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Assessing Accurate Placement of Non-Wire Localization Markers in Non- Palpable Breast Tumors Using Breast CT: A Technical Note

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Abstract

Background: Dedicated photon-counting breast-CT is an emerging imaging technology for imaging of the breast without need for compression of the breast and with radiation dose comparable to mammography. In this study, we assessed the potential use of breast-CT to confirm accurate placement of localization markers in non-palpable breast tumors before breast-conserving surgery.

Methods: We first evaluated the artifacts caused by 5 different metallic markers in 2 different phantoms and applied a computer algorithm to effectively remove the beam hardening artifacts. Next, we tested the potential of dedicated photon-counting breast-CT combined with the artifact-removing algorithm to assess accurate marker placement in 5 patients with non-palpable breast tumors.

Results: In the phantoms, all markers caused beam-hardening artifacts, but the computer algorithm successfully removed them. In the patients, the correct placement of the markers was visualized with breast-CT and confirmed post-surgery, as all markers and tumors were present in the surgical specimen.

Conclusion: Dedicated photon-counting breast-CT is an effective modality for demonstrating accurate placement of localization markers.

Keywords: Breast-CT; Tumors; Breast; localization; Markers.

Abbreviations:

CT: Computed Tomography

MAR: Metallic Artifact Reduction

HR: High Resolution

CE: Conformité Européenne

DCIS: Ductal Carcinoma In Situ

HU: Hounsfield Units

WL: Wire-guided Localization

Introduction

Dedicated photon-counting breast-CT is an emerging imaging technology for breast examination. Unlike mammography and limited angle tomosynthesis, it offers the advantage of high-resolution, isotropic 3D images without tissue overlap [1-6]. Additionally, the use of a photon-counting detector allows for

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radiation doses that are comparable to or possibly lower than those in mammography and tomosynthesis [3].

One of the key advantages of breast-CT is that it eliminates the need for breast compression, greatly increasing patient comfort and compliance [7]. Additionally, image acquisition is fast, taking less than 20 seconds per breast.

As a patient-friendly method, breast-CT holds promise in accurately confirming the placement of localization markers before breast-conserving surgery. After seed insertion, commonly guided by ultrasound, a post-procedure mammogram is usually obtained to verify proper marker placement and serve as a roadmap for the surgeon. However, in situations where patients decline mammography or have dense breast tissue and mammographic occult lesions, assessing the accurate marker placement can be challenging. Breast-CT may solve this problem.

Metallic markers, however, cause beam-hardening artifacts in CT. In whole body CT and cone beam CT algorithms to reduce metal artifacts (MAR) are already established [8,9,10]. In this feasibility study in phantoms we evaluate the size of the beam-hardening artifacts caused by metallic markers in photon-counting spiral breast-CT and the efficacy of a MAR- algorithm to reduce these artifacts. The potential of photon-counting breast-CT combined with MAR to evaluate accurate marker placement was tested in 5 patients with non-palpable breast tumors.

Methods

Breast-CT:

Examinations were performed on a dedicated CE-marked spiral Breast-CT system equipped with a photon-counting cadmium-telluride detector (nu:view; AB-CT–Advanced Breast CT GmbH, Erlangen, Germany). During one rotation around the object, up to 2,000 projection images are created without compression. A full spiral scan takes 7 to 12 seconds, scan length is chosen according to the object size (possible lengths are 80, 120, and 160 mm). A fixed X-ray tube voltage of 60 kV and a chosen tube current of 32 mA as well as the high- resolution (HR) mode "HighRes" were used for image acquisition, resulting in 0.15 mm thick slices.

After acquisition of images, the raw data were transferred to a dedicated research workstation for performing reconstructions and application of the metallic artifact reduction algorithm.

Phantom experiments:

Two types of phantom models were used to illustrate the presence of artifacts and subsequent removal of artifacts using the algorithm.

Phantom 1 (Figure 1) consisted of a 9 cm water cylinder in which 15 ml plastic centrifuge tubes were inserted, filled with low density plastic pellets and water.

Four different metallic markers were inserted in the tubes: two different titanium tissue markers (UltraClip II Tissue Marker Ribbon (C.R.Bard, IJsselstein, The Netherlands) and a BIP O-Twist-Marker (BIP medical, Türkenfeld, Germany)), and two different pre-operative localization markers: one dummy radioactive I125 seed marker, of which the radioactivity had decayed (Pi medical, Raamsdonkveer, The Netherlands), and one magnetic marker (Pintuition Seed, Sirius Medical, Eindhoven, the Netherlands).

