Upright dedicated cone-beam breast CT: Short-scan, non-uniform, sparse-view angular sampling for radiation dose reduction

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INTRODUCTION

The current version of diagnostic prone patient-position breast computed tomography (BCT) eliminates tissue superposition and improves sensitivity over digital mammography (DM).[1] However, the mean glandular dose (MGD) from BCT is approximately twice that of 2-view screening DM.[2] To translate BCT for screening, lowering the radiation dose to be comparable to the standard 2-view DM is necessary. Upright position BCT (UBCT) is a next-generation BCT. Our UBCT design has high potential to provide early detection and also make impact on diagnosis and breast cancer treatment. Additionally, the upright geometry reduces the space requirements and also makes a easy way to setup in mammography suites. Finally, unlike current BCT, patient discomfort and difficulty of movements due to the prone position are eliminated.

AIM

This study is aimed at designing a spatial arrangement of the x-ray sources combined with a compressed sensing (CS) image reconstruction algorithm to attain the radiation dose reduction, compared to the current prone position BCT 360-degree with 300 projection views), without sacrificing the image quality.

METHOD

In UBCT, the dimensions of the breast in the coronal plane are expected to be asymmetric. Ten cases (four with calcified lesions) with asymmetric dimensions in the coronal plane were selected from an existing de-identified database of prone position BCT exams to simulate the breasts in upright position with a breast support. Feldkamp-Davis-Kress [3] (FDK) reconstruction of the full-scan prone position BCT data served as the reference. Projection data encompassing 192-degree short-scan acquisition with non-uniform angular sampling (96 views) were selected retrospectively such that the view sampling is finer for rays traversing along the longer dimension of the breast. Fast, Iterative, TV-Regularized, Statistical reconstruction Technique [4] (FIRST) was used for incomplete data reconstructions. Hyper-parameters of FIRST were tuned to match the variance of FDK images. Image quality was quantified by the full-width at half-maximum (FWHM) of calcifications in two orthogonal directions, bias and root-mean-squared-error (RMSE) computed with respect to reference.

RESULTS

The FWHM of calcifications in short-scan, sparse-view, non-uniform sampling UBCT were similar to reference (median difference of 0%), indicating comparable spatial resolution. Regarding RMSE and bias, the observed median of 11.95×10^{-6} cm^{-1} and 12.02×10^{-3} cm^{-1} correspond to approximately 0.004% and 4%, respectively, for the range of linear attenuation coefficients expected for breast tissue. The computational time (40 iterations) was less than 7 minutes.

Recon	FDK	FIRST			
Views & Scan Angle	300 views 360 degree	96 views 192 degree			
Case #	Variance (10^{-3})	Variance (10^{-3})	RMSE (10^{-6})	Bias (10^{-3})	FWHM (Difference)
Case #1	10.833	10.5	13.11	12.13	0
Case #2	8.4293	8.6	10.79	11.50	none
Case #3	7.8	7.9	17.45	13.16	none
Case #4	11.2	11.5	16.04	12.64	None
Case #5	8.8	8.4	21.49	11.71	none
Case #6	9.7	9.9	5.51	10.69	0
Case #7	7.5	7.4	6.09	9.34	0
Case #8	8.6	8.3	8.25	11.94	none
Case #9	12.2	12.2	13.95	13.46	0
Case #10	8.5	8.5	9.62	12.10	0
Median	*8.6*	*8.6*	*11.95*	*12.02*	*0*

