A COMPUTATIONAL APPROACH TO BONE REMODELING POSTOPERATIVE TO FACET FUSION

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INTRODUCTION

The mechanical and biologic factors that drive bone fusion can be better understood. This is evident in the fact that of the approximately 200,000 spine fusion procedures performed each year failure to achieve a bony union can occur in as many as 40% of the cases (Boden 2002). Advances in computational methods and mathematical modeling of bone fusion make it advantageous to use numerical methods such as the finite element method, to better understand bone remodeling mechanics.

It has been observed for some time that bone adapts due to mechanical stimulus. Wolff described bone as a self optimizing material. Mullender et. al. (Mullender and Huiskes 1995) described the process of maintenance and adaptation in the hip as a local, cell-based control process.

Jovanovic and Jovanovic (Jovanovic and Jovanovic 2004) used a similar method to model the 2D structure of a cross section through the body of a vertebra. These studies demonstrate the usefulness of applying methods of bone remodeling to answer biologic questions, and they give a sound justification for the methods proposed here.

METHODS

In this work, a bone remodeling algorithm is adapted from the methods introduced by Mullender et al. (Mullender and Huiskes 1995). A general outline of the remodeling algorithm is shown in figure 1.

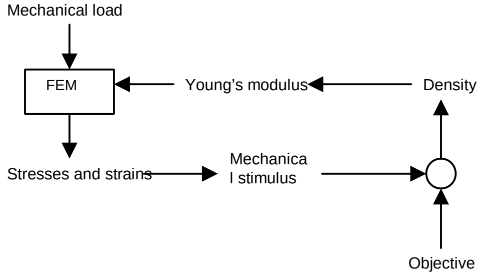

Figure 1. Proposed remodeling algorithm

A user material is developed for integration into Abaqus finite element software. Each Gauss point is assigned a material property based upon the strain energy density calculated from the previous analysis step. Using a gauss point approach eliminates discontinuous solutions. A 4th order Runge-Kutta solution approach is used to calculate the density change for each analysis step.

A vascular model is developed from literature and clinical observation. This model is incorporated into the remodeling approach, and is shown to improve the accuracy of the solution when compared to data from a study of posterolateral fusion in sheep.

Geometric data is taken from computed tomography (CT) scans of sheep specimens and is digitally instrumented in a manner consistent with actual surgical alteration used in an animal study. Figure 2a shows the digital model, and figure 2b gives a surface representation of the actual specimen.

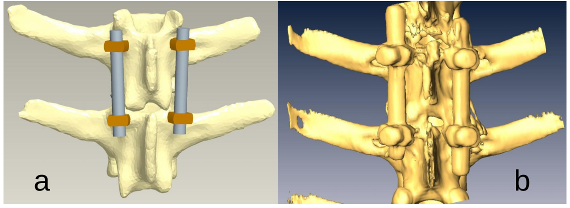

Figure 2. Instrumented a) CAD model and b) isosurface of specimen 1.

Loading is determined from static analysis of an adult sheep. This load is applied to the superior surface of the superior vertebra while the inferior surface of the inferior vertebra is fixed. The remodeling algorithm presented previously is applied and the simulation is run until steady state is reached.

RESULTS AND DISCUSSION

The predicted results agree well with actual results. Accuracy is improved when the vascular model is included as is seen in figure 3. Figure 4 shows the final configuration of bone with an increased mass at the facet joint and a reduction of the lateral mass consistent with clinical practice and study data.

SUMMARY/CONCLUSIONS

Once adequate validation is achieved, the method is applied to human CT scans to evaluate the response to loading subsequent to facet fusion surgery. This method allows for simulation of bone remodeling response to an altered stress state. A better understanding of the response to surgical alteration can benefit surgeon and patient. This can also lead to improved designs of fixation instrumentation that improves the environment for bone growth and leads to increased rates of fusion.

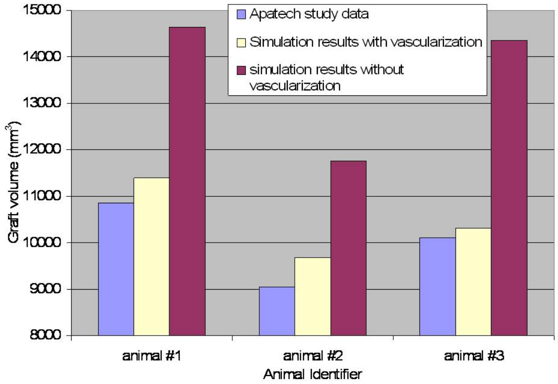

Figure 3. Volume of graft from physical study and simulations.

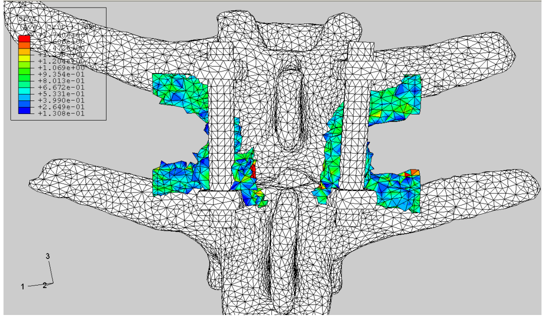

Figure 4. Approximate geometry for remodeled bone graft predicted by simulation including vascular effects for animal #1.

ACKNOWLEGEMENTS

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