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Optimal Acquisition Parameters for Compressed Sensing-based Sparse View, Upright, Cone-Beam Breast CT: Phantom Study

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ABSTRACT

Purpose: To optimize acquisition parameters for sparse-view acquisition and compressed sensing-based image reconstruction to achieve a targeted mean glandular dose (MGD) of 4.5 mGy while maintaining microcalcification visibility for a short-scan, upright, dedicated cone-beam breast CT (CBBCT).

Methods: A homogeneous breast phantom (20% fibroglandular fraction) with 0.24–0.32 mm calcium carbonate microcalcification test objects was imaged at 60 kVp, 0.15 mm Cu filtration, 210° short scan. Tube current (40–50 mA), X-ray pulse width (18–20 ms), and angular sampling were varied. All images reconstructed with FRIST. Two readers evaluated microcalcification visibility blinded to the protocol.

Results: Three parameter combinations achieved MGD of approximately 4.5 mGy: (a) 90 views/50 mA/20 ms; (b) 100 views/50 mA/18 ms; and (c) 114 views/40 mA/20 ms. The 50 mA/20 ms/90-view protocol provided superior 0.24 mm calcification visualization.

Conclusion: FRIST-based sparse-view reconstruction enables upright CBBCT at 4.5 mGy with 0.24 mm microcalcification visibility. Multiple viable protocols offer flexibility for clinical implementation.

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INTRODUCTION

Cone-beam breast CT (CBBCT) provides fully three-dimensional, compression-free imaging of the breast, eliminating the tissue superposition inherent to mammography and the slice-separation artifacts in digital breast tomosynthesis (DBT).

The upright geometry improves accessibility for patients who experience discomfort in prone positioning (39% of prone CT participants) and allows installation in standard mammography rooms.

Achieving screening-compatible dose (≈4.5 mGy, comparable to 2-view digital mammography) requires sparse-view acquisition. However, reducing views with standard FDK reconstruction introduces streak artifacts that degrade diagnostic quality.

FRIST (Fast, total variation-Regularized, Iterative, Statistical reconstruction Technique) [1-3] enforces a data consistency constraint while minimizing total variation, enabling artifact suppression in sparse-view acquisitions. The key acquisition parameters — tube current (mA), X-ray pulse width (ms), and number of views — jointly determine dose and image quality, and their optimal combination has not been systematically evaluated for upright CBBCT.

METHODS AND MATERIALS

The upright CBBCT uses a CsI:Tl scintillator coupled CMOS detector (151.8 µm pitch, 30×30 cm active area). The X-ray source travels inferior to breast through 210° short-scan. SAD = 503 mm, SDD = 703 mm. All imaging were performed at 60 kV with 0.15 mm Cu + 1 mm Al filtration (HVL = 4.23 mm Al).

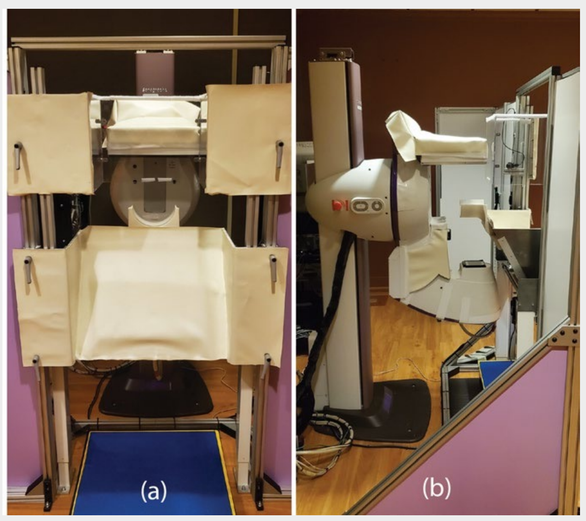


Figure 1. Picture of the upright CBBCT system. (a) Front View (b) Side View.

