A Prototype Gamma Tomosynthesis System for Molecular Breast Imaging

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***Abstract*— We are developing an improved gamma camera for molecular breast imaging (MBI) that allows tomographic imaging and improved signal-to-noise over conventional planar methods. We have built a novel gamma camera for MBI that utilizes limited angle tomography, similar to x-ray tomosynthesis, to generate images with depth information and improved signal-to-noise. A unique feature of the gamma tomosynthesis system is a variable-angle slant hole (VASH) collimator. This collimator allows the camera to remain flush against the compression paddle during the tomographic acquisition, which achieves high spatial resolution and simplified detector motion. We constructed a VASH collimator from a stack of tungsten sheets, each sheet containing a matrix of holes created by photo-etching. With the holes of the sheets aligned, a parallel-hole collimator is created; shearing the sheets creates a variable angle slant hole collimator. The shearing is controlled by a motorized mechanism. The collimator was mounted on a commercial MBI camera and projection data were acquired of a set of capillary tube line sources over a 50° range of angles. The projection data were reconstructed using the iterative MLEM method. Results demonstrated the ability of the system to resolve in the depth dimension, and spatial resolution matched expected values. We conclude that the proposed gamma tomosynthesis system has the potential to provide improved signal-to-noise over conventional MBI methods and allow a reduction in the administered radioactivity and patient dose..**

I. Introduction

Nuclear medicine imaging using 99mTc-sestamibi and dedicated gamma cameras has demonstrated the potential to complement mammography (MM) in women with radio-dense breasts [1,2]. These procedures have been referred to as molecular breast imaging (MBI) or breast-specific gamma imaging depending on specifics of the camera design. Wider application of MBI, including the potential use as a screening tool for high-risk women with dense breasts, requires a reduction in radiation dose and improved imaging methods to assure satisfactory image quality at lower dose.

One approach to improve image quality is to use tomographic imaging methods, which generally offer improved contrast-to-noise ratio over planar methods. For x-ray breast imaging, limited angle tomography, or digital breast tomosynthesis (DBT), has shown great promise in this regard [3]. In a similar manner, the MBI system developed here is designed for limited angle tomography, or "gamma tomosynthesis". While other approaches for tomographic MBI have been proposed, particular features of this design include a high spatial resolution/sensitivity trade-off, the capability to incorporate into MM or DBT systems for multi-modality imaging, and the capability for on-board biopsy systems.

The gamma camera developed here uses a unique variable-angle slant-hole (VASH) collimator. Rather than rotate the camera around the breast, the VASH collimator allows limited angle, tomographic acquisition while the detector remains stationary and flush against the compression paddle (Fig. 1A and 1B). This design minimizes object distance for high spatial resolution. This collimation technique was originally proposed in 1983 for tomographic imaging of the heart [4]; however, the advantages of a rotating cardiac SPECT system with complete angular sampling and relatively close object-to-detector distance have been preferred. For a gamma camera that is integrated with a MM or DBT system (i.e. utilizing a compression paddle), the limited angle approach has greater potential because of the difficulty in staying close to the object while obtaining complete angular sampling (Fig. 1C).

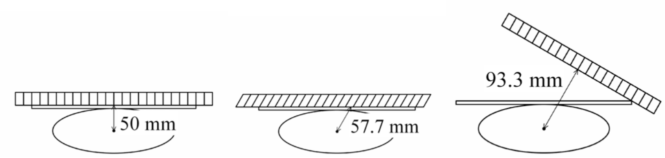

Fig. 1. VASH collimator in coronal slice with breast outline and compression paddle. (A) 0° projection, (B) 30°, (C) parallel hole collimator, 30°.

In our previous studies, theoretical analysis and Monte Carlo simulations demonstrated the advantages of the VASH collimator relative to a conventional parallel hole collimator in terms of contrast-to-noise ratio in reconstructed images [5]. Based on these studies, a prototype VASH collimator was built. The purpose of this study is to evaluate the prototype

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collimator and camera system based on reconstructed image quality using a multiple line source phantom.

II. Methods

A. Description of VASH Collimator

Based on our previous simulation studies [5], the VASH collimator was constructed from a stack of tungsten sheets, each containing an identical array of holes created by photo-etching. A total of 52 tungsten sheets were produced, each 0.25 mm thick. The tungsten sheets have square 1.35 mm holes with 0.25 mm septa for a hole pitch of 1.6 mm. The collimator mounts to the Dilon 6800 camera, which has NaI(Tl) crystal pixels exactly twice this pitch (3.2 mm) and same thickness septa. This design allows collimator septa to be aligned with crystal septa so that the inactive area of the crystal due to the septa is effectively eliminated, and photon sensitivity of the camera is substantially increased.

A parallel hole collimator is created by vertically aligning the holes/septa of the sheets (Fig. 2A). A slant hole collimator is created by shearing the sheets like a deck of cards (Fig. 2B). Variable degrees of shearing create variable slant angles.

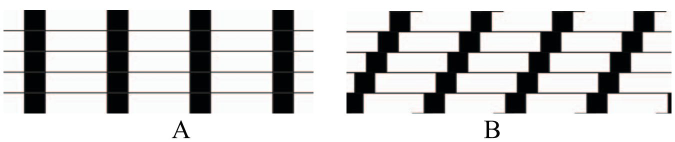

Fig. 2. Illustration of VASH collimator concept

The mechanism for shearing the tungsten sheets utilizes four sliding wedges placed along the side of the VASH collimator (Fig. 3).

