm the advantage of the proposed gamma-camera, we estimated the required gamma-ray emissions for obtaining an image with sufficient quality. For this purpose we performed Monte Carlo simulations with various gamma-ray emissions in the geometry shown in **Fig. 2**. The gamma-ray images projected onto the IPs were calculated. The reading pixel size of IPs was 1x1 mm^2. We additionally reconstructed images from the results of Monte Carlo simulations with a maximum likelihood-expectation maximization (ML-EM) algorithm [5]. The reconstructed image matrix was 36x36 pixels, which has 3.45x3.45 mm^2 pixel size. The reconstructed image was obtained after 5 iterations in the ML-EM algorithm. The reconstructed images with and without utilization of information of the collimator wall surface is shown in **Fig. 3**. When using the information of the collimator wall surface, we can clearly recognize an 8 mm diameter disc source even for 10^6 gamma-ray emissions. On the other hand, the image reconstructed without the wall surface information is unclear for even a 20 mm diameter disc source for 10^6 gamma-ray emissions. The detection efficiency of the gamma rays with and without the wall surface information were 7x10^{-3} and 1x10^{-4}, respectively. The gamma-ray detection efficiency improved by a factor of 70 by using the wall surface information. We conclude that the required gamma-ray emissions for image reconstruction can drastically be reduced by using the collimator wall surface information. The images obtained without wall surface information had some artifacts. The conventional gamma-camera using no wall surface information has some blind areas in the reconstructed plane. These blind areas result in artifacts. The proposed gamma-camera using the wall surface information can eliminate artifacts due to its wide viewing angle.

3. 2. Characterization of imaging ability

To evaluate the fundamental properties such as spatial resolution, uniformity and field of view, we reconstructed images from simulated results in the line source geometry as shown in **Fig. 4**. In this case, the RI line sources had the diameter of 1 mm and emitted 141 keV mono-energetic gamma rays, which corresponds to gamma rays emitted from ^{99m}Tc. In these evaluations, 10^8 gamma rays were emitted from whole source regions. The reconstructed image matrix was also 36x36 pixels, which has 3.45x3.45 mm pixel size. The reading pixel size of IPs was 1x1 mm^2. **Figure 5** shows the reconstructed images obtained from the line sources with various intervals. The spatial resolution is defined as the smallest distance with which we can clearly distinguish two lines in the reconstructed image. From **Fig. 5**, the spatial resolution was estimated to be 10 mm. **Figure 6** shows the vertical (b-b') and horizontal (a-a') profiles in the reconstructed image obtained from the line sources with 10 mm interval. From the horizontal profile, the uniformity, defined as the relative standard deviation of each peak value, was evaluated to be 11%. The field of view is considered as the region in which uniform response is obtained. From the vertical profile, the field of view was the region with the size of 100x100 mm^2 corresponding almost to the size of the gamma-camera.

4. Experimental Studies

4. 1. Collimator fabrication and reading procedure of PSL

We made the prototype gamma-camera with the functional collimator to experimentally demonstrate feasibility of the proposed gamma-camera. **Figure 7** shows the photograph of the functional collimator assembled with the comb-shaped IPs and the tungsten rubber sheets. The collimator had 9x9 square holes with 7.1 mm pitch. The aperture size and the wall height were 5x5 mm^2 and 30 mm, respectively. We also used the IP as the bottom detector under the collimator. The fabricated functional collimator can easily be disassembled into the comb-shaped parts. The disassembled IPs were regularly arranged and read out by the IP reader (FLA-5000, Fuji Film).

