Volume Preserving Coregistration of Longitudinal Breast MRI during Chemotherapy for Accurate Localization of Tumor

R. Chittineni[1,2], M-Y. Su[1], J-H. Chen[1,3], and O. Nalcioglu[1]

[1]Tu and Yuan Center for Functional Onco-Imaging, University of California, Irvine, CA, United States, [2]Electrical Engineering and Compuer Science, University of California, Irvine, CA, United States, [3]Department of Radiology, China Medical University Hospital, Irvine, CA, United States

Purpose

Neoadjuvant chemotherapy is fast gaining popularity as an important part of breast-cancer treatment and management. The goal of neoadjuvant chemotherapy is to down-stage cancers to render them operable and/or to facilitate breast conservation surgery. If therapy failure can be predicted early, it can be aborted to spare the patient from ineffective treatment and the associated morbidity, and also to allow earlier switch to the next effective regimen. MRI has been proven as the most accurate imaging modality to predict residual tumor size. When residual diseases were still visible, they may be easily detected by visual examination. Comparing the volume of tumor measured in follow up MRI taken during the course of therapy to its baseline may provide the most accurate assessment for determining response. However, when the tumor started to disappear, the location may be difficult to be determined, also enhanced tissues due to treatment induced mastitis (inflammation response) developed at the adjacent normal breast tissues may be mis-diagnosed as residual cancer. Co-registration of the baseline images to the follow-up study would allow the location of the previous tumor site to be correctly identified, and that would allow accurate evaluation of response, either by visual assessment or by computer-aided analysis. Due to the highly deformable nature of the breast, the shape of breasts may change a lot between different studies. Numerous algorithms, based on non-rigid registrations that include affine transformations are available to register pre-contrast and post-contrast images collected in the same study [1.3]. However, they do not perform well under large deformations in different scans due to different positioning, as shown in figure 1. Also transformations such as shear and scale alter the tumor sizes. In this study we developed an algorithm to establish one-one co-registration between baseline MR and each follow-up MR without inducing volume changes. A co-registration between any two studies is established via characteristic morphological features such as curvature extremes. Tumor volume is preserved by constraints.

Methods

For better accuracy, the breast region is segregated from the breast-chest boundary. The delineated region is further sliced to handle each breast separately. A Bezier model of the same is generated and this forms the input to the registration algorithm. The baseline MR forms the reference volume and follow-up MR form the floating volume. The floating volume is morphed such that its outline overlays the outline of the reference volume. The control points of the underlying bezier model correspond to key morphological features of the breast volume. Some of these features are user-selected to enhance the accuracy of the end result. Others are computed using gradient detectors.

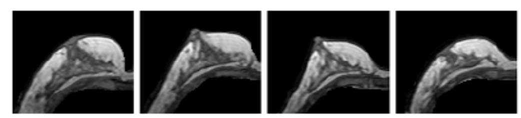

Fig 1: Shape variations in baseline (B/L) and three follow-up (F/U) MR of a patient undergoing neoadjuvant chemotherapy

A transformation from the floating volume to the reference volume is obtained by performing a warp operation. An initial rigid registration of the two volumes, helps speed-up the alignment process. The elements of the translation and rotation matrices are computed using simple math as opposed to computation-intensive calculations using multidimensional line minimization algorithms [1,2,3]. Our algorithm computes the centroid of the two volumes. The difference between the two, gives the elements of the translation vector. Computation of the rotation matrix uses the angle between the line segment joining the centroid to the peak curvature of the breast volume. Vector projections in the appropriate planes provide the values for rotation in degrees. To ensure that the volume is preserved locally, control points associated with the tumor are grouped such that a transformation on any one control point, results in the same transformation on all the other control points of the group.

Results

Our algorithm emphasizes on the alignment at the skin surface, i.e the boundary of the breast to ensure an accurate correspondence. Figure 2 demonstrates the original images and the co-registration results. The first row shows the subtraction of pre-contrast and post-contrast MR images to show tumor location. The first column corresponds to the baseline MR image. The second column refers to the first follow up MR image conducted 35 days later. The third column corresponds to third F/U at 6 months. A comparison of the images in the first row shows that the patient is responding to this chemotherapy regimen. There are no malignant regions in the 3rd follow-up MR indicating a complete response. An accurate evaluation of the therapy results can only be made if we know the exact location of the tumor from baseline MR. The second row shows the results of applying our warp transformation to the images taken at F/U. To understand the extent of mis-registration of the two volumes, an overlay of baseline with follow-up is shown in the third row. The fourth row, shows the results of our algorithm for registration of warped F/U with baseline image. The outlines of the breast overlap or lie very close to each other as is seen the zoomed image of the highlighted region. It may be noted that the accuracy of our algorithm depends on its ability to morph the follow-up images such that the volume is preserved as well as a one-correspondence is established between the features in the baseline MR and the features of the follow-up MR. As mentioned, volume preservation is achieved via coupling of control points in the underlying spline model. A volume computation of tumor in B/L and F/U-1 shows that the tumor size is shrinking, indicative of a good response to this chemotherapy protocol.

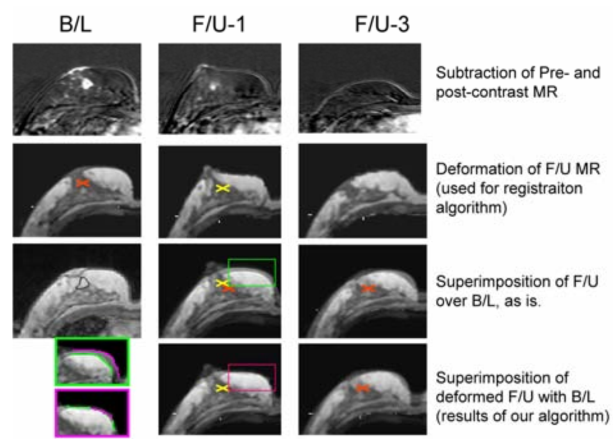

Fig 2: Tumors marked with red and yellow crosshairs are corresponding ones. Due to change of breast shape, the location was not matched on the superimposed images, shown in row 3. To determine the exact location of this tumor within the B/L MR, F/U-1 MR is warped to align well with the B/L.as is shown in row 2. A registration of this with the B/L is shown in row 4. The yellow crosshair is now directly over the red one indicating that the tumor visible in F/U-1 is actually the remaining tumor. F/U-3 shows no sign of tumors at the location seen in B/L, confirming a complete response.

Discussion

We described an algorithm to register longitudinal MRI of breast taken at different times. Due to the deformable nature of the breast, depending on how the patient is positioned the shape of the breast can be very different. If a co-registration algorithm can be developed, it would be very helpful to locate the tumor site from the previous study, thus to directly compare whether the tumor volume has changes. This is especially important when the tumor has disappeared, and treatment-induced mastitis at the near-by normal tissues showing contrast enhancements, thus mistakenly diagnosed as residual disease. Furthermore, this may allow computer-aided analysis to measure volume for evaluation of response. Our algorithm has demonstrated promising results. Extensive testing needs to be conducted using more patient data sets each having varying degrees of breast and tumor sizes, to establish the sensitivity and robustness of our algorithm.

[1] Reukert et al, IEEE Trans Med Img 1999; 18:712-721. [2] Jenkinson et al, Med Image Anal 2001; 5:143-155. [3] Rohlfing et al, IEEE Trans Med Img 2003; 22:730-741.

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