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Monte Carlo design of optimal wire mesh collimator for breast tumor imaging process

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ABSTRACT

This paper presents the modeling of breast tumor imaging process using wire mesh collimator gamma camera. Previous studies showed that the wire mesh collimator has a potential to improve the sensitivity of the tumor detection. In this paper, we extend our research significantly, to find an optimal configuration of the wire mesh collimator specifically for semi-compressed breast tumor detection, by looking into four major factors: weight, sensitivity, spatial resolution and tumor contrast. The numbers of layers in the wire mesh collimator is varied to optimize the collimator design. The statistical variations of the results are studied by simulating multiple realizations for each experiment using different starting random numbers. All the simulation environments are modeled using Monte Carlo N-Particle Code (MCNP). The quality of the detection is measured directly by comparing the sensitivity, spatial resolution and tumor contrast of the images produced by the wire mesh collimator and benchmarked that with a standard multihole collimator. The proposed optimal configuration of the wire mesh collimator is optimized by selecting the number of layers in wire mesh collimator, where the tumor contrast shows a relatively comparable value to the multihole collimator, when it is tested with uniformly semi-compressed breast phantom. The wire mesh collimator showed higher number of sensitivity because of its loose arrangement while the spatial resolution of wire mesh collimator does not shows much different compared to the multihole collimator. With a relatively good tumor contrast and spatial resolution, and increased in sensitivity, a new proposed wire mesh collimator gives a significant improvement in the wire mesh collimator design for breast cancer imaging process. The proposed collimator configuration is reduced to 44.09% from the total multihole collimator weight.

1. Introduction

A low energy high resolution (LEHR) gamma camera using tungsten wire mesh as the collimator has a very high potential to detect tumors at their early stages [1,2]. With the loose arrangement of wire mesh configurations, the sensitivity of the collimator is increased rapidly without affecting the camera spatial resolution. The main idea of introducing the wire mesh collimator is to design a collimator that is lighter in weight than the conventional multihole collimator. Since the multihole collimator is big and heavy, the portability of the collimator is limited. By utilizing all the trade-off parameters, this paper manages to find the best optimal configuration of the wire mesh collimator for the purpose of imaging breast tumors.

In gamma camera imaging, the properties of the collimator geometry play a major role in controlling the sensitivity and resolution of the collected data. This trade-off ultimately has a significant effect on the performance of mathematical observation on various types of detection tasks and the collimator itself. This includes brain scanning, breast cancer imaging and even in testing using a realistic phantom.

Previously, the design concepts of wire mesh collimator for gamma camera have been introduced by Saripan et al. [3,4]. Almost similar concept has also been tested by Chamberlain [5], and Ogawa and Kato [6,7] using limited wire layers and rods, respectively. The wire mesh collimator introduced by Chamberlain [5], and Ogawa and Kato [6,7] were tested and the results showed lack of performance and it could not compete with the multihole collimator available [3]. Saripan et al. [3] introduced the design of collimator that could be a direct replacement to the original multihole collimator. There are two types of wire mesh collimator designs proposed by Saripan et al. [3], which are WMC1 and WMC2. WMC1 is an arrangement of wire mesh and empty space of intermesh layer; whereas WMC2 has a wall at both ends of the collimator, created by adding an extra wire mesh layer in between the intermesh layer of WMC1 as shown in Fig. 1. In this paper, we utilize the configuration of WMC2, to search for the most optimal configuration for breast cancer imaging by

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assessing the performance with a conventional multihole collimator. The configuration of both wire mesh collimators will be further explained in the coming section. When WMC1 and WMC2 were designed, the simulations were performed using a single and double point source located inside of the water cylinder [3]. As noted in the literature, the simulations were performed using MCNPX software with only one realizations of each experiment. This paper utilizes Monte Carlo N-Particle Code Version 5 (MCNP5) [8] to simulate multiple realizations for each experiment in order to study the statistical variation of the results.

Some preliminary studies on simulation of WMC1 and WMC2 with a semi-compressed breast phantom have been conducted in Refs. [1,4]. In those works, we looked into the different size of tumors and different tumor to the background ratio (TBR) to observe the effect on its sensitivity and the tumor contrast to the background ratio (CBR) of WMC1 and WMC2 in comparison to the multihole collimator. The results, on one hand, show a better characteristic of sensitivity but, on the other, are insignificant in tumor CBR for small tumor size and small TBR used. In this paper, we extend our research to find the best possible configuration of wire mesh collimator for semi-compressed breast phantom by looking into four major factors, which are the weight, the sensitivity, spatial resolution and the tumor contrast.

