



Research article

High-attenuation artifact reduction in breast tomosynthesis using a novel reconstruction algorithm



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ABSTRACT

Purpose: To assess the effect on reducing the out-of-plane artifacts from metal objects in breast tomosynthesis (BT) using a novel artifact-reducing reconstruction algorithm in specimen radiography.

Methods and Materials: The study was approved by the Regional Ethical Review Board. BT images of 18 partial- and whole mastectomy specimens from women with breast cancer were acquired before and after a needle was inserted close to the lesion. The images were reconstructed using both a standard reconstruction algorithm, and a novel algorithm; the latter uses pre-segmentation to remove highly attenuating artifact-inducing objects from projection images before reconstruction. Images were separately reconstructed with and without segmentation, and combined into an artifact-reduced reconstruction. Standard and artifact-reduced BT-algorithms were compared visually and quantitatively using clinical images of mastectomy specimens and a physical anthropomorphic phantom. Six readers independently assessed the visibility of the lesion with and without artifact-reduction in a side-by-side comparison. A quantitative analysis was performed, comparing the signal-difference to background ratio (SDBR) and artifact spread function (ASF) between the two reconstruction methods.

Results: The magnitude of out-of-plane artifacts was clearly reduced with the novel reconstruction compared to BT-images without artifact reduction. Lesion masking by artifacts was largely averted; tumour visibility was comparable to standard BT images without a needle. In $76 \pm 8\%$ (standard deviation) of cases overall, readers could confidently state needle location. The same figure was $94 \pm 6\%$ for whole mastectomy cases, compared to $62 \pm 17\%$ for partial mastectomies. With metal artifact reduction, SDBR increased by 97% in the phantom, and by 69% in the mastectomies. The artifact spread function was substantially narrower.

Conclusion: Artifact reduction in BT using a novel reconstruction method enables qualitatively and quantitatively improved clinical use of BT when metal artifacts can be a limiting factor such as in tomosynthesis-guided biopsy.

1. Introduction

Breast tomosynthesis (BT) is emerging as an important new breast imaging method, both in breast cancer screening [1–5] and for clinical imaging [6]. When it comes to interventional procedures, BT has the potential to provide more accurate breast biopsies compared to the stereotactic method since it omits the need for triangulation, and most

importantly, provides improved visualization of non-calcified lesions [7,8]. Furthermore, the access to tomosynthesis-guided biopsies as well as pre-operative wire localization with BT is vital for an efficient work-up of lesions not visible on ultrasound or mammography [9–11]. However, the highly attenuating biopsy needle or localization wire introduces out-of-plane artifacts, as exemplified in Fig. 1, in the BT reconstruction which can severely degrade the image quality in the

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Fig. 1. A partial mastectomy specimen imaged with breast tomosynthesis. The image quality is degraded due to out-of-plane artifacts from metal objects.

vicinity of the lesion of interest. This hampers the use of post-insertion images for localization confirmation and is a drawback of using BT in interventional procedures.

Efforts have been made to reduce the high attenuation-generated artifacts with different image reconstruction methods, most based on using segmentation to find highly attenuating objects in the reconstructed BT slices [12–15]. These methods perform the segmentation on the reconstructed slices and not on the raw projections, unlike the novel algorithm evaluated in this study. This is much more difficult, but crucial for a faster reconstruction, which is necessary for BT. The novel algorithm does not require any prior information about breast composition or user input; artifacts caused by calcifications are reduced the same way as those from metal objects.

The purpose of this study was to assess the reduction of out-of-plane artifacts from metal objects in BT with the novel artifact reducing reconstruction algorithm, using specimen radiography as a substitute for patient biopsy images.

2. Methods and materials

Quantitative and qualitative aspects of the artifact-reduced reconstruction were investigated. For the qualitative analysis, a retrospective imaging study of 10 partial- and 8 whole mastectomy specimens from 18 consecutively included women with breast cancer was carried out. The specimens were imaged subsequent to the women having undergone surgery at Skåne University Hospital Malmö. There were no exclusion criteria. The study was approved by the Regional Ethical Review Board of Lund University.

