Comparison of registration algorithms for capturing intraoperative brain shift


Introduction

Recent advances in functional and diffusion imaging enable the delineation of eloquent cortex and their underlying white matter fiber bundles. Information from each of these modalities may dramatically impact the choice of surgical resection boundary, but the use of pre-surgical data for on-line, intraoperative decision making is hindered by the ongoing changes in patient anatomy during surgery. Intraoperative MRI has been developed to enable ready visualization of intraprocedural changes in the configuration of the patient, and to enable improved surgical navigation, monitoring and targeting (Schenck 1995, Nabavi 2001). We propose to increase the intraoperative utility of data acquired preoperatively by improving compensation for brain deformation, or shift, during surgery in real-time.

Methods

In this study, we compared the compensation of ongoing changes in patient anatomy induced by surgery through non-rigid registration to rigid registration. The current standard in commercial neuronavigation systems is rigid registration. Figure 1 illustrates the processing pipeline applied to 10 adult patients who underwent neurosurgery. Image data was acquired on a 0.5T GE system with an in-plane voxel size of 0.86mm x 0.86mm to 0.94mm x 0.94mm and a slice thickness of 2.5mm. We performed skull stripping by segmenting the intracranial cavity for both the preoperative and the intraoperative volumes and then masking the original data. To achieve an initial coarse alignment and to evaluate the current clinical practice, we used rigid body registration based on mutual information to align the preoperative data to the intraoperative data. Non-rigid registration for brain shift compensation was computed using two different algorithms: SuperBaloo (Commowick 2007), a block-matching algorithm, and ANTS, a dense deformation field algorithm using a probability mapping metric (Avants 2011). For evaluation of the registration accuracy using automatically generated features, an edge detection filter as proposed by (Canny 1986) was applied to the intraoperative and the registered preoperative images, and edges considered outliers were removed using a strategy similar to (Clatz 2005). Then the 95% Hausdorff distance between the edges in these images was computed, as used for registration validation by (Archip 2007).

Results

Both non-rigid registration algorithms outperform rigid registration for intraoperative alignment of brain images. The mean 95% Hausdorff distance between the automatically detected salient edges in the registered and intraoperative images for rigid registration was 3.10mm, and the mean 95% Hausdorff distances for SuperBaloo and ANTS registration were 2.12mm (p<0.002, paired t-test) and 1.96mm (p<0.001), respectively. This implies a very good overall registration, of subvoxel accuracy, given the intraoperative voxel size. The difference in accuracy between SuperBaloo and ANTS is not statistically significant (p=0.126). Mean processing time was 4 minutes for rigid registration, 17.2 minutes for SuperBaloo, and 33.9 minutes for ANTS (Intel Xeon, 2.66 GHz). Parallel implementations of these registration algorithms demonstrate similar results, and can enable alignment of images during surgery, on a time scale compatible with intraoperative decision making.

Conclusions

Non-rigid registration of preoperative MRI, fMRI and DTI significantly increases its utility for intraoperative decision making. Compared to the current clinical practice of rigid registration, non-rigid registration algorithms are able to compensate for brain shift during surgery in real time, and with very good overall registration accuracy. Combined with the availability of intraoperative MRI, preoperative data can be warped and adapted to the current configuration of the
patient's brain when required by the surgeon. Such visualization may dramatically improve surgical decision making, potentially leading to a more complete resection of diseased tissue with fewer adverse neurological consequences.

Figure 1. Illustration of the processing pipeline. Edges of the posterior part of the left hemisphere are shown.

References