Augmenting Surgery Planning for Neoadjuvant Chemotherapy Patients by 3D Transformation of Prone Breast MR Images to the Supine images in the Operating Room Setting

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Purpose:

Neoadjuvant chemotherapy (NAC) is increasingly used to facilitate breast conservation surgery [1]. The more effective chemotherapeutic regimens and the availability of targeted therapies such as Herceptin have greatly improved the response. Very large tumors can be shrunk down to minimal size or even achieve complete response. In such cases, patients and/or surgeons may opt for lumpectomy or only an excision biopsy. If the residual disease is palpable, the tumor can be localized in the operating room; but if the residual tumor is non-palpable or has achieved complete response, the surgery can be done only with the guidance of tissue markers that were left in the breast, most likely at the time of biopsy. This presents a problem for large tumors. When the tumor shrank, the residual disease might not always be close to the tissue marker, especially when there is heterogeneous shrinkage. Also when the tumor was showing fractionated response, one marker might not be sufficient to represent all areas that had residual disease. This might lead to larger excision of normal breast tissues, which could be conserved if the residual diseases were properly marked. Currently, minimal information from clinical or imaging findings is being incorporated into surgery planning. This may be due to the fact that NAC-monitoring by breast MRI acquires prone images while surgery is performed at the supine position. The purpose of this study is to develop a 3D transformation technique combining thin plate spline and optical flow based algorithms to model prone MRI to geometrically match supine images of the same patient.

Methods:

The method was developed using prone and supine images of one patient taken during the same imaging session. The acquired images were matched using external markers to augment the optimal algorithms. MRI was performed on a 1.5T Philips scanner. Dynamic contrast enhanced images were acquired using T1-weighted 3D SPGR (RF-FAST) pulse sequence, with TR= 8.1ms, TE=4.0ms, flip angle 20^o and FOV varying between 32cm and 38 cm. 32 axial slices with 4 mm thickness were used to cover the entire bilateral breasts. A total of 16 frames (4 pre-contrast and 12 post-contrast) were acquired. The contrast agent, Gadodiamide (0.1 mmol/kg) was injected at the 5th frame. The region of interest (ROI) of the tumor was determined based on the subtraction images at 1-min after contrast injection. This patient received a series of MRI studies for monitoring response (**Fig. 1**). In the last F/U study, after completing the entire prone position scan protocol, the patient was removed from the scanner and re-positioned into the scanner at the supine position. One set of T1-weighted images were acquired using the spin-echo pulse sequence, with TR= 643 ms, TE=10.0ms, flip angle 90^o, matrix size=256x192, FOV = 32cm, and a total of 26 axial slices, each 4mm thick. Eight MR-compatible doughnut-shaped markers of 1.5 cm outer diameter and 4 mm hole were strategically placed on the surface of both breasts to serve as landmarks for registration (**Fig. 2**). Another 12 correspondence points were identified from the images on the 1st , 12th and 25th slices to steer the registration. These 12 points, 4 from each of the 3 slices, formed the corner points of the breast volume for generating the bounding box of the control grid.

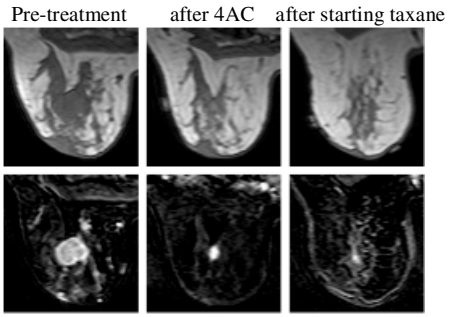

Fig. 1. The patient is showing a great response to NAC. Top: pre-contrast images; bottom: subtraction at 1-min.

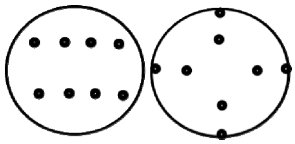

Fig. 2. Eight surface markers were placed on both breasts, linearly aligned on the right breast (with cancer), and circularly aligned on the normal left breast.

The registration process to deform the prone images to match the supine images consists of five key steps: a) segmentation of the breast regions from the body (manually, along the pectoralis major); b) Flip the prone image to supine view, c) generate a marker map-table based on the 8 surface markers and the 12 correspondence points. This would indicate the required displacement of the corresponding external markers on the pendant breast, d) weighted by the map-table, a thin-plate spline interpolation [2, 3] was employed to perform the bulk deformation. Finally, e) a non-rigid registration process that uses optical flow based techniques [4] was used to generate the desired transformation to match the prone images to the supine images. This step essentially resolves any discontinuities in the optical flow (brightness) of the images giving the transformed coordinates (S') for the residual disease (R). $S \approx S' = \tau(R)$, where S is the actual supine coordinates. The registration for the left and the right breasts were performed separately.

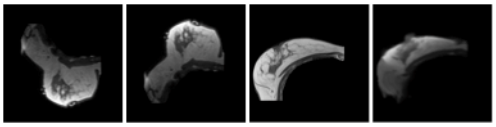

Fig. 3 Demonstration of the co-registration results. (a) original prone image; (b) flip of the prone image to supine view (more tissues in the medial side), (c) the original supine image acquired from the same patient (more tissues falling to the lateral side); (d) transformed prone images to match the supine images.

Results:

Fig. 3 shows the original prone and supine images taken from the same patient, and the transformed prone images to match the supine view. While the tissues were pushed to the medial side at the prone position, they were pulled to the lateral side by gravitational forces. An intermediate-step transformed image is obtained by incorporating the pre-defined mappings into a thin-plate spline interpolation (not shown graphically), which is further deformed by optical flow based registration (Fig. 3d). The accuracy of the transformation is quantitatively assessed by the deviation of the location of the surface markers on these two sets of images. Table 1 lists the results of 4 markers in both breasts, showing within 1 cm deviation.

Table 1: deviation of markers between transformed images from prone view and original supine images

Deviation (mm)	Right (cancer)	Left (normal)
Marker #1	6.2	4.3
Marker #2	2.1	5.6
Marker #3	7.6	8.7
Marker #4	5.0	7.2

Discussion:

We have developed the method to transform prone images to supine view using thin-plate spline and optical flow algorithms. The method was developed using external markers placed on the surface of the breast as reference points. The accuracy testes showed that the location was within 1 cm deviation. We are planning to test the transformation for patients with different body figures and breast sizes, aiming to develop a generalized scheme without the need of external markers. Currently it is difficult to incorporate the minimal residual disease information detected by MRI after neoadjuvant chemotherapy into the surgical plan. The tissue marker left at the time of biopsy may not be sufficient to guide the optimal breast conservation surgery after NAC. Our algorithm demonstrates the feasibility of providing such residual disease information to the surgeons in the OR setting. It is possible to generate computer-enhanced images, presenting to the surgeon about the possible location of residual diseases when the patient is on the operation table. Simultaneous exploration and development of accurate lesion segmentation and feature detection tools, in conjunction with prone-supine co-registration, would help to build an integrated suite for computer-aided surgical navigation.

References: [1]. Martincich L. et al, Journal of BCRT, Vol. 83, 2004, pp. 67-76. [2] Bab-Hadeshar, A. et al, http://citeseer.ist.psu.edu/77330.html. [3] Yoo T. S. et al, Proc. Of Med. Meets VR, 2002, pp. 586-592. [4] Thirion J.P, Medical Image Analysis, Vol. 2, No. 3, 1998, pp.243–260.

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