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3D Printed PLA Scaffolds to Promote Healing of Large Bone Defects

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Using Additive Manufacturing to Create Bone Tissue Scaffolds for Large Bone Defects

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INTRODUCTION

Small bone defects typically heal naturally, but large bone defects often do not, leaving remaining bone with sizable voids and functional deficiencies. The overall goal of our research is to develop a method of using 3D printing (3DP) to create biodegradable scaffolds which promote bone growth for tissue replacement.

OBJECTIVES

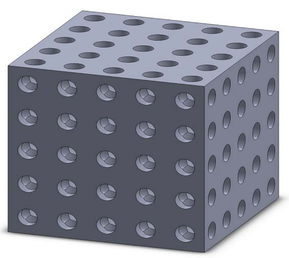
To achieve our overall goal, our objectives are to design a 3DP biodegradable scaffold that

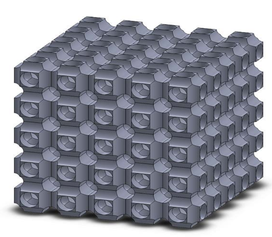
1. is capable of being shaped in implanted into cortical or trabecular bone cavities
2. Is compatible with the required bone stiffness
3. is promoting of cell growth.

SCAFFOLD DESIGN AND 3DP

Scaffolds were designed using Computer Aided Design (CAD). The scaffolds (Fig. 1) were created by pattering unit cells. The first two designs were simple porous blocks. Seeking to improve cell growth and maintain stiffness we created the T scaffold, which utilized rods of various sizes to create porous structure. The final models we created were the X scaffold line. These use angled rods to create a more intricate lattice. These scaffold geometries can be shaped, using our CAD software, to fit defects in bones. We selected poly lactic acid as an appropriate material due to its biocompatible and biodegradable properties

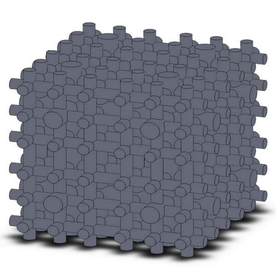
a) 1 Pore Scaffold
58.75% Volume Fraction
Right Angle Holes

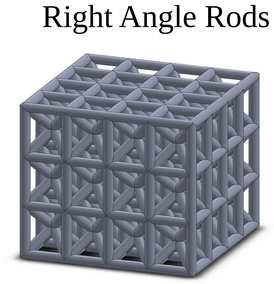




b) 2 Pore Scaffold
17.55% Volume Fraction
Right Angle Holes

c) T Scaffold
27.96% Volume Fraction
Right Angle Rods





d) X Scaffold (35°)
39.92% Volume Fraction
Irregular Rods

Figure 1: Scaffold Designs and Specifications

ANALYSIS AND TESTING

We performed Finite Element Analysis (FEA) using ABAQUS to simulate a scaffold implant in bone and investigated the effect of scaffold stiffness on bone and scaffold strain. The model had properties of trabecular bone (E= 2142 MPa, ν=0.3) while scaffold properties varied across the range found from mechanical testing.

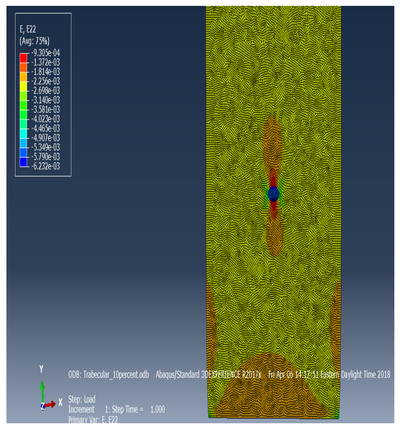


Figure 2 . FEA of simulated bone with implant.

We mechanically tested the scaffolds in compression to determine the stiffness of each scaffold construct and validate our simulation results (Fig. 3). Compression test were made between steel plates and specimens were only loaded within the elastic region of the material.

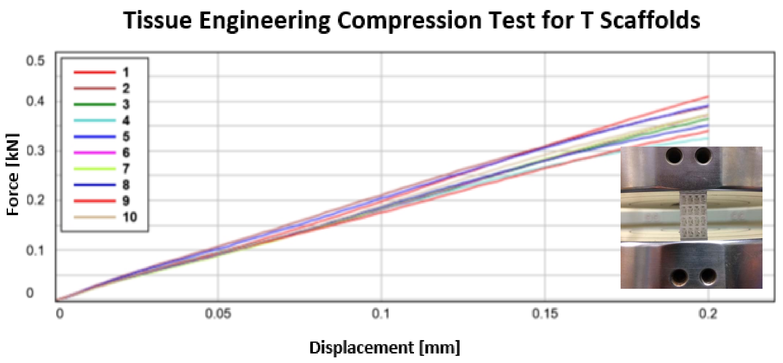


Figure 3: Force vs. Displacement graph and 3D printed scaffold in test fixture

Cell Culturing

Normal human fibroblast cells were maintained in required media and passaged every 4-5 days upon reaching confluency. At the time of plating and co-incubation with sterile scaffolds, cells were viable and proliferating. After one week, the scaffolds now containing cells were removed from dishes and preserved with 2% paraformaldehyde. To assess cell attachment scaffolds were submersed in trypan blue which binds cell structures and allows visualization under light microscopy.

