

Accuracy of lesion boundary tracking in navigated breast tumor excision

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ABSTRACT

PURPOSE: An electromagnetic navigation system for tumor excision in breast conserving surgery has recently been developed. Preoperatively, a hooked needle is positioned in the tumor and the tumor boundaries are defined in the needle coordinate system. The needle is tracked electromagnetically throughout the procedure to localize the tumor. However, the needle may move and the tissue may deform, leading to errors in maintaining a correct excision boundary. It is imperative to quantify these errors so the surgeon can choose an appropriate resection margin.

METHODS: A commercial breast biopsy phantom with several inclusions was used. Location and shape of a lesion before and after mechanical deformation were determined using 3D ultrasound volumes. Tumor location and shape were estimated from initial contours and tracking data. The difference in estimated and actual location and shape of the lesion after deformation was quantified using the Hausdorff distance. Data collection and analysis were done using our 3D Slicer software application and PLUS toolkit.

RESULTS: The deformation of the breast resulted in 3.72 mm (STD 0.67 mm) average boundary displacement for an isoelastic lesion and 3.88 mm (STD 0.43 mm) for a hyperelastic lesion. The difference between the actual and estimated tracked tumor boundary was 0.88 mm (STD 0.20 mm) for the isoelastic and 1.78 mm (STD 0.18 mm) for the hyperelastic lesion.

CONCLUSION: The average lesion boundary tracking error was below 2mm, which is clinically acceptable. We suspect that stiffness of the phantom tissue affected the error measurements. Results will be validated in patient studies.

Keywords: Breast-conserving surgery, lumpectomy, tracking validation, electromagnetic tracking

1. INTRODUCTION

Breast cancer is the most commonly diagnosed cancer in women. Early-stage breast cancer is often treated by breast-conserving surgery, or lumpectomy, which involves excising the tumor and a small margin of surrounding tissue while preserving the remaining healthy breast tissue. Maintaining adequate surgical margins while preserving cosmesis is an ongoing challenge in breast-conserving surgery. Wire-localization is the standard technique used to locate and excise non-palpable tumors. In this method, a hooked wire is inserted into the lesion preoperatively under the guidance of ultrasound or mammography. This wire helps the surgeon to properly localize and excise the tumor. Unfortunately, wire-localization does not always provide sufficient information on the location and orientation of the tumor to ensure complete excision. The current rate of cancer-positive margins in breast-conserving surgery ranges from 10%¹ to almost 50%². Cancer-positive margins increase the likelihood of repeat surgery or full mastectomy, and are associated with higher incurred costs and additional trauma to the patient.

To reduce the occurrence of cancer-positive margins in breast-conserving surgery, we have investigated the use of intraoperative electromagnetic (EM) lesion tracking³. As described by Ungi *et al.*, in this method a hooked needle is inserted into the target tumor preoperatively under ultrasound guidance. This needle is fitted with an EM sensor, and acts

as a rigid body to track the lesion’s location throughout the surgery. Prior to excision, the margins of the tumor are defined in the needle’s coordinate system using tracked ultrasound images. The resulting surface model is displayed on a three-dimensional navigation scene, along with a tracked cautery tip. An EM reference sensor on the patient’s sternum provides proper anatomical orientation. A schematic for the navigation system is represented in Figure 1. The navigation scene is displayed throughout the tumor excision to assist the surgeon in achieving cancer-free surgical margins.

