THE DESIGN AND FINITE ELEMENT ANALISYS OF BIOMIMETIC BONE SCAFFOLDS

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Introduction

An estimated 500,000 to 600,000 bone grafting procedures are done annually in the United States (Bucholz, 2002). The need for this procedure results from an array of disease processes including cancer, infection, trauma, and developmental defects. Synthetic bone graft substitutes (bone scaffolds) currently represent only 10% of the bone graft market, but their share is increasing as materials and methods continue to improve and experience and confidence in their use are accrued (Bucholz, 2002). In this research project, new architectural designs for bone scaffolds were created using knowledge of existing bone scaffolds as a guide to provide critical design parameters. It integrated a biomimetic inspired approach for scaffold design with the constraints imposed by rapid prototyping. The biomimetic design constraints obtained from the known structure of native bone as well as the constraints imposed by our Zetos® testing device, mandated that each design be equal to or smaller than a 7 mm high by 10 mm diameter cylinder, have pore sizes of 100 to 300μm, and a porosity of 50 to 80%. Finite Element Analysis (FEA) was done, ensuring that the design parameters were met. Three initial designs were created, with one final design.

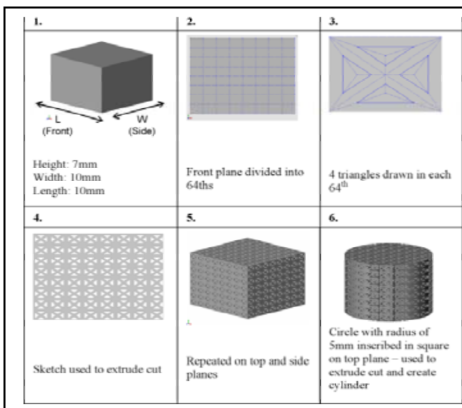

Figure 1: The design process for initial design 1 (triangular mesh).
The SolidWorks® design software program was used to create the solid models **1.** The initial structure chosen was a rectangular prism **2.** Front plane was divided into 64ths **3.** Each 64th was then divided into 4 isosceles triangles. **4.** The intrinsic triangular features were extruded and cut through the entire structure of the rectangle. **5.** Steps 2-4 were repeated on the side and top planes. **6.** A cylinder was created out of the rectangular prism by extruding a circle with a radius of 5 mm inscribed in the square of the top plane.

Methods

Three initially distinct architectural models were created in SolidWorks and then tested in ABAQUS® 6.4, a FEA program. In two of the initial designs, triangular pores of differing dimensions were used and the third design employed circular pores. Each design was tested with FEA in ABAQUS® 6.4.. The scaffolds were meshed using quadratic tetrahedral elements with a global element edge length of ? mm. The elements were assigned a Young's modulus of 2740 MPa and Poisson's ratio of 0.3, representing the rapid prototype material (name, manufacturer) to be used in the manufacturing of the scaffolds. To meet the memory capacity of the software and hardware, each design was sectioned into a manageable slice, the largest being a half cylinder with a height of 0.7 mm and a radius of 5 mm. Boundary conditions were created within the software to mimic the structure surrounding the slice. A displacement of 0.042 mm was applied, giving a compressive strain of 0.006, the maximum strain for bone (Davies, 1993). The FEA was then run, resulting in field outputs of stress and nodal displacement. The results were displayed on a contour plot, and were analyzed for the maximum and minimum stress values. The minimum principal stress was compared to the compression strength -79 MPa. The maximum principal stress value was compared to the tensile strength 55 MPa of the rapid prototyping material.

Discussion and Conclusions

Differences between the three designs in how the compressive load was distributed within the scaffold structures is demonstrated in Figure 2. Considering bone's response to load, it is hypothesized that the differences in strain distributions within the structures will affect the bone's ability to grow within the scaffolds.

Three distinct scaffold designs were created that met the geometric and strength requirements of biomimetic bone scaffolds. In a continuing study, mechanical tests will be performed on the structures manufactured through rapid prototyping.

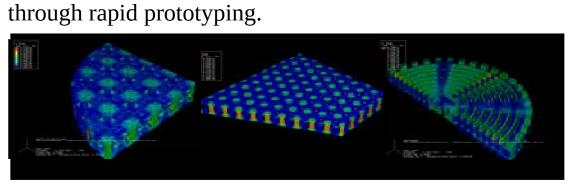

Figure 2. Von Mises stress results of compressive displacement to the top face of designs 1, 2, and 3 (left to right)

References:

Bucholz RW. Clin Orthop Relat Res. 2002. 395:44-52.
Davies H.M., McCarthy R.N., Jeffcott L.B., Acta Anat (Basel) 146(2-3):148-53,1993.