A total cell count on two sides of the scaffolds was performed. The counts were performed by 2 observers using light microscopy and normalized for 1 cm^2.

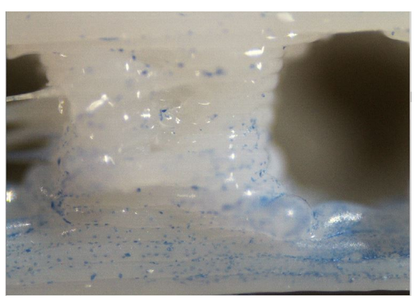


Figure 4: Photo micrograph of cultured scaffold with cell indicated in blue

RESULTS

Scaffold design was found to significantly alter scaffold stiffness (Fig. 5) (obj. 2) via mechanical test and resultant strain in bone and implant (Fig. 6) according to our FEA. Cell culture experiments provided information concerning the potential for each scaffold to promote cell growth (obj. 3).

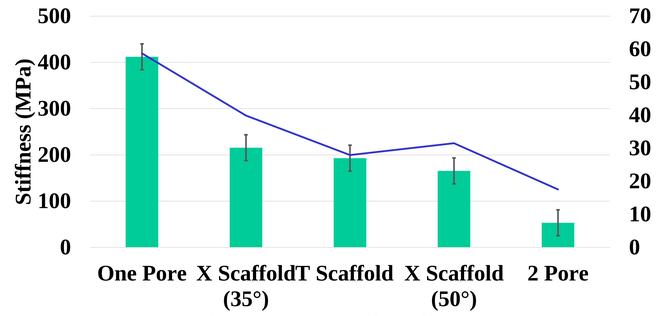


Figure 5: Stiffness Perpendicular to Printing Layers

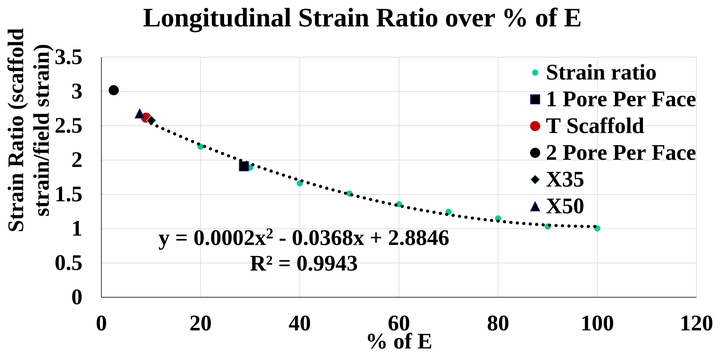


Figure 6: Strain Ratio (Implant/Far Field) from FEA

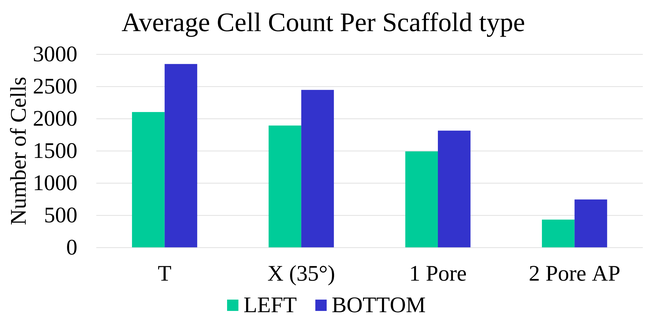


Figure 7: Cell Culture Results

DISCUSSION

Our research has created several unique scaffold designs with variable stiffness. We found all architectures allowed cells to attach and proliferate with significant variation. Through the use of FEA, we also found the stiffness of our scaffolds can create a differential strain which could stimulate bone modeling. Based on these results, we believe our implant designs could stimulate healing of large bone defects. Further studies are required to examine the in vivo behavior of the implants. Objective 1 in part of ongoing research.

SIGNIFICANCE

These research has provided some preliminary and promising results for the development of 3DP tissue engineered scaffolds