For the quantitative analysis, a physical breast phantom with added metal objects was imaged and the strength of the resulting artifacts calculated. Further quantitative measures were estimated from images of the mastectomy specimens.

2.1. Image acquisition

All specimens underwent conventional specimen radiography with digital mammography (DM) as part of clinical routine (not analysed in our study). In addition, the specimens were imaged with BT with and

without a surgical steel needle (22 G) inserted at close proximity to the lesion. Needle insertion was done by the radiographer after acquiring the initial DM image, with the aim of putting it as close as possible to the lesion. All DM and BT-images were acquired with a Siemens Mammomat Inspiration system (Siemens Healthcare GmbH, Forchheim, Germany).

The BT specimen radiography were reconstructed with two different methods: (i) standard BT reconstruction method using filtered back projection together with a statistical artifact reduction-algorithm (Empire), and (ii) a novel Siemens algorithm (not commercially available) using pre-segmentation to remove highly attenuating artifact-inducing objects from projection images before reconstruction, and then separately reconstructing the original projections with the highly attenuating objects using appropriate filter settings to minimize artifacts [16,17]. Reconstructed slices with and without the highly attenuating objects are then combined into a single set of image slices, which should theoretically remove artifacts without adversely affecting the representation of the surrounding area compared to if the highly attenuating object was not present. As mentioned before, compared to other similar methods the advantage of this method is that it performs segmentation on projections rather than reconstructed slices, speeding up the process.

Three sets of BT images were created for each specimen, one set with the standard reconstruction without inserted needle (set I), one set with the standard reconstruction with inserted needle (set II) and finally one set with the artefact-free reconstruction with the needle inserted (set III). Sets I and III were used in the reader assessment of the quality of the artifact-free reconstruction. Set II was only used in the quantitative analysis.

To investigate quantitative measures, additional BT images were acquired using an anthropomorphic physical breast phantom manufactured by CIRS under a license from the University of Pennsylvania (Penn), with inserted metal objects [18]. The Penn phantom is based on a procedural mathematical representation of the breast [19], consisting of compartments intended to mimic the general appearance of fibroglandular breast tissue. In this study we used a physical 3D-printed version of the phantom which consists of 5 slabs, each 10 mm thick, manufactured using plastic materials with tissue-like attenuation properties. A solid lead sphere with a 0.95 mm diameter, representing a high density metal object, was inserted in the approximate centre of the phantom. We acquired BT images on the same system used for specimen radiography. Phantom images were reconstructed in the same manner as for mastectomy specimens, using both standard reconstruction and metal-artifact reducing reconstruction.

2.2. Reader assessment

Six readers (four experienced breast radiologists and two medical physicists) independently viewed mastectomy image sets I and III, displayed side-by-side using ViewDex [20]. The readers assessed the visibility of the needle and the lesion answering the following questions (with yes or no): (1) Can the location of the needle be confidently stated, (2) comparing with the image without needle, is the surrounding area affected by the presence of the needle, (3) if so, is the effect substantial. The last question is understood to mean that the effect is substantial enough to prevent adequate visualization of a lesion.

Question 1 was intended to answer the main issue of effectiveness; i.e. can the method be used for its intended purpose of saying whether or not a biopsy is taken from the correct location. Questions 2 and 3 focus on the secondary issue of whether or not artifacts can be fully removed.