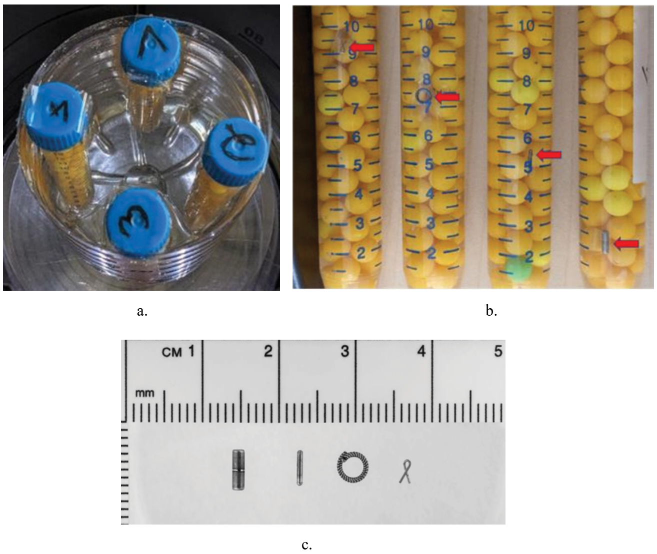

Figure 1: Phantom 1 a: cylinder with plastic tubes; b: tubes filled with plastic pellets and vertically inserted markers; c: markers from left to right: magnetic marker, I125 marker, O-Twist marker, UltraClip marker; the magnetic marker is the largest, 5x1.6 mm.

Phantom 2 was a non-anatomical phantom that did not mimic the anatomy of the breast, but mimicked breast and tumor tissue in terms of attenuation properties. In contrast-enhanced breast-CT in patients with breast tumors we found the attenuation property of fibroglandular tissue to be -27.5 ± 16.5 Hounsfield units (HU). The average HU of tumor tissue in contrast- enhanced breast-CT was 101 ± 44.9. As substance for mimicking attenuation properties of fibroglandular tissue we chose hairstyling gel, -51,99 ± 6,77 HU. Two layers of grapes of varied sizes were inserted in the gel to represent contrast-enhancing breast cancers, 44,70 ± 6.59 HU. And 2 of the grapes were marked with a magnetic marker (Pintuition Seed, Sirius Medical, Eindhoven, the Netherlands) in horizontal or vertical orientation.

Metal artifact reduction

To remove the artifacts on CT created by the metallic markers, the method of 3D linear interpolation combined with edge-preserving attenuation-normalization was used as described by Prell et al. (11). This method consists of quasi-iterative correction steps after a first reconstruction of the acquired raw data, and in a final combination procedure, the metal implants are reinserted into the corrected images.

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All reconstructions were made on a dedicated research workstation on which the MAR- algorithm had been installed.

Patient cases

The potential value of breast-CT to assess the position of inserted markers was examined in 5 patients who underwent presurgical placement of an 125I-marker (n=3) or a magnetic marker (n=2). These patients refused to undergo mammographic confirmation of marker position, so we offered them a breast-CT examination instead. In 4 of the patients, localization seeds had been placed in an invasive ductal carcinoma under ultrasound guidance. In the fifth patient with biopsy proven DCIS, a 125I marker had been placed next to the calcifications under ultrasound guidance. In all patients, presence of the marker in the surgical specimen after operation was retrospectively retrieved from the pathology report.

Results

Phantom 1

All the examined metallic markers cause beam-hardening artifacts, but the severity of the artifact is related to the size of the marker (Fig 2). The small UltraClip II marker only causes a very tiny artefact. With the other markers the size of the artifacts is larger, especially with the magnetic marker, (marker-size 5 x 1.6 mm). After application of the MAR algorithm, all artifacts largely disappear.

