Kombinierte Simulation und Registrierung für die Bestimmung der mechanischen Eigenschaften von Hirngewebe

Combined Simulation and Registration for the Determination of the Mechanical Properties of Brain Tissue

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Purpose

Defining correct mechanical parameters of tissue is a crucial issue for reliable finite element model calculations. In this paper a new approach is presented for the estimation of the Young‚s modulus (E) and Poisson‚s ratio (nu) describing the mechanical properties of brain tissue. It is based on the interaction of a biomechanical model of brain shift and the information extracted from pre- and intraoperative MRI. Both elastic moduli are estimated in an iterative process.

Material & Methods

Experiments were conducted with pre- and intraoperative MR data (voxels: 512x512x160, voxel size: 0.49x0.49x1.0 mm) obtained with a Siemens Magnetom Sonata Maestro Class 1.5 Tesla scanner.

The basis of the algorithm is a physically-based model of brain shift which can be chosen arbitrarily. Here, the brain is assumed to be a linearly elastic medium saturated by a viscous fluid. The describing equations are discretized on a tetrahedral grid using the

Galerkin scheme and are solved with a finite element method. The result contains for each node of the discretization domain its displacement vector and the scalar value of the pressure.

During optimization, the reconstructed volume is registered to the real intraoperative MR image using. Thereby, both elastic moduli are set as free parameters for the optimization. In each iteration, the obtained displacement vector field is taken for the volume reconstruction.

For the registration, a special similarity function is introduced, containing a penalty term which restricts the search space for the parameters (E) and (nu). This allows incorporating a priori knowledge about resonable values for the elasticity parameters and reduces the number of calculation steps. In order to represent the intraoperative situation, the boundary conditions are set according to the location of the skull opening.

Results

In the first experiment, the simulation was conducted on a tetrahedral grid consisting of 9952 elements. The resulting Poisson.s ratio (nu=0.452) is very close to the value reported in works by Miga.

In the second experiment, a very fine grid consisting of 123496 elements was considered. The global maximum was observerd for the value (E=8196.21) Pa for the Young.s modulus, which is close to the value of (E=7425) Pa reported by Miller for the swine brain in an in vivo experiment. For the Poisson.s ratio the value of (nu=0.461) was found. Generally, this experiment showed a more stable behavior, which results from the finer resolution of the grid.

Additionally, a simulation based on the obtained optimized elasticity parameters was performed. This lead to an improved correspondence between the model and the real situation.

Conclusion

This work combines finite element simulation and registration in a novel approach determining optimized mechanical properties of brain tissue. The value of the method was experimentally shown and the obtained results correspond very well to the parameters reported in the literature. The strength of the proposed strategy is the inherent validation ensured by the registration as part of the method.

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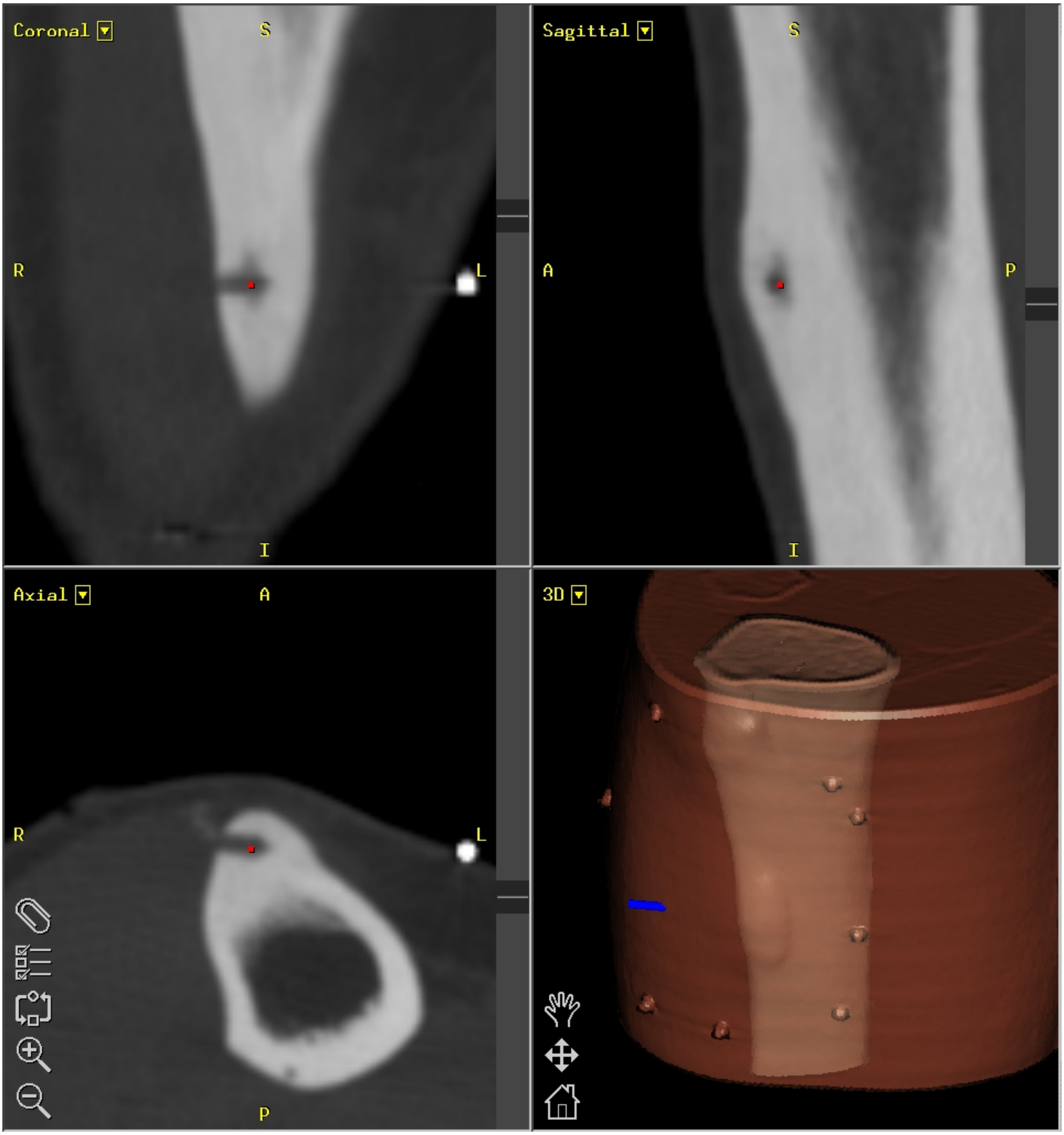
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