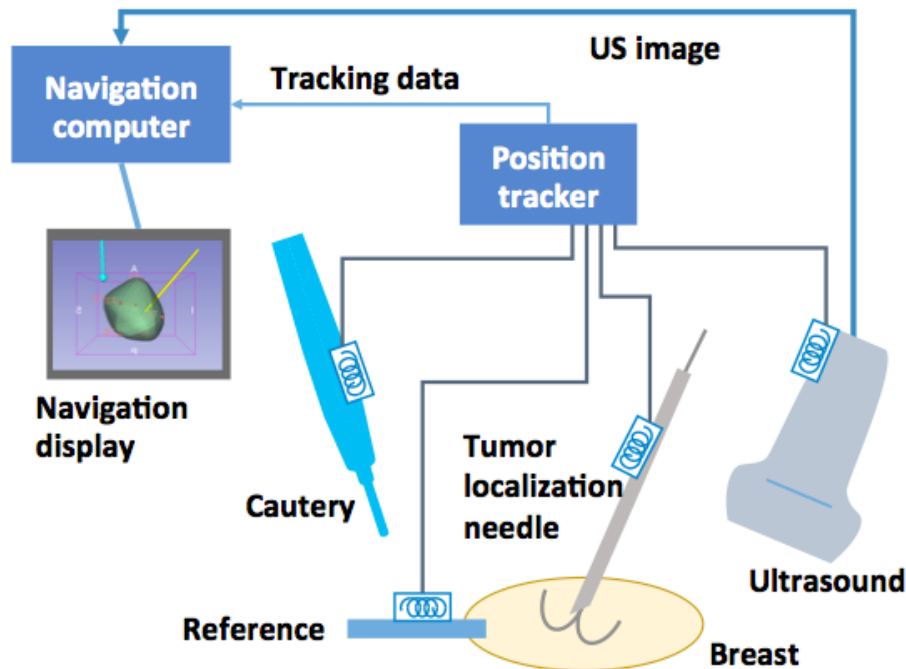


Figure 1. Schematic of navigation system. Coils mark EM sensors.³

Initial patient studies suggest that the EM navigation system is more reliable when compared to standard wire-localization techniques³. To ensure the effectiveness of the proposed navigation system, the reliability of tracking the tumor using a hooked needle must be examined. Throughout the procedure, the tracking needle may move or bend and the tissue may deform, causing errors in tracking the excision boundary. The purpose of this study is to examine these tracking errors, allowing the surgeon to choose a sufficiently large resection margin.

2. METHODOLOGY

2.1 Experimental Setup

The commercial Blue Phantom Elastography Ultrasound Breast Phantom (CAE Healthcare, Sarasota, FL, USA) was used as a breast tissue model. For the purposes of this study, a hyperelastic lesion with largest diameter of 16.5mm and an isoelastic lesion with largest diameter of 13.2mm were examined. These lesions were chosen because these are typical lesion sizes suitable for breast-conserving resection. Lesion stiffness was determined by palpating the phantom. Equipment was tracked electromagnetically using the Ultrasonix SonixTouch ultrasound system with GPS extension (Ultrasonix, Richmond, BC, Canada).

For each lesion, a needle was first inserted into its center. Needle placement was confirmed visually using ultrasound. The needle’s position was tracked with a model 800 Ascension sensor (Ascension Technology Corporation, Shelburne, VT, USA), which was fitted to the needle hub using a custom 3D-printed needle clip. A second model 800 Ascension

sensor, secured to a board on which the phantom sat, defined the reference coordinate system. Ultrasound scans were recorded using an Ultrasonix L14-5gps probe with an integrated electromagnetic (EM) tracking sensor (Figure 2). To apply deformation, the phantom was placed on a horizontal platform of 2.3 cm in height, with the lesion centered about the edge. Manual pressure was used to deform the phantom about this edge in a repeatable manner, simulating deformation of the breast that may occur during breast-conserving surgery (Figure 3).

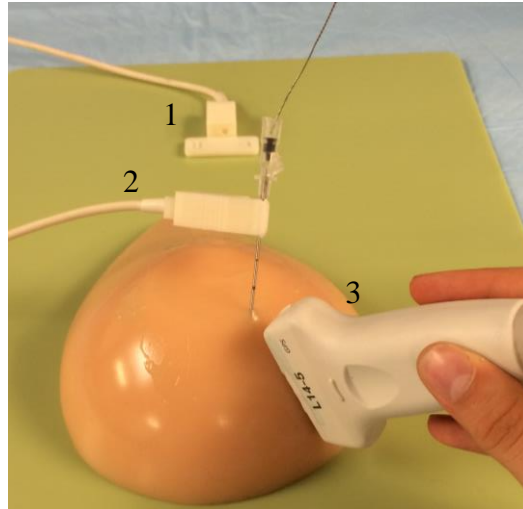


Figure 2: Experiment setup, showing the reference tracker (1), the tracked needle (2), and the tracked ultrasound probe (3).