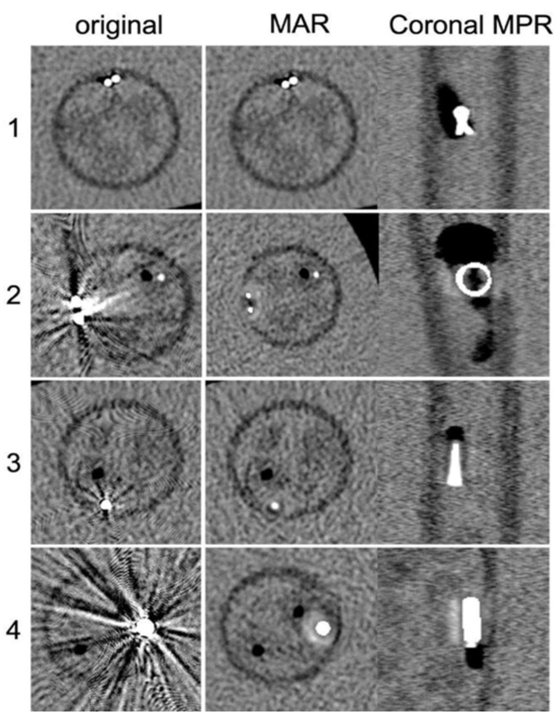

Figure 2: Beam-hardening artifacts of various markers in plastic tubes filled with plastic pellets, reconstructions before (left) and after (right) application of the MAR algorithm.1: UltraClip II Tissue Marker Ribbon; 2: BIP O-Twist-Marker; 3: I125 radioactive seed; 4: magnetic Pintuition marker

Phantom 2

In our breast tissue mimicking phantom of styling gel and grapes, magnetic markers cause a large artifact rendering the grapes hardly visible anymore (figure 3.1a and 3.1b). After application of the MAR algorithm, the artifacts disappear, while the background information of the grapes is preserved without decreasing the spatial resolution (figure 3.2a and 3.2b). Figure 3.3a and 3.3b show the calculated subtraction images between the uncorrected and corrected image by using a sharp reconstruction kernel. Orientation of the markers affects the orientation of the metallic artifacts as can be seen on a coronal MIP (maximum intensity projection) reconstruction of the artifacts (figure 3.4a and 3.4b).

Two types of artifacts can be seen on the uncorrected images as shown by the subtraction images (fig. 4A and B): streak artifacts in the surrounding of the marker and helical stripes throughout the FOV, mirroring the spiral trajectory of the X-ray tube/detector combination. The size of the streak artifacts especially depends on the radiopaque size of the markers.

On magnification images and after adjusting contrast window width and level, a small hyperdense rim of 1 mm remains visible around the magnetic marker after application of the MAR algorithm (figure 5).

Patient cases

We tested the potential value of breast-CT in assessing the result of metallic marker placement in 5 patients scheduled to undergo surgical resection of an invasive breast carcinoma (4 patients) and DCIS (1 patient).

The magnetic markers cause significant beam-hardening artefacts, which are successfully removed by the MAR-algorithm (figure 6). The subtraction image shows the removed artifacts.

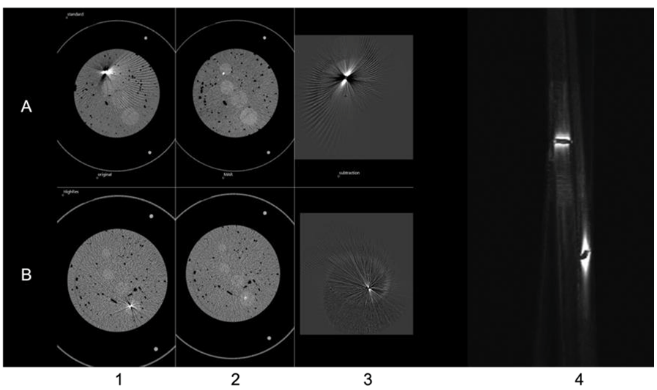

Figure 3: Effects of magnetic markers on visualization of 2 layers of 4 grapes in styling gel (1A and B). After application of the MAR algorithm (2A and B), the artifacts have disappeared, and the grapes are clearly visible. Subtraction images (3A and B) show only the artifacts of the horizontally and vertically oriented markers, visualized on the coronal MIP-images (4A and B).