1.1. *Wire mesh collimator configuration development*

When Chamberlain [5] first introduced the design of wire mesh collimator, he came out with a collimator using three layers of wire grid. Chamberlain [5] analyzed the modulation transfer function for the optimal parameter value of the collimator and he found that his proposed configurations did not match the quality of image produced by the multihole collimator. He suggested putting more layers instead of just three.

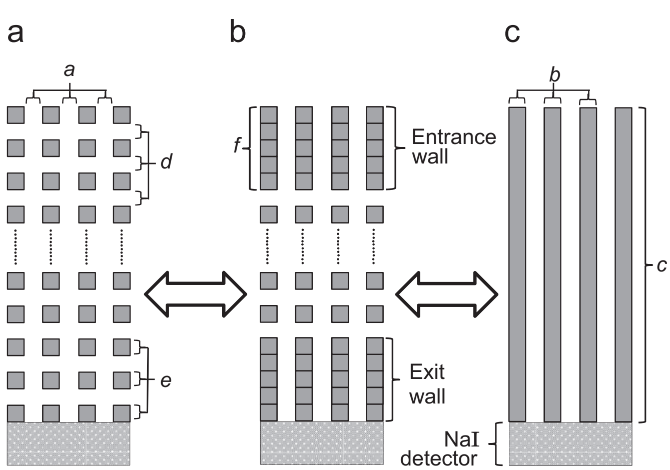

Fig. 1. The side view of (a) WMC1, (b) WMC2 and (c) multihole collimator.

Ogawa and Kato [6,7] came up with several designs of light weight collimator by arranging a rod-shaped of wire in *x*-direction only or *y*-direction only with a gap between the rod. Then, it is arranged alternately without spacing in the *z*-direction. In the third design proposed by them, they used the block of entrance wall and the exit to improve the collimator performance, and this idea had been used by Saripan et al. to develop their own design [3].

Saripan et al. [3] used a combination approach by Chamberlain and Ogawa and Kato to develop a wire mesh collimator and come up with two new types of wire mesh collimator configuration: WMC1 and WMC2. WMC1 is an arrangement of alternate filled of wire mesh layer and empty space; whereas in the WMC2 design, the entrance and exit walls are introduced. WMC1 and WMC2 parameters are based on the original configuration of multihole collimator as listed in Table 1. Entrance and exit walls in WMC2 are formed by filling an intermesh space in WMC1 by a wire mesh layer [3]. By adding more layers to form the entrance and exit walls, the collimator sensitivity will be decreased and the weight will be increased. The number of wire mesh can be add up to 50 layers for each wall. Increasing more layers for the entrance and the exit wall would make a wire mesh collimator become closer to the featured of a multihole collimator. On the other hand, less wires added would make it resembles the WMC1. The relationship between WMC1, WMC2 and multihole collimator can be seen in Fig. 1. The suitable numbers of wire added to the wall would give an optimal configuration of wire mesh collimator. The search for configuration that could compromise between resolution, sensitivity and collimator weight would result in the optimal configuration of wire mesh collimator.

Weight reduction of the collimator is one of the major reason to introduce wire mesh collimator as an alternative of conventional multihole collimator. Light weight helps in the development of the portable gamma camera. Using a rectangular wire, the weight can be reduced up to 49% and cylindrical wire reduces the weight down to 60.5% as compared to original weight of the multihole collimator.

2. Simulation environment descriptions

Toshiba GCA 7100A gamma camera has been used as a reference for the simulation model platform prepared in this paper. As shown in Fig. 2, the model of the given gamma camera design in the Monte Carlo simulation was validated with real gamma camera for validation and can be retrieved in Ref. [9]. The Monte Carlo technique is a numerical method for obtaining the solution of a problem that depends on a stochastic process, in this case the distribution of photons that are emitted by a radioactive material, which will go through all scattering materials before recorded by a detector using pulse height tally. There are two major components that we take into consideration in designing the gamma camera simulation environment; the first part is the collimator and the second part is the scintillation detector. The collimator used is an LEHR collimator

Table 1
Specifications of collimator configuration.

Specifications	Multihole collimator	WMC1	WMC2	Ogawa and Kato-B	Ogawa and Kato-C
Hole dimension (a)	0.15 cm	0.15 cm	0.15 cm	0.15 cm	0.15 cm
Septa thickness (b)	0.02 cm	0.02 cm	0.02 cm	0.02 cm	0.02 cm
Collimator thickness (c)	4.02 cm	4.02 cm	4.02 cm	4.02 cm	4.02 cm
Intermesh spaces (d)	Not applicable	0.02 cm	0.02 cm	No space	No space
Wire diameter (e)	Not applicable	0.02 cm	0.02 cm	0.02 cm	0.02 cm
Wall thickness (f)	No wall	No wall	0.62 cm	No wall	0.1 cm
Weight reduction	Reference	60.5%	48.8%	58.3%	57.7%