Design of an ultra-low-dose, stationary, tomographic molecular breast imaging system.

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***Abstract*– Molecular Breast Imaging (MBI) has been shown to have high sensitivity in detection of cancer, even in patients with dense breasts where conventional mammography has issues. However the technique has limited acceptance due to the relatively high radiation dose and long imaging time. Improved lesion detection can be achieved using tomography, however this normally involves detector motion and complex mechanics. Our goal is to develop a low-dose stationary tomographic MBI system with similar or better sensitivity for lesion detection to conventional planar MBI. The proposed system utilizes state-of-the-art cadmium zinc telluride (CZT) detectors based on 2mm pixels, with sub-pixelization and depth of interaction (DOI) capability, combined with densely packed multi-pinhole collimators. Use of closely-spaced pinholes improves efficiency and angular sampling, but results in significant multiplexing. De-multiplexing algorithms have been developed that take advantage of the DOI acquisition to achieve tomographic reconstruction using two opposing planar detectors which apply mild compression to the breast. Simulation studies of multiple lesions with clinically realistic contrast have been used to demonstrate the feasibility of the design and to characterize the expected performance. Reconstruction without de-multiplexing resulted in significant artefacts. De-multiplexing without DOI had limited success but with DOI resulted in artefact-free images, with good contrast and axial plane definition. Lesion detectability was preserved even with reduction of acquisition time (or radiation dose) by a factor of 4. Further optimization has potential for even greater dose reduction. A prototype system is currently being constructed to validate these findings.**

I. Introduction

MAMMOGRAPHY is widely used as a screening procedure for breast cancer, however, its sensitivity for lesion detection is severely hampered in patients with dense breasts. Molecular Breast Imaging (MBI) using dual planar detectors has been shown to have much better sensitivity in this patient group [1] but its widespread use has been limited due to its relatively high radiation dose and long imaging time. Dedicated tomographic MBI systems have been designed involving complex mechanics [e.g.2]. Simpler systems based on opposing detectors and multiple non-multiplexed pinholes have been suggested but these require detector motion to cover the required field-of-view (FOV) [3]. Our goal was to design a low-dose stationary tomographic system which would be suitable for complementary breast screening. In this paper the overall design concept is presented and performance compared with conventional planar MBI.

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II. Methods

The overall design concept is to use dual opposing high resolution detectors with multi-pinhole (MPH) collimators, applying mild breast compression in the same way as conventional planar MBI systems (Fig.1). Usually multiplexing is avoided by utilizing widely spaced pinholes, which limits the angular sampling and/or FOV. Instead we propose the use of closely packed pinholes positioned close to the high intrinsic resolution detectors. The acquired data have significant multiplexing (overlap of projections from adjacent pinholes) which leads to artefacts due to ambiguity in the origin of emitted photons. We have developed algorithms to de-multiplex the data, either before or during reconstruction, which make use of the variable degree of multiplexing in different detector layers identified by depth-of-interaction (DOI) information. To demonstrate the proof of principle a possible configuration for the MBI system was simulated and compared with conventional planar imaging using high resolution parallel-hole collimators.

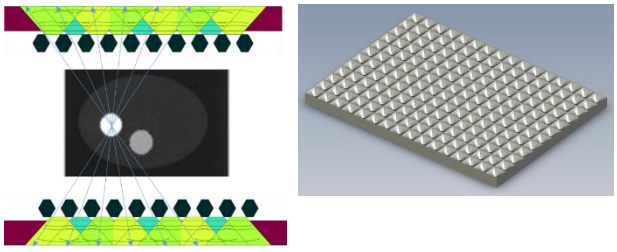

Fig 1: Closely-packed pinholes (right) enables acquisition of multiple projection angles (left) using stationary detectors. Note that the degree of multiplexing varies across the detector depth.

A. Detector design & de-multiplexing

Based on detector panels constructed from 7.3mm thick cadmium zinc telluride (CZT) with 2mm pixelated anodes [4], simulations were performed, assuming that 1mm sub-pixelization and DOI determination can be achieved. Tungsten MPH collimators with square apertures were positioned close to the detector surface. Detector-collimator distance (3mm), aperture diameter (1.75mm), maximum opening angle (85°) and inter-aperture spacing (9mm) were chosen to optimize lesion detection [5] and compared with conventional planar

MBI. The collimator design resulted in 64% of detected counts being multiplexed.

Projections were constructed for multiple layers using DOI information. These were used either to iteratively construct a virtual de-multiplexed projection for conventional reconstruction (2-step) or to incorporate the multiplexing in a modified system matrix for direct reconstruction (1-step). A combination of the two approaches was also used in this study (hybrid) [6]. The approaches differ from that of Moore et al. [7] where a 2-step process is used during reconstruction. Reconstruction was performed using a MAP algorithm to encourage a regularized solution. Correction for the known uniform attenuation was included but scatter was not simulated.

B. Phantoms

A phantom with constant size lesions (5mm) of varying tumour to background ratio (TBR=5-20) was used to evaluate the reconstruction algorithms. The phantom (Fig. 2 left) was placed at depth of 1.5cm in a 6cm thick phantom to represent typical lesions in a compressed breast. The mean lesion contrast and noise were calculated for reconstructions using the three approaches (1-step, 2-step and hybrid) varying the distance between pinholes from 20-10mm, thus introducing an increasing degree of multiplexing.

