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Quantification of the stress generated by the endoscopic movement in the brain parenchyma during intra ventricular surgical procedure

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KEYWORDS Brain; Hydrocephalus; Endoscope; Finite Element Analysis

1. Introduction

Endoscopy is increasingly used for intra ventricular surgeries such as hydrocephalus and tumor removal (Miwa et al. 2015).

Robotic based surgeries are more and more developed to control the trajectory and the movement of the endoscope and then to enhance the accuracy of surgical procedures and to reduce post-operative issues. The use of computer- aided robot is then well-suited to accurately reach ventricles cavities through the brain parenchyma and to minimize cerebral damage caused by the movement of the endoscope. On a mechanical point of view, moderate and severe traumatic brain injury (TBI) had a 50% risk to locally occur when Von Mises stress respectively exceeds 18 and 38 kPa (Willinger & Baumgartner 2003).

The purpose of this study was to assess the Von Mises stress generated in the brain by the endoscopic movement.

2. Methods

2.1. FE model: geometry and material properties

The geometry and the mesh of both the endoscope and the surrounding cerebral layer were designed with the Hypermesh® software (Altair Engineering, 1985). Endoscope and brain were represented by two cylindrical parts, respectively 5.2 mm and 80 mm of external diameters. Brain model was a hollow at its center along its principal axis, of 5.6 mm of diameter; the endoscope part was placed along its center (Figure 1).

The thickness of the cerebral layer of one patient and the center of rotation of the endoscope were personalized using MRI images.

Incompressible hyper-elastic material constitutive law was implemented for the brain model (Table 1), with a Poisson coefficient of 0,495 (Mihai et al. 2015).

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_p \frac{C_p}{m_p}(\lambda_1^{m_p} + \lambda_2^{m_p} + \lambda_3^{m_p} - 3)$$

A linear perfectly elastic material was used for the endoscope model (E = 69 GPa and ν = 0.33). An interface TYPE 19 (a node to surface combined with a surface to surface interface) was set to simulate the contact between the endoscope and the brain model. It was assumed that the movement between the endoscope and the brain is nearly frictionless. Thus, a friction coefficient of 0.01 was set. Brain and endoscope models were meshed with H8C Standard 8-nodes elements, with 2*2*2 integration points, no hourglass, and a Lagrangian solid full integration formulation.

The size of the elements in the radial direction was linearly interpolated in order to have smaller elements close to the contact.

2.2. Boundary conditions

On the upper face of the model, the nodes with a radial position higher than 20 mm were fully constrained in order to simulate the contact between the brain and the inner surface of the skull.

The node at the center of the upper surface of the endoscope (the center of rotation CR) was constrained in translation in the three directions and free to rotate. The movement was imposed to the node set at the center of the bottom surface of the endoscope.

A real trajectory measured by a robot (Renishaw®) during an actual hydrocephalus surgery (3300 s of surgery)

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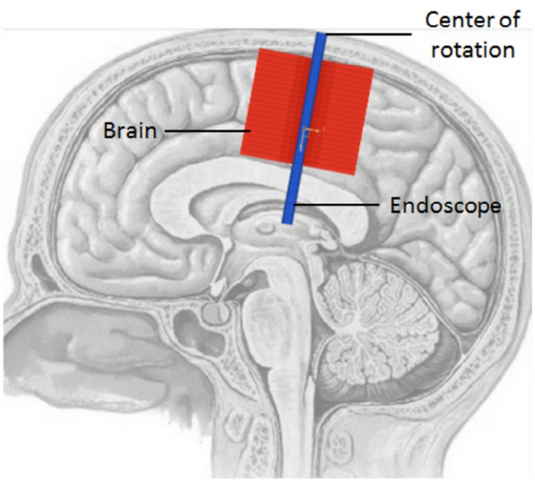

Figure 1. Personalized position of the model: mesh of the endoscope (blue) and the surrounding cerebral layer (red). The center of rotation of the endoscope (CR) corresponded to the enter point in the head. (Adapted from Netter 2002).

Table 1. Fourth order Ogden law for hyper-elastic properties.

Order	1	2	3	4
C (Pa)	5877	−5043	1161	−501
m	1	−1	2	−2

was implemented in the model to simulate the motion of the endoscope.

Numerical test was performed with the FE solver Radioss® (Altair Engineering, 1985).

3. Results and discussion

The generated Von Mises stress was mapped on the 3D geometry of the model until the 70th second. Due to numerical convergence problem, the simulation had to be stopped. Results were presented Figure 2.

The maximal Von Mises stress locally reached at this step of the simulation was 23 kPa, which corresponds to about 90% of risk of moderate neurological lesions and less than 10% to get a severe TBI (Willinger & Baumgartner, 2003).

Several improvements are planned. First, convergence problems have to be solved in order to simulate the 3300s of surgery. The shape of the mesh was designed to avoid too highly distorted elements creation during the simulation. More realistic boundary conditions can be implemented. Due to numerical optimization, the brain is not in contact with the endoscope at the initial time step, whereas it completely surrounds it in real context. The viscosity was neglected because the speed of the endoscope was very low (0.417 mm/s). Nevertheless, a visco hyper-elastic law will be implemented to improve the model.

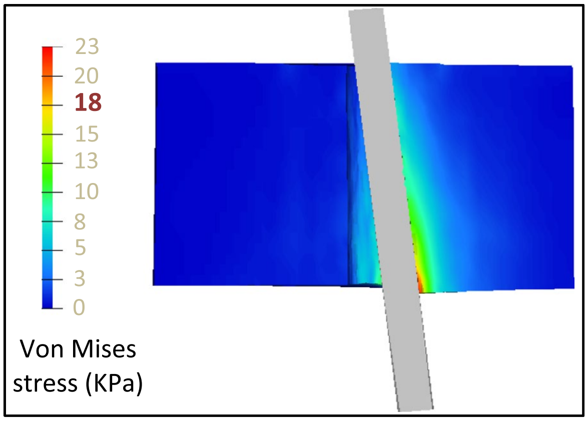

Figure 2. Example of Von Mises stress (MPa) generated by the endoscope path, slice view, after 7 s of surgery (18 kPa: 50% of risk of moderate TBI).

The two thresholds to evaluate the brain lesions after the surgery (18 kPa and 38 kPa) were determined for external impact tests (Willinger & Baumgartner, 2003). In a first step, it gives good estimation of brain damage, but in the future, further work should be performed to use a more suitable criterion for the present clinical procedure. Even if this model can be personalized regarding the thickness of the cerebral layer and the position of the center of rotation of the endoscope, it still remains to take into account the variation of mechanical properties between a patient and another. Finally, this model might be evaluated using the visible injury scares on MRI after the surgery.

4. Conclusions

A finite element model simulating an actual endoscopic movement in the cerebral parenchyma had been designed in order to quantify the Von Mises stress generated into the brain. It could be used downstream hydrocephalus surgeries to evaluate the physiological state of the brain and to better plan the procedure in term of lesion.

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