

Quantifying the intraoperative brain deformation using interventional MR imaging

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Introduction

The increasing use of image guided surgery systems for neurosurgery has lead to considerable recent interest in quantifying brain deformation during neurosurgery. Traditional image guided neurosurgery systems determine the rigid body transformation between pre-operative images and an intraoperative coordinate system (eg.: defined by an optical localiser). These systems can be very accurate, especially if bone-implanted fiducial markers are used, provided the rigid body assumption is valid. However, recent studies have shown that the brain surface can deform by 10mm or more underneath a craniotomy even before any resection take place. Such significant tissue deformation invalidates the rigid body assumption. Since the recent work quantifying brain deformation has concentrated on surface features, the deformation of the structures below the surface of the brain remains unknown.

We demonstrate that we can quantify brain deformation throughout the brain using an automatic non-rigid registration algorithm, and that the volume change per voxel can be calculated and displayed using the Jacobian of the calculated 3D deformation field. We demonstrate this on a series of 8 resection cases carried out in the interventional MR suite at the University of Minnesota.

Method

The scanner used in the interventional suite at the University of Minnesota is a Philips Gyroscan NT 1.5T system with specially modified bed. During interventions, the scanner normally acquires small numbers of slices in the vicinity of the resection site at various stages during the procedure. To quantify the deformation throughout the brain, we changed the acquisition process to acquire whole 3D magnetisation prepared rapid gradient echo (MP-RAGE) volume images just before resection, and after resection was complete.

We use a *non-rigid* registration algorithm [1] to align the pre- and post-resection images. This non-rigid algorithm uses a two stage transformation model. The first stage captures the global motion of the brain and is modelled by a rigid transformation calculated in the previous step. The second stage captures the local motion of the brain and is modelled by a free-form deformation (FFD) based on B-splines. The similarity measure is normalised mutual information. The transformation determined by this non-rigid algorithm defines a deformation field providing a displacement vector for each voxel.

We validated the deformation values calculated using this algorithm by interactively marking corresponding points in the pre- and post-resection image after *rigid* registration. The distance between these points was compared with the deformation value calculated by the automatic algorithm.

In order to gain a better understanding of the underlying mechanisms of brain deformation, it is desirable to calculate the tissue volume change for each voxel in the images. This can be calculated from the Jacobian of the deformation field D , defined as:

$$Jacobian = \det(\nabla D) = \begin{vmatrix} \frac{\partial}{\partial x} D_x & \frac{\partial}{\partial y} D_x & \frac{\partial}{\partial z} D_x \\ \frac{\partial}{\partial x} D_y & \frac{\partial}{\partial y} D_y & \frac{\partial}{\partial z} D_y \\ \frac{\partial}{\partial x} D_z & \frac{\partial}{\partial y} D_z & \frac{\partial}{\partial z} D_z \end{vmatrix}$$

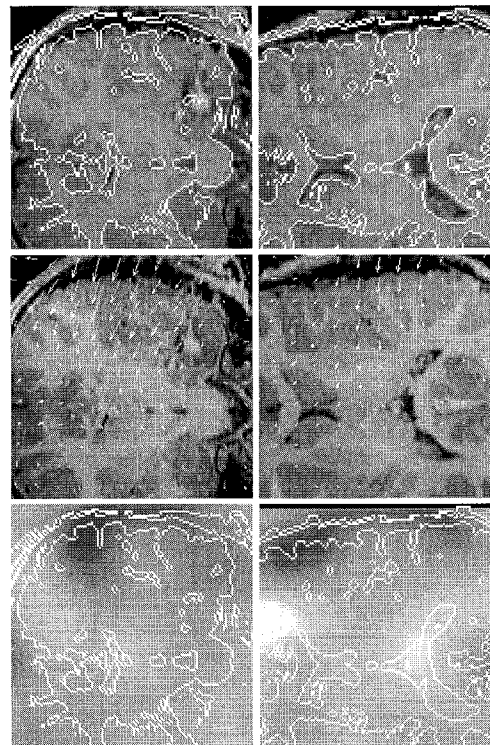
We compared the volume change calculated by this operator with the volume change calculated by manual segmentation of the ventricular system in the pre- and post-resection images. The mean value of the Jacobian within the ventricles is compared to the segmented volume difference in order to assess CSF volume change resulting from the resection. To assess reproducibility the ventricle system is segmented two times in both images.

Results

Example images from one resection case are given in the figure. The coronal and axial images are shown for: post-resection image with contour from non-rigidly transformed pre-resection image overlaid (top); with the deformation map overlaid on the post-resection image (middle); with the values of the Jacobian operator overlaid on the contour of the pre-resection image (bottom). In the Jacobian image, mid-grey represents no deformation,

dark areas have expanded from pre- to post-resection image, and bright areas have contracted. This technique was applied to eight patients. The algorithm used to calculate the deformation field provides deformation values that agree with interactively measured deformations to within 1.5mm for 95% of points recorded. For all but one patient, the deformation was significantly greater ipsilateral to the lesion than contralateral ($P < 0.05$), with the contralateral deformation being of the same order as the precision of the measurements.

The Jacobian operator provides a way of visualising the volume change during the brain resulting from the resection. It has the potential to contribute to a better understanding of the underlying mechanisms of brain deformation.



Conclusions

We have shown that a non-rigid registration algorithm can be used to quantify intraoperative brain deformation using volume data acquired with interventional MR. We believe this will contribute to an improved understanding of the mechanisms of brain deformation, and assist in identifying which patients are likely to benefit from neurosurgery using interventional MR compared to using traditional image guided surgery techniques.

References.

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