2.3. Quantitative measures – signal-difference-to-background ratio and artifact spread function

Using image set II and III, the Signal-Difference-to-Background

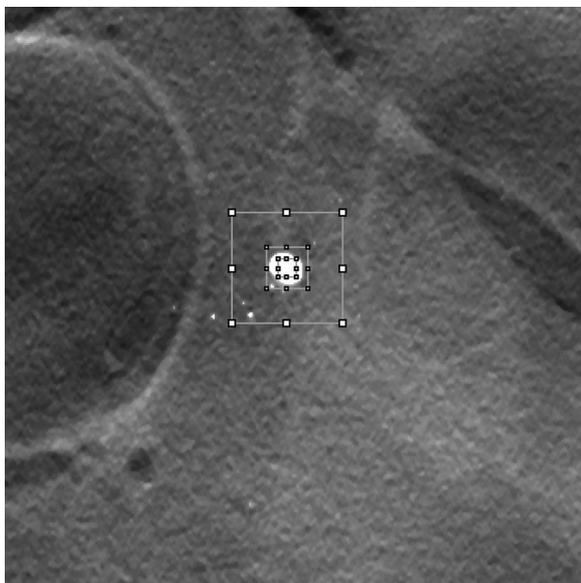


Fig. 2. Illustration of regions used in estimation of the Artifact Spread Function. Inner square: reference signal (11 × 11 pixels), middle square: exclusion area (25 × 25 pixels), outer square: background reference signal (67 × 67 pixels).

Ratio (SDBR) was calculated in slices of interest of the standard and artifact-reduced reconstructions, based upon a 5 × 5 pixel signal window centred on the inserted needle and an overlapping 67 × 67 pixel background window. The SDBR of the two reconstructions were compared to assess the improvement in signal. The same calculations were also performed for phantom images, for the lead sphere.

The Artifact Spread Function (ASF), showing the propagation of out-of-plane artifacts, was also estimated from phantom images, using an inner area of 11 × 11 pixels centred on the metal sphere and a background value calculated from a 67 × 67 pixel area (excluding 25 × 25 pixels in the centre, see Fig. 2) [21]. ASF was not calculated in the clinical images, as it is not defined for needle-like objects. For a high-frequency feature, such as a small metal sphere, the ASF can, using the definition provided by Wu et al. [21], be calculated as

$$ASF(z) = \frac{\bar{\mu}_{Signal}(z) - \bar{\mu}_{Background}(z)}{\bar{\mu}_{Signal}(z_0) - \bar{\mu}_{Background}(z_0)}$$

where z_0 is the in-focus plane containing the feature, and, z an off-focus plane. The ASF function describes the ratio between the difference in pixel intensities, $\bar{\mu}$, of the signal and background in the in- and off-focus slices.

2.4. Statistical analysis

The Wilcoxon rank sum test was used to test for differences based on reader answers while the Student t -test was used for differences in SDBR. Spearman's rank correlation method was used for assessment of correlation.

The mode of the answers from the readers was calculated for each case on all three questions, i.e. majority voting. Continuous variables are reported with mean value and standard deviation, while other data is presented with the median and inter-quartile range.

3. Results

The needle location could be confidently stated in 14/18 cases, including all eight whole mastectomy cases (Fig. 3). Nine out of 18 cases showed an effect on the area surrounding the needle, all of which were partial-mastectomy specimens (Fig. 4). In five of these nine, the effect was considered substantial. Table 1 summarizes reader scores.

The readers could confidently state the location of the needle in $76 \pm 8\%$ of the cases. Stratified into partial and whole mastectomy specimens, readers had more confidence in the whole mastectomy specimens, where needle position could be confidently stated in $94 \pm 6\%$ of the cases, compared to $62 \pm 17\%$ for partial mastectomies. The Wilcoxon rank sum test showed that there was a significant difference, $P = 0.015$, between the percentage of readers confidently stating the needle location in partial (67% IQR 33%) versus whole mastectomies (100%, IQR 8%).

SDBR was 1.7 ± 0.5 for the standard reconstruction and 2.8 ± 1.6 after metal-artifact reduction, a significant difference ($p = .017$, Student's t -test) corresponding to a 69% increase in SDBR with the novel reconstruction (in the in-focus central slice). The difference in SDBR had a significant inverse correlation with the percentage of readers considering a case to be affected (reader question 2) by the presence of the needle, ($r = -0.63$, $p = 0.005$) and a likewise significant positive correlation with whether the percentage of readers were able to determine the needle position in a case (reader question 1), ($r = 0.72$, $p = 0.0007$).

