Intraoperative brain-shift compensation using MR/US elastic registration by means of a constraint-based biomechanical simulation

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Introduction

During brain tumor procedure, accurate localization of the target is essential. However, the intraoperative deformation of soft tissues, called "brain-shift", is a major source of error. Even if this topic has been widely studied, few of the brain-shift correction methods are usable in a clinical practice [1, 2, 3], namely easily integrable in the surgical workflow, relevant in terms of execution times and user interactions and validated on actual surgical cases. In this abstract, we present a constraint-based biomechanical finite element (FE) simulation method that fulfills these requirements.

Materials and methods

Preoperatively, brain soft tissues and blood vessels are respectively extracted from MRI and MR Angiography. The tetrahedral FE mesh, only accounting for the hemisphere affected by the tumor, is then mechanically coupled with the vascular tree skeleton. Intraoperatively, navigated US images are acquired in contact with the brain [1]. Power Doppler and B-mode information are recorded simultaneously, respectively allowing to extract the blood vessels and probe footprint. A biomechanical simulation, relying on a linear constitutive law solved with a co-rotational approach, is used to compensate for brain-shift, accounting for the following Lagrangian Multipliers constraints:

- the brain model is prohibited to exit the cavity formed by the dura mater and slides in contact with the *falx cerebri* and the *tentorium cerebelli*
- the cortical surface is situated under the probe footprint but both are not necessarily in contact
- the pre- and intraoperative vessels skeletons are registered

After resolution, preoperative MR images are updated with the FE model deformations.

Results

Our method was validated over retrospective data of five patients using landmarks set on vessels and anatomical structures delineated by a clinician. On average 72% of the deformation occurring at the opening of the dura is corrected with our method, with mean error under 1.5 mm for each patient, against 54% with [1]. US images were also available during resection for four of these patients. For tumor close to the cortical surface, our method still shows an improvement over [1] (65% against 56%). However, for deep tumors that necessitate a chimney for the surgical approach, our method fails to correct the deformation, showing the importance of a specific treatment.

References

[1] Reinertsen I. et al. *Acta Neurochirurgica* **156**:1301-1310, 2014.
[2] Rivaz H. & Collins D.L. *Int. Jour. of Comp. Assisted Radiology and Surgery* **10**:1017-1028, 2015.
[3] Miga M.I. et al. *Int. Jour. of Comp. Assisted Radiology and Surgery* **11**:1467-1474, 2015.

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