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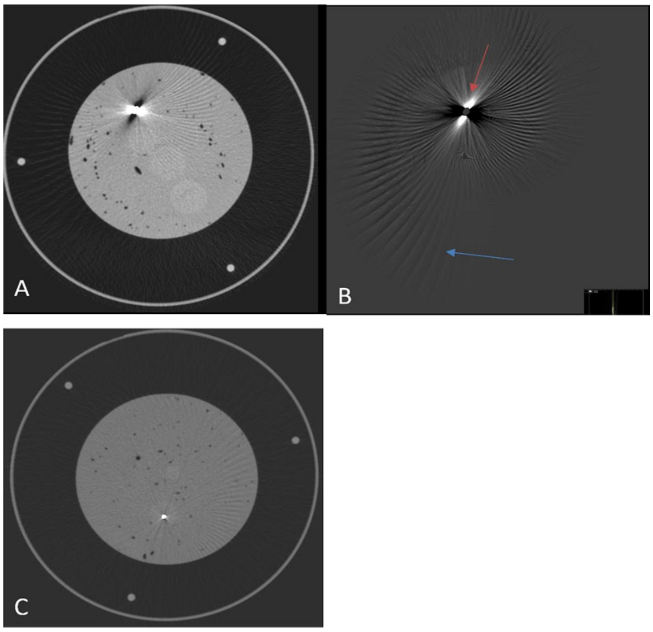

Figure 4: Unsubtracted and subtracted images of a magnetic marker (A and B) and unsubtracted image of the small UltraClip II Tissue Marker Ribbon (C). Two types of artifacts are caused by the markers: streak artifacts surrounding the marker (B, red arrow) and arc- shaped artifacts in larger areas around the marker (B, blue arrow). Especially the streak artifacts are much smaller in the case of the UltraeClip marker compared to the magnetic marker.

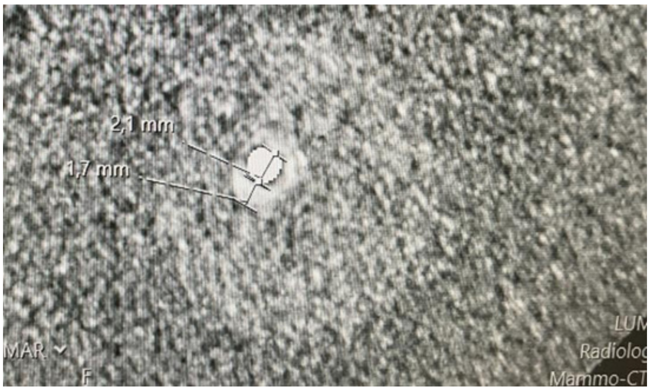

Figure 5: Magnified image of a magnetic marker-containing grape after application of MAR. A small hyperdense rim remains visible around the marker.

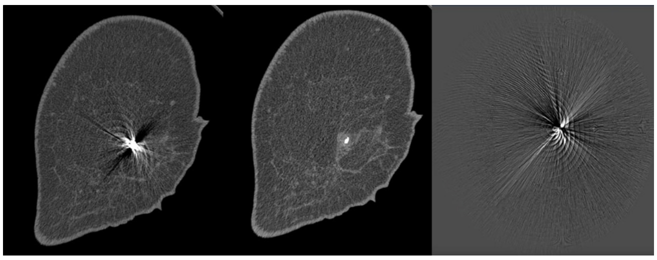

Figure 6: Breast-CT images of a patient after pre-operative implantation of a magnetic marker in a tumor before and after application of the MAR algorithm (no iv-contrast administered). The subtraction of these two images only shows the removed artifact.

In the patient with DCIS, the calcifications remain visible after application of the MAR algorithm (Figure 7) and removal of the artifacts from a 125I marker. Application of the MAR does not result in digital removal of calcifications.

Figure 8 shows the volume rendered image of a magnetic marker, placed next to a previously inserted titanium marker in a tumor. This "virtual mammogram" was used as a roadmap by the surgeon during operation.

In all patients, the localization marker was visible in the tumor in the surgical specimen as stated in the pathology report.

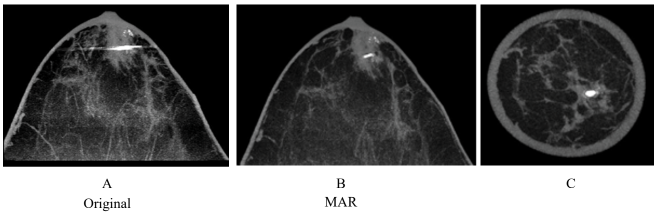

Figure 7: I125 marker placed next to DCIS-calcifications, before (A) and after application of MAR (B: transverse MPR and C: coronal 4.4 mm MIP slab). The calcifications remain visible and are not removed by the MAR.