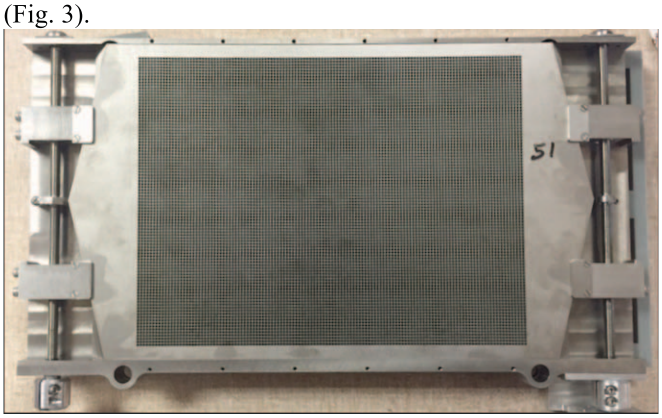

Fig. 3. Photograph of prototype VASH collimator

The desired angle of the slant hole collimation is selected by moving four sliding wedges, such that the wedge moves the leaves along their free dimension each with a different displacement. The slant angle range is determined by the cut profile of opposing sides of each leaf and a matching profile for the sliding wedge. Since the displacement by wedge motion of each leaf is continuous, the collimation angle can be varied continuously within a range of ±30°. On each side of the leaves the two wedges move in opposite directions to balance the force and eliminate racking. Actuators for the wedges, which ride on twin-lead screws, are driven by a servomotor with a high ratio gear box.

B. Line Source Study

Lines sources were constructed from capillary tubes each filled with approximately 200 µCi of ^{99m}Tc. Five lines sources were arranged with two oriented in a plane parallel to the collimator surface at 4 mm distance and three stacked in a plane perpendicular to the collimator surface at 11 mm, 31 mm, at 57 mm distance (Fig. 4). Projection data were acquired using 11 slant angles over a range of ±25° with 5° increments and 100 seconds per angle. The projection data were reconstructed using the MLEM algorithm with 100 iterations.

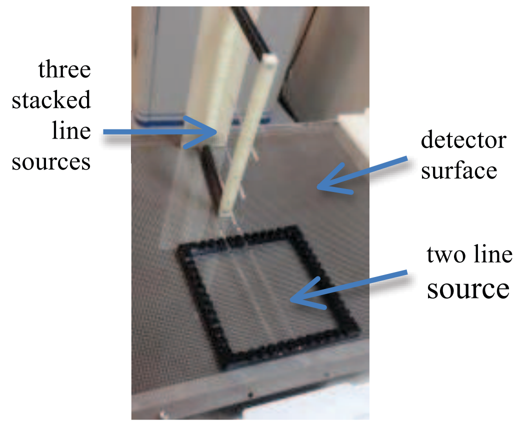

Fig. 4. Photograph of line source fixture on camera

III. Results

Figure 5 shows projections images of the line source phantom for the 0° and 25° slant angles. Note that in the 0° image the three stacked line sources superimpose in the projection.

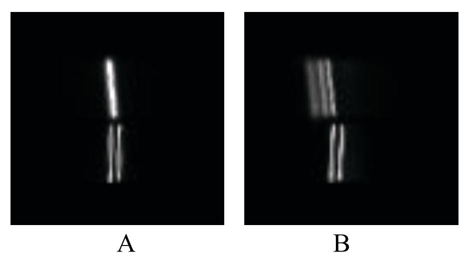

Fig. 5. Projection images at (A) 0°, and (B) 25°.

Reconstructed images and image profiles are shown in Figs. 6 and 7. In both cases, the horizontal dimension in the images is the depth dimension (perpendicular to the camera surface), and the camera is positioned to the right of the image. Figure 6 is a slice image through the two-line source region of the projections. The two sources are clearly distinguishable. Figure 7 represents the more challenging situation with the sources aligned in the depth dimension. The expected blurring due to the limited angle nature of the data is evident. The distance between the sources (approx. 2cm) approaches the limiting resolution in this dimension.

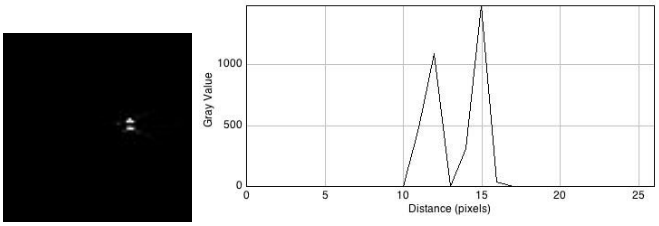

Fig. 6. Reconstructed image at a two line source slice and a vertical profile through the source centers

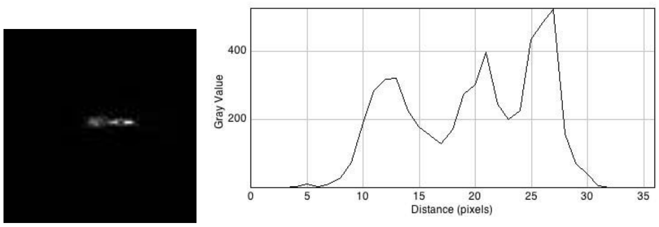

Fig. 7. Reconstructed image at a three line source slice and a horizontal profile through the source centers

IV. Discussion

This paper presents the initial testing of a prototype camera for MBI gamma tomosynthesis. The tomographic data are acquired using a variable angle, slant hole collimator. The system has the advantages of high spatial resolution/sensitivity trade-off due to maintaining a close object distance, simplified camera motion, compatible with MM or DBT systems and capability for on-board biopsy. Initial results show the spatial resolution performance of the system including the expected blur in the depth dimension.

V. Acknowledgment

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