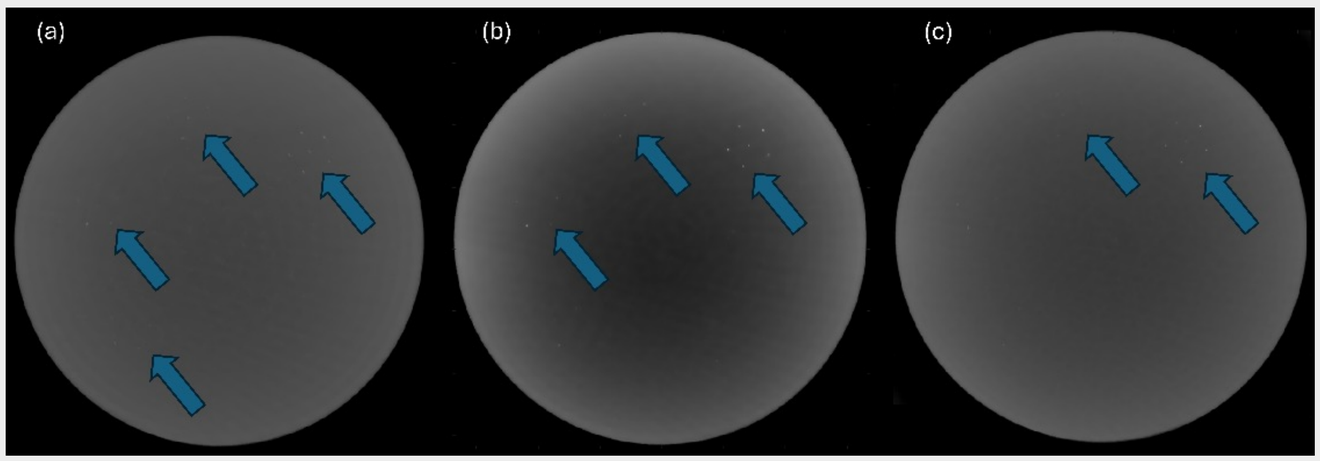
RESULTS

KEY FINDING: 50 mA / 20 ms / 90 views is optimal for visualizing 0.24 mm microcalclfications at MGD of 4.5 mGy.

Table 1. Average number of microcalcifications visualized in each cluster (2 readers, FRIST reconstruction).

Calcification size	Protocol A * 50 mA /20 ms / 90 views	Protocol B 50 mA /18 ms /100 views	Protocol C 40 mA / 20 ms / 114 views
0.32 mm	6/6	6/6	6/6
0.29 mm	5.5/6	4.5/6	4.5/6
0.27 mm	6/6	4/6	2.5/6
0.24 mm	4.5/6	2.5/6	2/6

★ *indicates optimal protocol (superior 0.24 mm visibility).*



(a) 50 mA / 20 ms / 90 views (b) 50 mA / 18 ms / 100 views (c) 40 mA / 20 ms / 114 views

Figure 2. FRIST 10-slice Maximum Intensity Projection (MIP) images. Blue arrows indicate microcalcification clusters.

DISCUSSION

Why does Protocol A (50 mA / 20 ms / 90 views) outperform B and C?

Three protocols achieved the targeted MGD (≈4.5 mGy) through different combinations of tube current, X-ray pulse width, and number of projection views. Their differential performance on 0.24 mm calcification detection reflects the competing effects of quantum noise and angular undersampling.

Relative to protocol A, protocols B and C progressively increase the number of projection views and reduce the mAs per projection. The reduced mA increases quantum noise. Although the higher view count provides better angular sampling, the compressed sensing-based FRIST is effective at 90 views, indicating the additional views in protocols B and C provide diminishing returns while the reduced fluence per projection compromises calcification conspicuity.

Key insight: For compressed sensing-based reconstruction and at a fixed dose, maximizing photon fluence per projection while using the minimum number of projection views that is sufficient for FRIST artifact suppression (≈90 views) outperforms strategies that spread the dose across more views at lower per-projection fluence. This is consistent with the Poisson noise characteristics of X-ray detection, where reducing photons per projection increases noise, and FRIST can compensate for reduced angular sampling through its total variation minimization framework.

CONCLUSIONS

1. 50 mA / 20 ms / 90 views with FRIST reconstruction is the protocol for low-dose upright CBBCT and can detect 0.24 mm microcalcifications at MGD of approximately 4.5 mGy.
2. Maximizing photon fluence per projection (mAs) outperforms spreading dose across more views at lower per-projection fluence for sub-mm calcification detection.
3. Multiple viable protocols (A, B, C) provide clinical flexibility, all achieving the target MGD of 4.5 mGy with FRIST reconstruction.
4. Results support upright CBBCT as a viable, compression-free, volumetric alternative to mammography at screening-compatible dose.

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