学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Development of a Real-time Brain Retraction Simulator Using Patient-specific Model
（患者固有モデルを用いた実時間脳組織圧排シミュレータの開発）

The progress of computer technology has enabled the real-time computing of physical phenomena. An application of the computing technique is surgery simulator, in which the deformation of soft organs is calculated in real-time. In addition, using haptic device, users can touch the virtual organs with artificial sense of touch. One difficulty in the clinical application of surgery simulator is the generation of the patient-specific model. When a surgeon wish to conduct a preoperative surgery planning, he/she need to prepare the models for mechanical analysis, e.g. finite element (FE) mesh, from medical images. Especially, the model generation for a brain is challenging because the structure of the brain is highly complex. From the point of the real-time application, the model is required to be simple for reasonable calculation cost. At the same time, the model is required to preserve the geometrical and topological features of the target organ. Although models that fulfill these requirements can be generated using current software, the generation task takes several hours or days with a specialist. Ideally, the model generation should be conducted by medical stuffs in a hospital and should not require special knowledge on the numerical analysis for them.

In this thesis, a generation method of patient-specific FE mesh from medical images is proposed for enabling brain retraction procedure in virtual environment. The method relies on an idea of the use of nonconforming mesh. The input geometry is embedded in a regular hexahedral mesh. The deformation of the input geometry is interpolated by the hexahedral mesh in a master-slave manner. An advantage of this approach is the simplicity of the mesh generation compared with the conforming mesh generation. Thanks to the simplicity, the mesh generation can be performed quickly and robustly. Thus, a user can generate a patient-specific model without special knowledge on a specific software. A drawback of this method is the possibility of the loss of fine structure. For example, if multiple domains are included in a hexahedral element, they are considered as connected domains even when they are separated in the input geometry. To resolve this issue, an approach using element duplication is proposed. An efficient algorithm of the mesh generation for segmented medical image is also described. The effectiveness of the method in the topology preservation of brain fissure is presented.

Additionally, a simulation method for a patient-specific nonconforming FE mesh is also proposed. The deformation of the brain tissues is calculated using corotational finite element method. The contact problem between brain tissues and surgical instruments is formulated using penalty method. For stabilizing the simulation, implicit time integration is utilized for dynamic problem. This framework enables to simulate the interaction between a brain retractor and a brain model with stable force feedback.