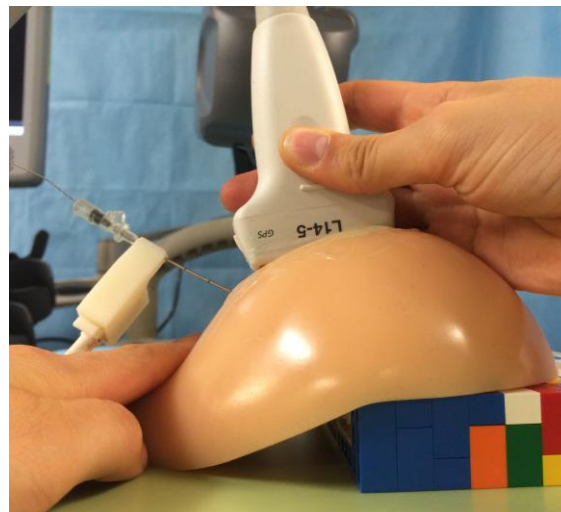


Figure 3: The phantom being deformed about the ledge and scanned.

2.2 Data Acquisition

Tracked ultrasound scans were acquired from each lesion before and after deformation. Each lesion was first scanned in an undeformed state. The lesion was then deformed and scanned five times. Image and tracking data were collected using the surgical navigation system described by Ungi *et al*³. A 3D Slicer visualization of the tracked ultrasound data is shown in Figure 4.

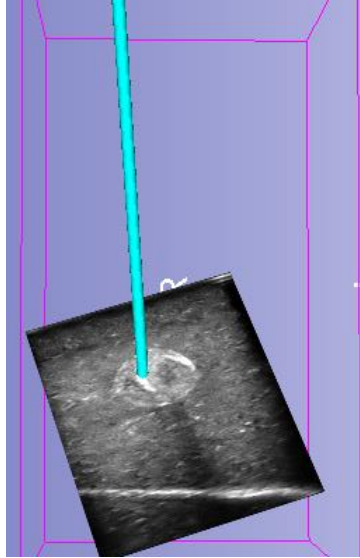


Figure 4: A 3DSlicer view of the setup, showing the hooked needle in cyan and the tracked ultrasound image

2.3 Data Analysis

The recorded data were processed using the PLUS application (www.plustoolkit.org)⁴. Each scan was used to construct a 3D volume of the lesion in its deformed or resting state. Volume reconstructions were done in the needle sensor's coordinate system to account for shift in lesion position. The 3D volumes were segmented to create surface mesh models of the lesions in various states of deformation. The accuracy of the segmentation was confirmed visually; lesions in the phantom were clearly discernible. The distance between the tumor models before and after deformation was compared using the Segment Comparison module of the SlicerRT software suite (www.slicerrt.org)⁵. Using the undeformed tumor model as a reference, the Hausdorff distance between different tumor models was computed. The Hausdorff distance is the maximum distance from one data set to the nearest point in a second set. The Hausdorff distance between the deformed and undeformed lesion without needle tracking was also computed to quantify the total amount of displacement caused by the deformation.

3. RESULTS

The data from the experiments is summarized in Table 1. As a result of the 23mm shift of the breast phantom surface, the total tumor contour displacement (without lesion tracking) was 3.7-3.9mm Hausdorff distance on average. With tracking compensation, the estimated isoelastic lesion had an average Hausdorff distance from the actual tumor surface of 0.88mm (STD 0.20mm), and the same measurement for the hyperelastic lesion was 1.78mm (STD 0.18mm). Examples of tumor dislocation and deformation and the effect of lesion tracking is shown in Figure 5. An example of an isoelastic lesion before and after deformation is shown in Figure 6.

Table 1: Results recorded for the Hausdorff distance from the tumor surface in an undeformed state for an isoelastic and hyperelastic lesion, with and without needle tracking.

<i>Metric</i>	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Trial 4</i>	<i>Trial 5</i>	<i>Avg.</i>	<i>STD</i>
<i>Untracked Isoelastic Hausdorff Distance (mm)</i>	3.48	2.61	4.44	4.38	3.70	3.72	0.67
<i>Tracked Isoelastic Hausdorff Distance (mm)</i>	0.81	0.84	0.80	1.27	0.68	0.88	0.20
<i>Untracked Hyperelastic Hausdorff Distance (mm)</i>	4.22	3.22	3.62	4.42	3.92	3.88	0.43
<i>Tracked Hyperelastic Hausdorff Distance (mm)</i>	1.95	1.44	1.75	1.85	1.78	1.78	0.18