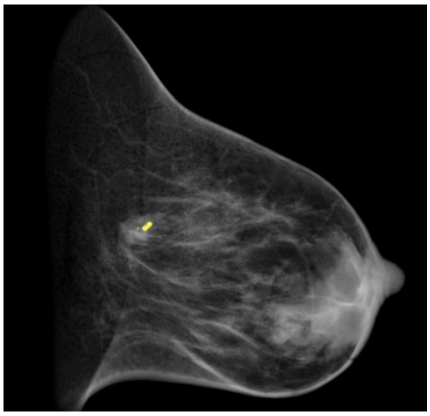

Figure 8: Volume rendering 3D sagittal view of a tumor in the breast marked with a magnetic localization marker next to a small titanium marker.

Discussion

Breast conserving surgery is the treatment of choice in patients with early-stage non- palpable breast malignancies and ductal carcinoma in situ (DCIS) [12]. For optimal surgical outcome, accurate pre-operative localization of these tumors is essential.

Wire-guided localization (WL) is the most widely used method for localization of non-palpable breast lesions. However, the limitations of WL (patient discomfort, logistic challenges, possible wire migration and transection) have led to the development of alternative approaches, such as radioactive seed localization, radar reflector localization (SAVI SCOUT), magnetic seed localization and radiofrequency identification (RFID) [13].

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In addition to logistic and patient-comfort-related advantages, non-wire marking devices have the advantage that radiologists can place the device without concern for the surgical approach. As the surgical approach is not directed by the path of a wire, there is potential for limiting specimen volume and improving cosmetic outcome. A post-procedure mammography is usually performed for assessment of the correct location of the markers, and for initial assistance of the surgeon in localizing the tumor in the operating room.

However, some women decline mammography, and in case of a dense mammogram or mammographic occult tumor it may be difficult to assess the correct position of the marker. This is important, since the main challenge in resection of non-palpable tumors is to obtain clear resection margins while minimizing resection of healthy breast tissue for good cosmetic outcomes.

MRI (Magnetic Resonance Imaging) is not an alternative since these localization markers (except for the radar reflectors and the small 125I-markers) cause large susceptibility artifacts.

Breast-CT is an emerging 3D isotropic imaging technology for the breast, which overcomes the limitations of 2D compression mammography. Moreover, the examination is pain-free and may be a patient-friendly alternative to mammography to confirm marker position. But Breast-CT can only be used as an alternative to mammography if both the tumor and the marker can be simultaneously visualized. All metallic markers cause some beam-hardening artifacts on CT, these are size-dependent. Especially the artifacts of the larger markers may be detrimental to imaging of small tumors and calcifications.

In phantom experiments, we tested the potential of a computer algorithm to remove these artifacts. The MAR can successfully remove even the large artifacts of relatively large magnetic markers. Only a small hyperdense rim of 1.5 mm remains visible around the marker. In 5 patients we could successfully demonstrate the potential of breast-CT and the MAR in confirming the position of localization markers in invasive tumors and DCIS. The MAR only removed the beam-hardening artifacts, calcifications remained visible after application of the algorithm.

Conclusion

Conclusion: photon-counting breast-CT is a promising modality to confirm accurate placement of non-wire markers in non-palpable breast tumors.

Declarations

Ethics approval and consent to participate:

Approval by the Medical Research Ethics Committee (Leiden Den Haag Delft) (reference number nWMODIV2_2023019) was waived for this retrospective reconstruction of the breast-CT data of the 5 patients on a separate workstation. These patients refused mammography and consented in obtaining breast- CT as an alternative modality for confirmation of the correct marker position. All experiments were performed in accordance with relevant guidelines and regulations.

Consent for publication:

All patients gave informed consent for publication of their data, although the images presented in this paper are entirely unidentifiable and there are no details on individuals reported within the manuscript.

Data availability:

All data generated or analyzed during this study are included in this published article.

Competing interests:

D. Kolditz is an employee of AB-CT – Advanced Breast-CT GmbH, Erlangen, Germany and provided the MAR software.

All other authors have no disclosures.

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Authors' contributions:

M.Wa.: conceptualization, methodology, formal analysis, investigation, writing - original draft, review & editing.

L.C.: phantom experiments, writing – original draft

D.K.: provided the MAR software, methodology, writing – review & editing

J.D.: methodology, writing – review & editing, supervision

M.We.: conceptualization, methodology, writing – review & editing

N.V.: conceptualization, methodology, patients investigation, writing – review & editing

J.H.: conceptualization, writing – review & editing

All authors have approved the submitted version and have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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