4. 2. Demonstrations of image reconstruction

We demonstrated image reconstruction by using the fabricated prototype gamma-camera. A point like ^{241}Am gamma-ray source (14.4 kBq) was placed at the distance of 30 mm from the top surface of the collimator and just above the center of the collimator. The gamma-camera was placed in the lead shield box to reduce the influence of background gamma rays and was irradiated by ^{241}Am gamma rays for various periods of time. **Figure 8** shows the projection images into the disassembled IPs from the collimator wall surface and the bottom. **Figure 9** shows the reconstructed images from these projection images. We successfully reconstructed the image corresponding to the point-like gamma-ray source. Point-like artifacts are considered to be caused by undesired latent images that are due to leaks from clearance gaps of the assembled collimator. When gamma-ray emissions were low, lattice-shaped artifact emerged. The lattice-shaped artifact is considered to be caused due to uniform background in the latent image. We found that a much larger contribution from the gamma-ray emitters than background results in reduction of the lattice-shaped artifact.

5. Conclusions

We proposed the novel gamma-camera with the functional collimator, that has detection ability on the collimator wall surface. The gamma-ray detection sensitivity of the proposed gamma-camera was improved by a factor of 70 compared with the conventional method. Through Monte Carlo simulations, the required gamma-ray emissions for image reconstruction was confirmed to dramatically be reduced by using the information detected on the collimator wall surface. The spatial resolution was estimated to be 10 mm. In addition, we experimentally demonstrated image reconstruction procedure including reading out the collimator wall surface information. We successfully acquired the reconstructed images of the point-like ^{241}Am gamma-ray source from the projection image of the prototype gamma-camera with the functional collimator. We found that a much larger contribution from the gamma-ray emitters than background results in reduction of the lattice-shaped artifact. As future works, we will try to fabricate a full system of the gamma-camera with the functional collimator. In addition, we should improve the reading and analyzing procedures of projection images by, for example, rejection of the counts due to leakage through the clearance gaps of the collimator, improvement of positioning precision of the latent images and simplification of the image reading procedures.

References

[1] H. O. Anger, “Use of a Gamma-ray Pinhole Camera for in vivo Studies“ *Nature*, **170** (1952) 200-201.

[2] H. O. Anger, “Scintillation camera” *Rev. Sci. Instrum.*, **29** (1958) 27-33.

[3] Y. Amemiya and J. Miyahara, “Imaging plate illuminates many fields”, *Nature*, **336** (1988) 89-90.

[4] J. Miyahara, K. Takahashi, Y. Amemiya, et al.,”A new type of x-ray area detector utilizing laser stimulated luminescence”, *Nucl. Instrum. Meth.* **A246** (1986) 572−578.

[5] L. A. Shepp and Y. Vardi, “Maximum likelihood reconstruction for emission tomography.”, *IEEE Trans Med Imag*, **1**, (1982) 112-121.

Captions

Figure 1 Fundamental configuration of the proposed gamma-camera with a functional collimator.

Figure 2 Simulation geometry for estimation of the required gamma-ray emissions for image reconstruction.

Figure 3 The reconstructed images a) –c) with and d)-f) without utilization of information of collimator wall surface obtained from the geometry shown in Fig. 2. Gamma-ray emissions were 10^8, 10^7 and 10^6 gamma rays for a) and d), b) and e), and c) and f), respectively.

Figure 4 Simulation geometry with line sources for evaluation of the fundamental properties, such as spatial resolution, uniformity and field of view.

Figure 5 The reconstructed images obtained from the line sources with various intervals.

Figure 6 The a) vertical (b-b' in Fig. 5 a)) and b) horizontal (a-a' in Fig. 5 a)) profiles in the reconstructed image obtained from the line sources with 10 mm interval.

Figure 7 Photograph of the functional collimator assembled with the comb-shaped IPs and the tungsten rubber sheets.

Figure 8 The projection images into the disassembled IPs from the collimator wall surface and the bottom. The gamma-camera was irradiated by a point-like ^{241}Am gamma-ray source.

Figure 9 The reconstructed images from the projection images for the fabricated prototype gamma-camera with the functional collimator. The gamma-camera was irradiated by the point-like ^{241}Am gamma-ray source.