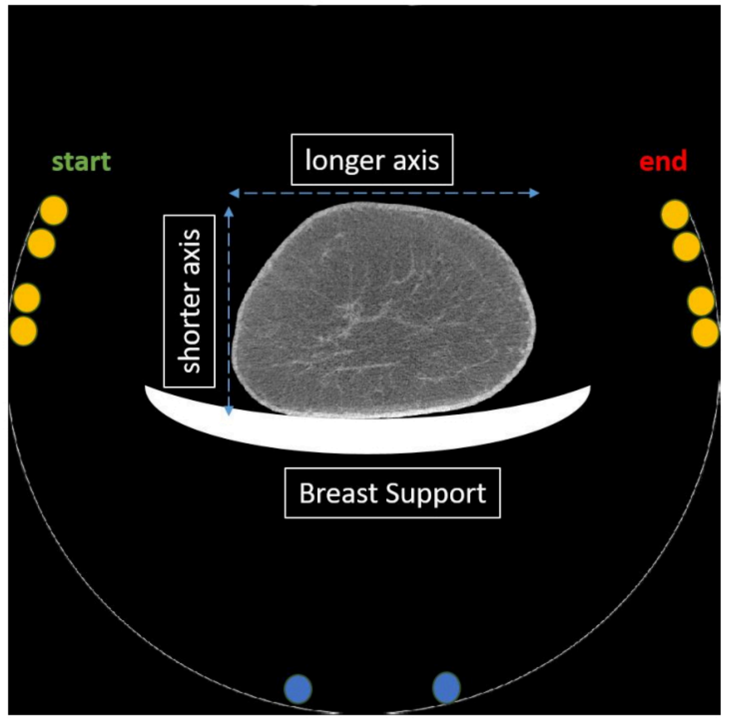

Figure 1. Demonstration of upright-position cone-beam dedicated breast CT. The x-ray source trajectory encompasses an angular range of 192-degrees (marked as "start" and "end"). Non-uniformly distributed sparse-view acquisition (total 96 views) was simulated by retrospectively selecting the projections. These projections were selected so that the view sampling is finer for rays traversing the longer axis of the breast (yellow circles, n=64 views) and coarser for rays traversing the shorter axis of the breast (blue circle, n=32 views). Note: The breast support was added manually to show the intended approach. X-ray transmission through the breast support was not modeled.

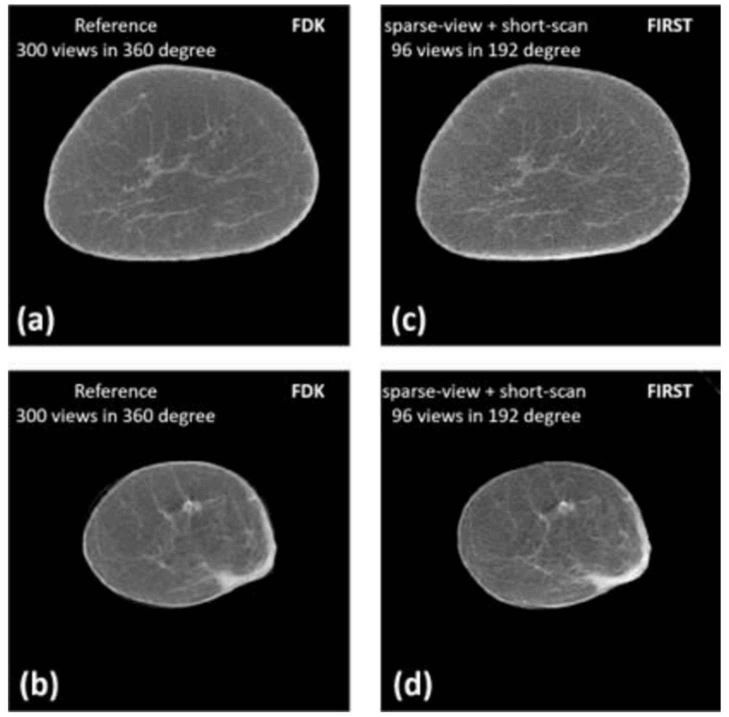

Figure 2. (a) Reference full-scan (360-degree; 300 views), equiangular sampling, FDK reconstructed image; (b) FDK reference image of the slice with calcification; (c) Short-scan (192 degree; 96 views), non-uniform angular sampling, ASD-POCS reconstructed image corresponding to (a). The hyper-parameters of ASD-POCS were chosen so that the image variance is similar to the FDK reconstructed image; (d) ASD-POCS image of the slice with calcification.

CONCLUSIONS

This study indicates the feasibility of a non-uniform angular undersampling acquisition schemes applied to UBCT using compressed sensing-based iterative reconstruction. This suggests that shorter scan times and reduced radiation dose without sacrificing image quality are potentially achievable. Reader studies are planned in the future.

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