A Study of Bone Remodeling Around Titanium Mesh Cage Using in Total en Bloc Spondylectomy

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Introduction

Total en bloc spondylectomy is the most efficient surgical treatment to prevent recurrence of malignant vertebral tumors (Tomita et al., 1997). In this surgery, a tumorous vertebra is totally removed and replaced by a titanium mesh cage filled with morselized bone graft, and spinal instrumentation is carried out by using pedicle screw system. When once fusion was obtained between grafting bone inside the mesh cage and the neighboring vertebrae, spinal reconstruction became more biomechanically strong (Hertlein et al., 1992). Fatigue fracture risk of the spinal instruments attached to posterior side of vertebra can be reduced by anterior fixation of grafting bone fusion. It is considered that fusion and remodeling of the grafting bone depend on mechanical environment. If mechanical stimuli were not adequate, sufficient fusion was not obtained. Even though fusion of the grafting bone was obtained, severe bone resorption occurred by mechanical adaptive bone remodeling after the fusion. Adequate mechanical stimuli are necessary to maintain the bone fusion. So that, it is important to consider the relationship between mechanical condition and bone remodeling of the bone graft inside mesh cage.

Although initial stability and rigidity of the reconstructed structure have been investigated well (i.e. Oda et al, 1999), study about the bone graft fusion and remodeling in mesh cage related to mechanical condition has been rare. In this study, mechanical condition of the grafting bone in the titanium mesh cage was evaluated to discuss adaptive bone remodeling after the fusion. Furthermore, bone remodeling of the grafting was simulated using an adaptive bone remodeling theory, and bone density distribution obtained by the simulation was compared with bone tissue condition of a clinical data.

Materials and Methods

A schema and an example X-ray image of reconstructed structure of spine using a titanium mesh cage after total en bloc spondylectomy is shown in figure 1 (side view). A couple of pedicle screws are screwed into posterior element of each two vertebrae above and below the mesh cage with bone graft. These pedicle screws are connected with a couple of spinal rods. Spinal rods of both sides are linked each other by using transverse connector at several points to prevent unsymmetrical distortion. This type reconstruction is called as multilevel posterior instrumentation.

A clinical case that malignancy osteosarcoma occurred in a thoracic vertebra (T6) of 16 years old male was subjected. Total en bloc spondylectomy and spine reconstruction with multilevel posterior instrumentation was performed for T4-L1 vertebrae. The patient died 16 month after the surgery because of lung tumor. Bone tissue preparation in a sagittal plane including the titanium mesh cage was made and grafting bone morphology was evaluated.
Figure 2 shows HE stained bone specimen that was sliced with the mesh cage and pedicle screws in median sagittal plane. There was another grafted bone outside of the mesh cage in anterior side, but it was not mechanically connected between T5 and T7 vertebrae in this cross-section. Trabecular structure was formed in grafted bone inside of the titanium mesh cage, and bone fusion with T5 and T7 vertebrae was obtained perfectly. Density distribution of the trabecular bone was not uniform. It was considered that mechanical bone adaptation was occurred in the grafted bone during the bone fusion.

To evaluate the mechanical bone adaptation, stress of the grafting bone was analyzed by FEM. Simplified model of the mesh cage and grafted bone was considered, and plane strain condition was assumed in this analysis. Finite element mesh and boundary conditions are shown in figure 3. Inclined compressive load distribution was assumed on top and bottom surface considering as flexion condition. Average pressure is denoted as p. Equivalent Young’s modulus of the titanium mesh cage was given as 2.4GPa determined by compressive loading test. Young’s modulus of the rim of mesh cage, cortical bone and grafting bone were given as 100GPa, 12GPa and 0.1GPa, respectively. Cortical end plates were considered at top and bottom surface of the model. Ilium bone was smashed and used for grafting bone, but cortical part seemed to be remained that was observed in figure 2 as clear vertical line. So the cortical part of the grafting bone was also considered in this model. Uniform density and material property were assumed in another part of the grafting bone as initial condition of bone remodeling. Internal bone remodeling simulation of the grafting was also carried out using this model. In the simulation, bone density and elastic coefficient of each finite element of the grafting were successively changed due to mechanical stress stimulus by using the theory of mechanical adaptive bone remodeling (Beaupré et al., 1990). Mechanical stress stimulus was formulated using strain energy density in this theory. Quantity of bone apposition or resorption due to adaptive remodeling was given in proportion to balance between the applied stress stimulus and regular stress stimulus (attracted state stimulus). Bone density could be changed from 0.02 to 1.8 (g/cm$^3$) in according to the bone apposition and resorption. Initial condition of graft bone density was set as 0.37 (g/cm$^3$) uniformly. The other computational parameters are given due to the literature.

**Results & Discussion**

Figure 4 shows distribution of strain energy density (SED) in grafted bone inside the titanium mesh cage. SED was normalized by average of distributed load. Low SED area was observed in posterior side and high SED area was observed in anterior side. The titanium mesh cage had a pair of rings at both sides for reinforcement. Particular high stress region was observed around anterior side of the bottom ring. Trabecular distribution of grafting bone of the preparation was dense around anterior side of the bottom
ring. SED was relatively higher between upper and bottom ring in anterior side. Trabecular arrangement also seems to be comparatively dense in the space between the rings. Tendency of the SED distribution was similar as bone trabecular distribution of the grafting. Density distribution of the grafting bone seemed to depend strongly on the SED distribution in initial condition. The SED distribution was analyzed for the initial condition that the grafted bone density was uniform before occurrence of adaptive bone remodeling. On the other hand, trabecular distribution of the bone preparation shown in figure 2 corresponded to condition after a certain bone remodeling process. SED distribution was changed due to bone density change during bone remodeling process. So, analysis of SED distribution in the initial condition was not sufficient to discuss that mechanical bone adaptation occur or not in the titanium mesh cage. To ensure the mechanical bone adaptation, adaptive bone remodeling simulation was indispensable. Figure 5 shows a density distribution of the grafted bone obtained by an adaptive bone remodeling simulation, and a photograph of bone tissue preparation enlarged the mesh cage inside. Bone density of the anterior region around top and bottom rings became higher than the posterior bone density in the remodeling simulation. Figure 4 shows that SED around upper ring is not so considerable in comparison with bottom ring. On the other hand, bone density around upper ring is high as same as bottom. SED near upper ring also seems to be sufficiently high to get bone formation. A path of high-density bone was observed between top and bottom rings in anterior part as same as the bone tissue preparation. So, it was ensured that the mechanical adaptive bone remodeling occurred inside the mesh cage. Although the computational model was simple and hypothetical, that stress analysis by FEM and the bone remodeling simulation were available to prospect adaptive bone remodeling inside of the mesh cage on the total en bloc spondylectomy.

References

Figure 4: Distribution of strain energy density in grafted bone inside the titanium mesh cage.

Figure 5: Trabecular bone distribution of grafted bone of the preparation (left) and bone density distribution obtained by simulation of mechanical adaptive bone remodeling (right).