In the phantom study, SDBR was 2.98 with the standard reconstruction and 3.83 with artifact reduction, a substantial increase of 29%. The estimated ASF for both reconstructions is shown in Fig. 5. As can be seen, artifacts propagate further in the volume with the standard reconstruction. Both reconstruction methods yield relatively comparable ASF values within 5 mm (i.e., five slices) from the in-focus slice (0.88 vs 0.84, for the artifact-reducing vs. conventional method.) The advantage of the artifact-reducing method is more evident at larger distances from the in-focus slice, (e.g., ASF of 0.41 vs. 0.025, for the conventional vs. artifact-reducing method at 7 mm, and 0.13 vs. 0 at 10 mm).

4. Discussion

In this study we found that a novel reconstruction algorithm efficiently reduced artifacts generated from metal objects. This is to our knowledge the first study of high-attenuation artifact reduction done on mastectomy samples with inserted metal objects. The effect of the artifact reduction was measurable both qualitatively and quantitatively, and results from the different analyses were found to correlate. It is notable that the six readers, of which four were experienced breast radiologists, were generally in agreement about their ratings and that there was no evidence of a significant difference in ratings. In 76% of the cases the readers felt confident that they could state the location of the needle. For whole mastectomy specimens, this rose to 94%. We consider this a reasonable figure for a clinically acceptable method. Subjectively, in many cases it seemed that the reason readers could not confidently state the location of the needle was interference from other metal objects present in the breast. In fact, some readers noted that the lack of artifacts from the thin needle sometimes made it hard to spot and it was only noticed when scrolling through the volume. One suggestion would be to use a contrasting colour to mark inserted high-density objects in the reconstruction.

The study shows clear correlations between reader ratings and the increase in SDBR from the reconstruction method. This must be construed to mean that the magnitude of SDBR increase between standard and novel reconstruction is a significant factor in the reader's impression of the image and in their ability to find the needle location, even though the readers do not directly rate the difference between the two reconstructions.

The phantom studies clearly show the improved appearance of the metal object. There are notably apparent undershoot artifacts in neither the ASF values nor the image (ringing artifacts denote under- or overshoot values observed during a signal transition, due to the limited bandwidth of the system). This is important, as ringing could potentially obscure breast lesions and substantial ringing artifacts would limit the usability of the method. ASF values within 5 mm from the in-