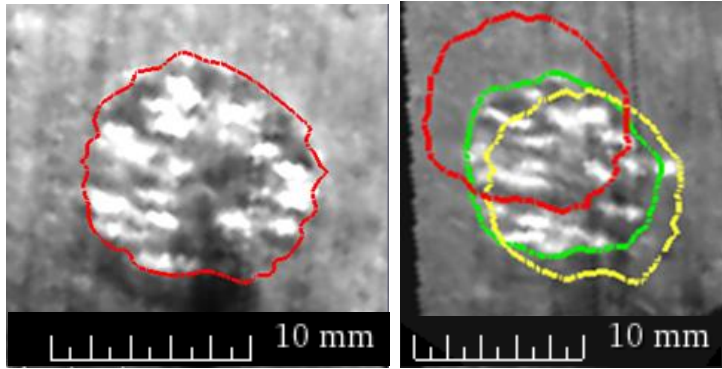


Figure 5. These images demonstrate the effect of the needle tracking. The left image shows an ultrasound scan of the hyperelastic lesion before deformation, with the segmentation shown in red. The same red segmentation is shown in the right image, superimposed on an ultrasound scan of the lesion in a deformed state. The segmentation of the deformed lesion is shown in green, and the tumor contour estimated from the undeformed contour and needle tracking is shown in yellow.

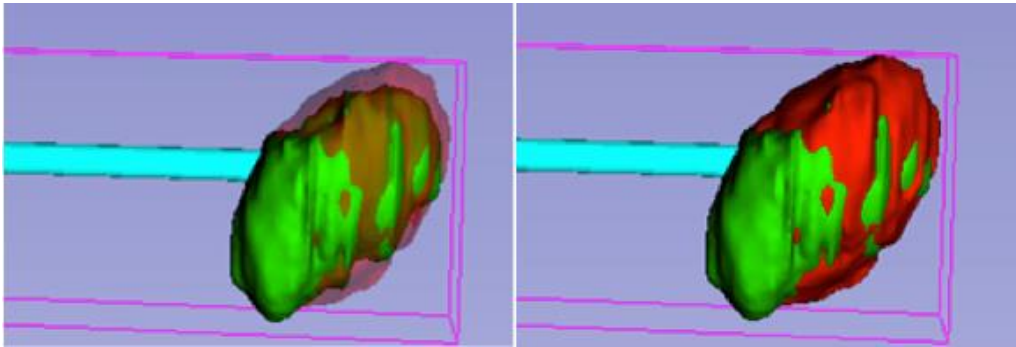


Figure 6. Models of the isoelastic lesion in an undeformed state (green) and deformed state (red), when needle tracking is used. The needle is shown in blue. In the left image the red model is semi-transparent, to show lesion boundaries.

4. DISCUSSION

Using needle tracking to update the position of the lesion resulted in a surgically acceptable tracking error of less than 2mm. When the lesion was tracked using the needle, there was still a small discrepancy between the models before and after deformation. This could be attributed to either needle flex or slippage of the needle tip within the tissue.

It should be noted that this particular phantom breast material is much less compliant than human breast tissue. The stiffness of the phantom tissue may augment deflection and flexing of the needle as well as torsion of the wire hooks.

This leads to inaccurate tracking of tumor pose. Lesions in breast tissue may exhibit less change in shape than indicated in the phantom study. Repeated studies with higher fidelity phantoms or *in vivo* studies are necessary to validate these results.

Changes in tumor shape and location could be further mitigated through intraoperative updates of the tumor model. If the surgeon suspects that the tracking needle has slipped or a major lesion deformation has occurred, tracked ultrasound could be used to quickly generate an updated model of the lesion. Such updates could be performed anytime during the lumpectomy procedure, preferably before the first incision is made. The ability to update the lesion model intraoperatively would result in a more robust and reliable system.

5. CONCLUSIONS

We examined the accuracy of using an electromagnetically tracked needle for compensating lesion dislocation and deformation in navigated breast surgery. The difference in estimated and actual location and shape of the lesion after deformation was quantified using the Hausdorff distance. Quantitative results from the phantom indicate approximate tumor contour estimation errors. This information is essential for determining optimal tumor excision margin size.

Initial results from the phantom study suggest that EM-tracking of lesion boundaries in navigated lumpectomy is accurate to within 2mm, which is clinically acceptable. However, translation errors may have been over-estimated and deformation errors may have been underestimated because of the phantom stiffness. Pending research ethics approval, the results will be verified and integration of real-time intraoperative lesion model updates will be examined in patient studies.

ACKNOWLEDGEMENTS

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