Real time navigation in breast tumor surgery

T. Ungi[1,2], G. Gauvin[2], C. T. Yeo[2], C. J. Engel[2], J. Rudan[2], G. Fichtinger[1,2]
[1] Queen's University, School of Computing, Kingston, ON, Canada
[2] Queen's University, Department of Surgery, Kingston, ON, Canada

Keywords: navigated surgery, image-guided surgery, breast cancer, electromagnetic tracking

Purpose: Breast cancer is the most common cancer in women. Currently the best known treatment of breast cancer is surgical excision in its early stage. The most challenging aspect of breast tumor excision is to remove all cancerous tissue, while preserving most of the healthy tissue. Approximately one in every four patients needs subsequent surgery, because postoperative pathological analysis revealed cancer cells at the margins of the removed tissue. We propose to increase cancer-free excision margins using a real time navigation system that shows the cautery (cutting) tool with respect to the expected tumor margins. Real time tracking and surgical navigation significantly influenced many procedures, mostly orthopedic and neurosurgical procedures. However, movement and deformation makes soft tissue surgery navigation challenging. Tumor tracking using needles has been proven beneficial in liver ablation guidance [1, 2]. This method cannot be directly applied in ultrasound-guided breast surgery because the breast deforms during ultrasound scanning. Therefore, breast tumor surgery requires new methods for preoperative surgical plan definition and registration to allow intraoperative navigation.

Methods: We use direct tumor tracking though a localizing needle. The needle is placed in the tumor under ultrasound guidance before the surgery, and is equipped with an electromagnetic position sensor. A wire hook is deployed through the needle to grab the tumor tissue and create a stable mechanical connection between the position sensor and the tumor. After needle placement, the surgery is performed in two phases (Figure 1). Before excision, the tumor margins are defined in the coordinate system of the needle. Tumor margins are contoured on tracked ultrasound. The ultrasound image is shown in the needle coordinate system, where the surgeon manually contours the tumor. Contour points are used to create a 3-dimensional surface model of the tumor that is tracked along with the localization needle. During excision, a three-dimensional navigation scene is displayed for the surgeon. The navigation scene shows the cautery tip and the tumor margins in a common frame of reference. An additional electromagnetic position sensor is attached above the patient’s sternum to enable visualization of the navigation scene in correct anatomical orientation. The navigation system is further improved by color change and sound warning played when the cautery tip breaches the tumor margins.

Results: The proposed navigation system was tested in phantom models, cadavers, and patients undergoing breast tumor surgery for palpable tumors (Figure 2), after approval by our institutional health sciences research ethics board. A total of 42 surgeries were performed in phantoms; 21 using the navigation system, and 21 using conventional wire localization method. Positive margins were detected in 4 cases with navigation, and 9 cases with the conventional method. These initial results show over 50% reduction in positive margin rate, while the total amount of tissue excised from phantoms were similar in both groups (36.3 ± 14.5 g and 37.7 ± 9.8 g). Subsequently, two simulated tumor excision surgeries were successfully performed on human cadavers, showing feasibility of navigation under realistic conditions. The system is currently under clinical testing for safety and feasibility. Five breast excision surgeries have already been completed. Setup and calibration of the navigation system takes 5 to 10 minutes, and requires one dedicated personnel operating the navigation computer. Surgeons had positive feedback on the navigation system as assessed by a survey completed after each operation. No breach of sterility or other issues have been detected with the safety and feasibility of the navigation system. In all patient cases the tumor excision was complete and the margins were negative.

Conclusion: Real time navigation of breast tumor surgery is safe and feasible using electromagnetically tracked cautery and tumor localization needle. Initial results are positive, but further clinical evaluation is necessary to prove the benefit of navigation compared to conventional methods.

Acknowledgements: Gabor Fichtinger is supported as a Cancer Care Ontario Research Chair in Cancer Imaging.

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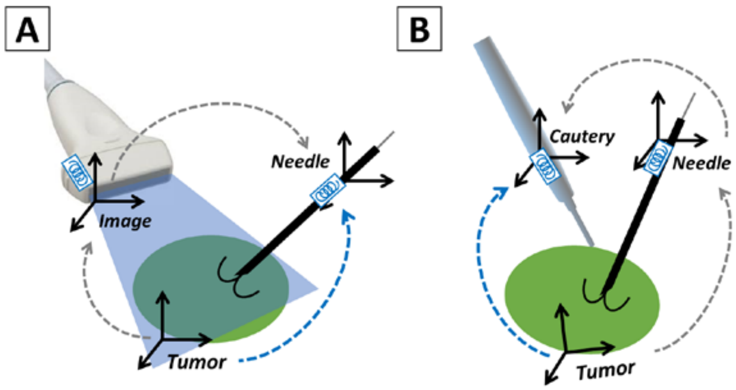

Fig. 1. (A) Coordinate systems of the navigation system when tumor is defined relative to the needle (blue arrow) through an alternative route of transformations (gray arrows). (B) The tumor position relative to the cautery (blue arrow) is computed using the tracked needle.

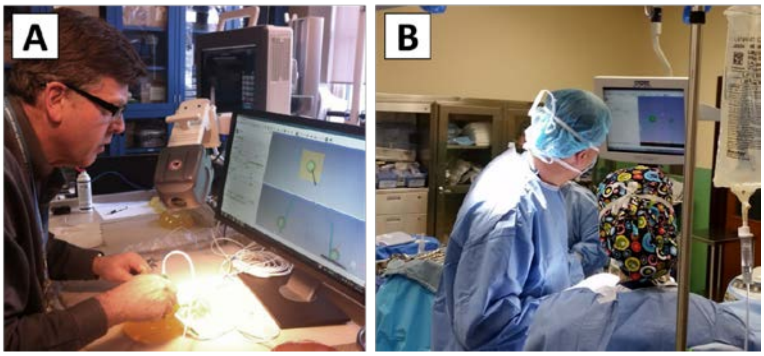

Fig. 2. Navigated breast tumor excision surgery in a phantom (A), and patient (B).