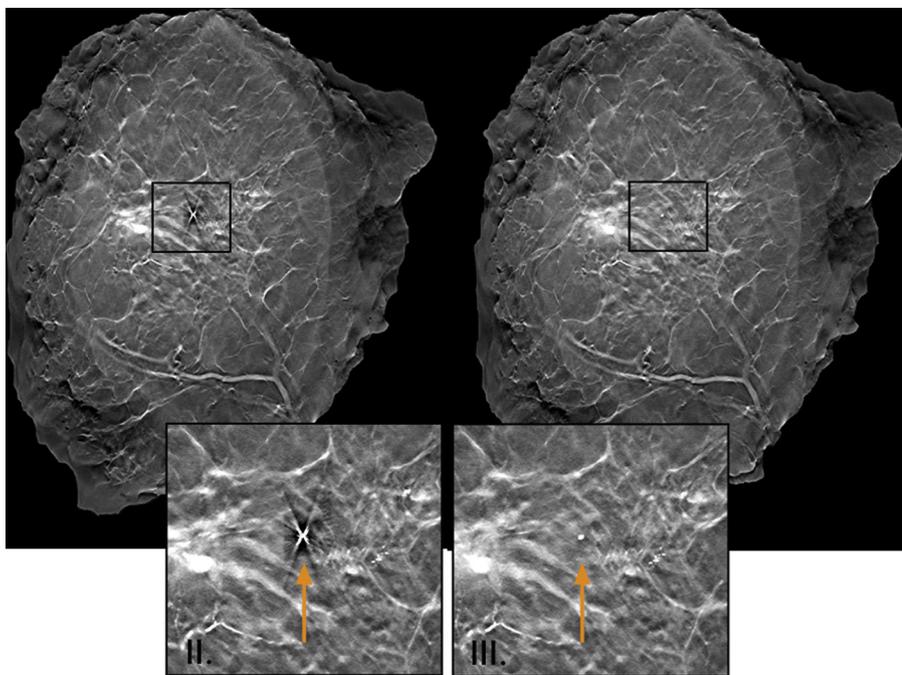


Fig. 3. Breast tomosynthesis of a whole mastectomy specimen with a needle inserted near the centre, perpendicular to the image plane. The images have been reconstructed with a standard (II) and the artifact-reduced reconstruction algorithm (III). The needle position is clearly visible on the artifact-reduced reconstruction (see insertions).

focus slice, are slightly lower for the conventional vs. artifact-reduced method. The max ASF difference in this range (1.01 vs. 0.94) occurred at 4mm. These observed persistent artifacts in the artifact-reducing method are likely caused by the effect of a low-valued undershoot area (near the metal object) on the background values.

An implication of our findings is that the reduction of high-frequency generated artifacts, including those caused by metal objects and coarse calcifications, have the potential to enable the use of true BT-guided biopsy. BT-guided biopsy is particularly important in the assessment of architectural distortions. Architectural distortions is a mammographic finding that can represent both invasive and *in-situ* cancers as well as benign diagnoses, such as complex sclerosing lesions and radial scars [22]. BT is especially sensitive to architectural distortions, which can be both mammographically and sonographically occult [23,24]. The finding of an architectural distortion can therefore pose a challenge in the clinical work-flow that without the access to BT-guided biopsy, often demands the use of the more costly and time-consuming MRI-guided biopsy procedure [25]. With the wide implementation of BT in the clinical setting, and with the increasing use of BT in screening [26], it is therefore important to facilitate the use of high-quality BT images in interventional procedures to enable a cost-effective assessment of findings only visible on tomosynthesis. With improved visualization of the breast lesion, BT-guided biopsy could potentially also increase the accuracy of core needle biopsies, reducing the need for the more resource-demanding vacuum-assisted biopsy [27,28].

Though intended to reduce metal-induced artifacts, the method could also potentially be useful for improving the appearance of large

Table 1

Reader consensus answers to questions 1–3 for the 18 mastectomy specimens.

Case #	Type	Reader Consensus, question 1	Reader Consensus, question 2	Reader Consensus, question 3
1	Partial	Yes (6/6)	No (3/6)	No (1/6)
2	Whole	Yes (6/6)	No (0/6)	No (0/6)
3	Partial	Yes (4/6)	Yes (4/6)	No (2/6)
4	Partial	No (1/6)	Yes (6/6)	Yes (5/6)
5	Partial	No (1/6)	Yes (5/6)	Yes (4/6)
6	Partial	Yes (5/6)	No (3/6)	No (2/6)
7	Partial	Yes (6/6)	Yes (4/6)	No (1/6)
8	Whole	Yes (6/6)	No (0/6)	No (0/6)
9	Partial	Yes (4/6)	Yes (4/6)	No (3/6)
10	Whole	Yes (6/6)	No (0/6)	No (0/6)
11	Whole	Yes (5/6)	No (0/6)	No (0/6)
12	Whole	Yes (6/6)	No (0/6)	No (0/6)
13	Partial	No (3/6)	Yes (5/6)	Yes (4/6)
14	Partial	No (3/6)	Yes (6/6)	Yes (5/6)
15	Whole	Yes (6/6)	No (0/6)	No (0/6)
16	Whole	Yes (6/6)	No (1/6)	No (0/6)
17	Partial	Yes (4/6)	Yes (6/6)	Yes (6/6)
18	Whole	Yes (4/6)	Yes (4/6)	No (2/6)

calcifications. This was however not investigated in the study.