Quantitative analysis was performed for a second phantom (Fig. 2 right) with spherical lesions of varying size (4-8mm) and TBR (5-25), with counts based on acquisition time (0.5-5mins) for the activity level routinely used in clinical scans (300MBq). The contrast to noise ratio (CNR) was measured for all lesions with sensitivity defined as the number of lesions that exceeded the Rose criterion, CNR>4. Results for planar images, with Gaussian smoothing with FWHM=5mm, were compared with the hybrid tomographic reconstructions (5 iterations with 3 subsets) using a prior that encourages constant resolution, independent of depth.

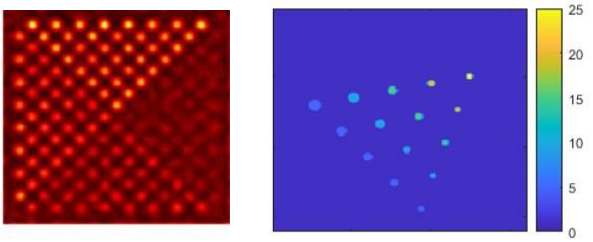

Fig 2: Phantoms used for evaluation of the reconstruction algorithms (left) and for lesion detection compared to planar imaging (right).

III. Results

Fig. 3 illustrates the mean TBR versus noise (CoV) for varying degrees of multiplexing. The 1-step and 2-step approaches demonstrate opposite characteristics with increased multiplexing. The hybrid approach provides a more stable reconstruction with a gain in performance even with significant multiplexing.

Comparison of reconstructed versus planar data are presented in Fig. 4 with a summary of the number of detected lesions based on CNR exceeding 4 presented in Fig. 5. The results confirm that reduction in acquisition time (or reduced activity/dose) can be achieved with minimal loss of performance. Administration of 75MBq appears to be feasible, which would result in a radiation dose (0.6mSv) similar to the typical radiation dose for conventional mammography.

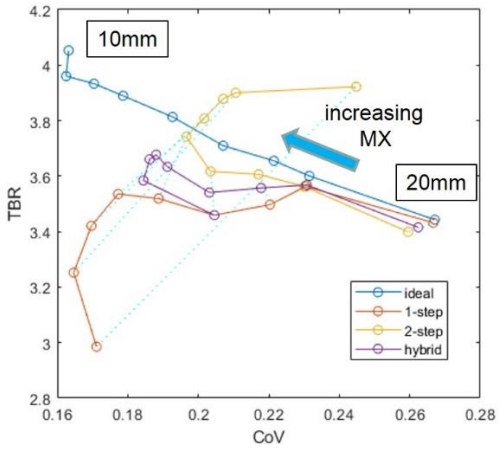

Fig 3: Plots of TBR versus noise (CoV) for different degrees of multiplexing using 1-step, 2-step and hybrid reconstruction, compared with the ideal case which excludes multiplexing.

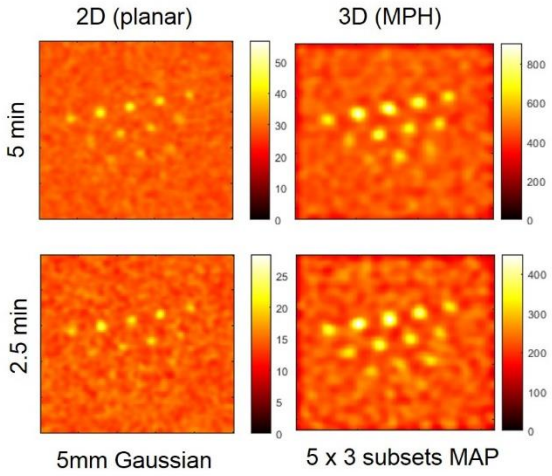

Fig 4: Simulated phantom studies with 2D acquisition (left) and reconstructed 3D data (right), with acquisition times of 5 min (top) and 2.5 min (bottom) (equivalent to reducing activity to 150MBq and 75MBq respectively).

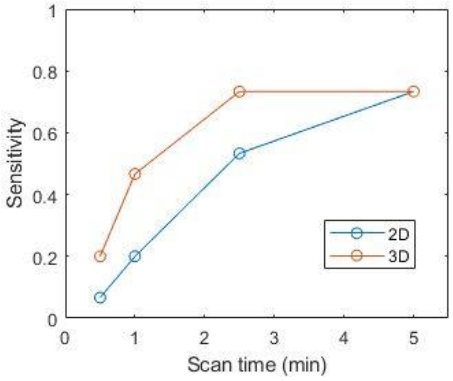

Fig 5: Sensitivity (defined as fraction of lesions with CNR>4) for different scan times based on 300MBq administered activity for planar acquisition and 3D reconstruction.

IV. Discussion

Usually MPH geometry is restricted due to the need to avoid multiplexing. The addition of DOI information to determine layers within the detector with variable degrees of multiplexing aids in the solution of the de-multiplexing algorithm. As a result a relatively large number of apertures can be used with better angular sampling and sensitivity.

Direct comparison of results from planar and tomographic studies is difficult especially as processing to optimize signal to noise will be different for the two situations. Contrast is clearly improved with tomography but at the expense of increased noise. We have chosen to use analysis of CNR in this study but a more comprehensive ROC analysis of clinically realistic datasets will be performed in future studies. Our results demonstrate that design of a stationary low-dose MBI system is feasible with potential to reduce radiation dose to levels comparable with x-ray mammography. An added advantage of the tomographic system is the 3D localization, which reduces the need for the second view as is typically required using planar detectors. This means that acquisition time can be significantly reduced. A prototype system has been constructed by Kromek Ltd to validate these findings and is currently under assessment.

V. References

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