学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Numerical Models of Blunt Dissection and Brain Retraction for Neurosurgery Simulations
（脳神経外科手術シミュレーションのための鈍的剥離と脳圧排数値モデル）

In the brain, parts that control important functions, such as language and motion functions are dense. In neurosurgeries, accidentally damaging the surrounding area of a lesion can result in serious after-effects. Therefore, extreme caution is necessary during neurosurgeries. A neurosurgery simulator is expected as a training method to train novice neurosurgeons in basic surgical skills. Neurosurgery simulators are expected not only for training novice surgeons but also for helping experienced surgeons in preoperation planning and operative procedure confirmation.

Several neurosurgery simulators have been developed. In such a haptic surgery simulator, the deformation of the brain tissue is displayed on the display, and the reaction force is presented to the operator through the haptic device.

Basic skills of neurosurgery include sharp dissection, blunt dissection, and brain retraction (to press the surrounding area to secure the path to the lesion). Among them, experiences are especially necessary for blunt dissection and brain retraction. Therefore, development of a neurosurgery simulator that can accurately simulate these two skills is expected.

The knowledge of situations that can cause damage and fracture of brain tissue is very important for the surgeon during a surgery. Macroscopic fracture, such as blunt dissection due to aspiration tube, as well as microscopic damage due to brain retraction can cause damage to the cranial nerve. Therefore, for neurosurgery simulation, it is necessary to construct stress relaxation and damage fracture models that can accurately calculate the stress and reaction force of brain tissue.

In this study, a finite element method is used as a numerical calculation method to construct a simulation, with a dynamic motion equation. The brain tissue is modeled as a homogeneous, isotropic, linear material.

Most of the previous studies about damage and fracture of brain tissues were conducted with high strain rate for traumatic brain injury. Strain rate dependence exists in the mechanical properties of brain tissues. Therefore, experimental results and numerical models of traumatic brain injury cannot be applied to neurosurgery simulations, which are usually performed at a low strain rate. In this study, we focus on damage of brain tissues at a low strain rate. Tensile tests were conducted using porcine brain tissues, and the mechanical properties of damage of brain tissues were measured.

As the existing damage fracture models cannot reproduce the mechanical characteristics of damaged fracture of brain tissues, new damage fracture models that can reproduce damage of brain tissue are proposed in the present study. The implementation of new models is easy, with low computation cost. In addition, parameters necessary for the new models were identified based on experimental data. Tensile simulations were conducted under the same conditions as the experiments, and it was

confirmed that the damage models accurately reproduce damage of the brain parenchyma.

For the viscoelastic model of the brain, many studies have used the generalized Maxwell model so far. However, in the original generalized Maxwell model, the inertial force due to mass of the brain is not considered. When the simulation is analyzed using the finite element method, the stiffness matrix may become a singular matrix when the brain tissue is cut or peeled off. In the deformation calculation of the simulation model, the inverse of the stiffness matrix is usually used. As such, numerical calculation becomes unstable when the stiffness matrix is singular. In this research, we propose a model that stabilizes numerical calculation even if the stiffness matrix becomes singular by adding an inertia term to the generalized Maxwell model. In addition, experiments were conducted using columnar specimens of brain tissues, and parameters were identified. Experimental results were reproduced through a simulation using the proposed method, and the usefulness of the proposed stress relaxation model was verified.

In mechanical experiments using animal brain, most of the previous researchers had cut out a part of the brain for experimentation. However, in such experiments, stress generation depending on the structure of the whole brain could not be measured correctly. Thus in this study, retraction experiments at longitudinal fissures of cerebrum were conducted using a whole porcine brain, and the reaction force was measured. It was confirmed that the parameters of the cylindrical specimen cannot be used for a whole brain model. Therefore, the parameters of the whole brain model were identified. In addition, simulations were performed using a finite element model of a porcine brain, and the stress characteristics of experiments were reproduced.

The goal of future studies will be the introduction of damage fracture and stress relaxation models into the neurosurgery simulation.