Limitations of the study include the small sample size and the use of specimens that might not fully represent an *in-vivo* situation. Still, the reconstruction method worked better for whole mastectomy specimens,

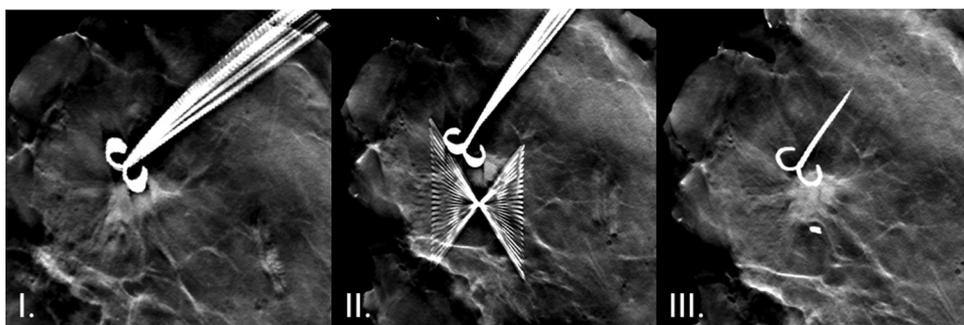


Fig. 4. A partial mastectomy specimen imaged with breast tomosynthesis. A small tumour is localized with a wire. In image (II) and (III) a needle has been inserted close to the tumour. Images (I) and (II) has been reconstructed with a standard breast tomosynthesis image reconstruction algorithm and image (III) with the metal artifact-reducing reconstruction algorithm.

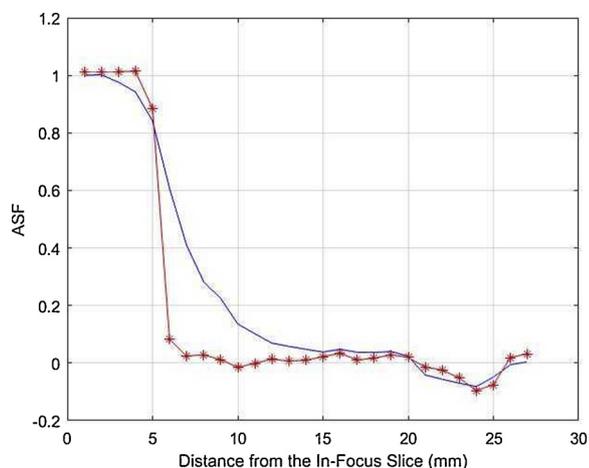


Fig. 5. One-sided Artifact Spread Function for standard reconstruction (blue) and metal-artifact reducing reconstruction (red). Note the wider peak of the standard reconstruction.

which more closely resemble imaging situation during tomosynthesis-guided biopsies, than for smaller surgical specimens. As the algorithm was designed for whole breasts the difference in performance was not unexpected. Likely, the lack of a skin line caused the segmentation to fail. A modification to accommodate partial mastectomies might be of interest as BT could be beneficial in a post-surgery setting.

Another limitation was that metal objects (surgical markers and localization wires) other than the needle were also present in some cases. These were additional sources of artifacts that would not in general be present in an *in-vivo* clinical situation.

The study is also limited to the use of one tomosynthesis vendor, but the same reconstruction principle should be applicable to other BT systems as well. Also, the inserted needle was small in comparison to the needle sizes used in core-needle or vacuum-assisted biopsies, which could have made the artifacts less noticeable than in a real clinical situation. To develop a full picture of the clinical utility of this novel reconstruction algorithm additional *in-vivo* studies will be needed.

5. Conclusion

The evaluated metal-artifact reduction method showed considerable promise, substantially and significantly reducing the magnitude of artifacts surrounding inserted needles and allowing adequate visualization of the lesion and accurate evaluation of the needle position, which could potentially improve the use of tomosynthesis in interventional procedures.

Disclaimer

The presented algorithm is not commercially available. Its future availability cannot be guaranteed.

Conflicts of interest

Author KL has received speaker's fees from Siemens Healthcare. Author JW is an employee of Siemens Healthcare. The other authors report no conflicts of interest

Role of funding source

Siemens Healthcare provided software for reconstruction. Full control of the data acquisition, analysis and interpretation rested with the authors not affiliated with Siemens Healthcare.

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