Quantifying brain tissue deformation in patients with cerebral hematoma through an iterative B-spline image registration approach

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Introduction

The challenges of quantifying brain tissue deformation in patients with hematoma include the extreme deformation of the brain tissue and the lack of the reference of the subject's normal brain anatomy. Towards this end, we have developed an iterative B-spline model based registration approach to co-register the abnormal brain images from patients with hematoma to an age-matched normal brain. Subsequently, a 3D voxel-based brain tissue displacement field and compression index maps were derived.

Materials and Methods

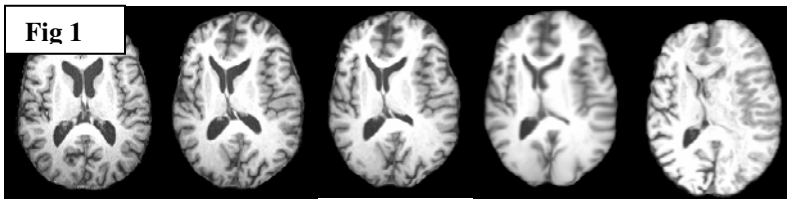
A total of 5 cerebral hematoma patients were included for this study. Affine registration was used to initially register patients images towards their age-matched normal templates. Subsequently, an improved B-spline model-based elastic registration over the work in [1] was performed iteratively. For each iterative step, a cubic B-spline model (M) represented the transformation from the abnormal images (I_a) towards the normal template (I_n). The optimal B-spline model was determined through minimizing a weighted sum of the following three terms, the image similarity measure which was computed as the correlation coefficient between the image pair (C_s), the positive Jacobian constraint (C_s) which enforced the positivity of the determinants of Jacobian matrices at all the voxels, and the landmark constraint (C_L) which incorporated a sets of user initialized landmarks. Once the optimization was converged, the normal template was reformatted for the next iteration step and this process was repeated until the maximal iterations were reached.

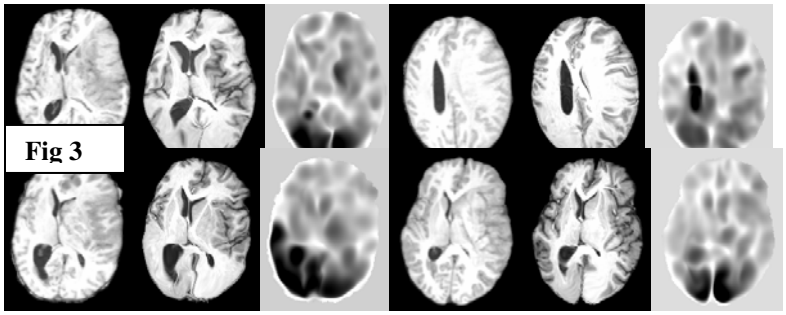
$C_s(M)=CC(I_a(\vec{x}),I_n(M(\vec{x}))$ $C_T(M)=\sum sigmoid(k\cdot\det(Jac(\vec{x})))$ $C_L(M)=\sum(\vec{x}_n-M(\vec{x}_a))^2$ $M^* = \arg\min(C_S + w_T C_T + w_L C_L)$

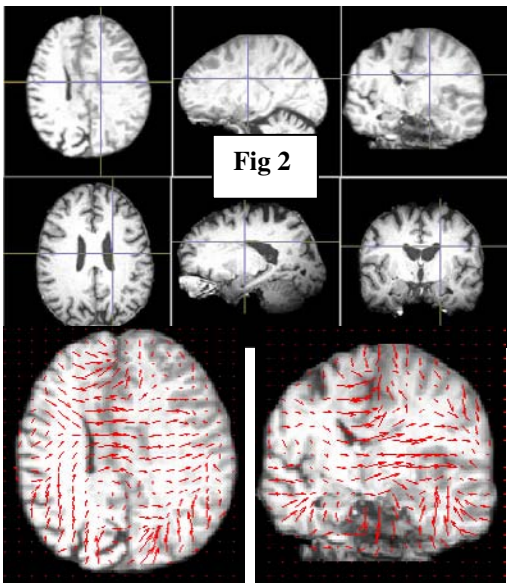
After the completion of registration, the location of a voxel in the abnormal images ($\vec{x}_a$) can be traced back to the original normal template ($\vec{x}_a=\vec{x}^N->\vec{x}^{N-1}...->\vec{x}_n$, $\vec{x}_n=M_1(M_2...(M_N(\vec{x}_a^N))...)$, where N is the total iterative steps) to construct the displacement field (DF, $\vec{x}_n-\vec{x}_a$), which represented the motions of the voxels within the abnormal image towards the normal. In addition, a brain tissue compression index (CI) at each voxel in the abnormal images was derived by summing the logarithms of the determinants of Jacobians in the backward route for all iterative steps ($CI=\sum_{i=N}^{1}\log(\det(Jacobian(\vec{x}^i))$).

Results

The images in Figure 1 from left to right are the initially affine aligned normal template (1st), the reformatted normal template after 1st, 2nd and 10th iteration steps (2nd through 4th), and the abnormal patient image from the same slice (5th). A comparison of the images before and after is given in the top two rows in Figure 2. The cross bars indicate the locations of a voxel in the vicinity of the compressed ventricle. The displacement fields are provided in the bottom row of Fig. 2 where the directions of arrows indicate the displacement directions from the patient's brain to the normal template. In other words, it shows the direction to which the abnormal brain needs to be deformed in order to match with the normal brain. Finally, the patient images and the corresponding final reformatted normal images and the CI maps (with dark areas representing compression and bright areas representing expansion) for the remaining four patients were shown in Figure 3.







Discussion

The proposed iterative registration approach was able to gradually reformat the normal towards the abnormal brain (Figure 1). Thus, it allowed the estimates of the DF (Figure 2) as to how the abnormal brain should be displaced in order to be consistent with the normal brain. After visual inspection, it is evident that the performance of the proposed algorithm in the ipsi-lateral hemisphere was not as accurate as that in the contra-lateral side. In Figure 2 (bottom row), the voxels close to the midline in the patient image moved towards right when they tried to reach their counterparts in the normal brain, since apparently, the mideline in the patient was shifted leftward. The CI maps suggested that the mass effect resulted from the presence of a hematoma may be more significant on the posterior than the frontal region (Figure 3). When a ventricle was severely compressed, the surrounding brain tissue has to be expanded to fill the vacancy. These areas had to be compressed when compared with the normal brain. This may explain the presence of these large dark areas in CI maps in Figure 3.

References [1] Rueckert IEEE-TMI Vol. 18, p. 712-21, 1999.