# Three Dimensional Printing of Gradient Scaffolds to Bridge the Gap Between Bone and Cartilage for Osteochondral Defect Repair

Margaret A. Nowicki, Nathan J. Castro and Lijie Grace Zhang
Department of Mechanical and Aerospace Engineering
The George Washington University, Washington DC

School of Engineering & Applied Science
THE GEORGE WASHINGTON UNIVERSITY

## Introduction

- Osteoarthritis (OA) is a degenerative joint disease with symptomatic pain and discomfort [1].
- By 2030, 67 million Americans are expected to have an OA diagnosis; 33% of this population will be workforce contributors aged between 45 and 64 years [2].
- Existing minimally-invasive methods of treatment or mitigation of disease progression exist, but in most severe cases, all treatments eventually lead to total joint arthroplasty.
- A significant challenge with tissue engineering scaffolds at joint surfaces is the diverse nature of bone and cartilage extracellular composition and mechanical properties, specifically at the osteochondral interface.
- This research hypothesizes that a gradient 3D scaffold, where pore size varies over the scaffold thickness, will have the ability to meet the needs of the complex bone and cartilage regions, as well as, the osteochondral interface.

## Experimental Methods

- Fused Deposition Modeling (FDM) of High Impact Polystyrene (HIPS) created the scaffold molds.
- A PEG/PEGDA hydrogel solution filled each mold and cured under ultraviolet light until firm.
- Heated sonication in a Dilimonene, ultrapure water solution, assisted in leeching the HIPS out of the hydrogel leaving a porous, channeled scaffold of PEG/PEGDA.

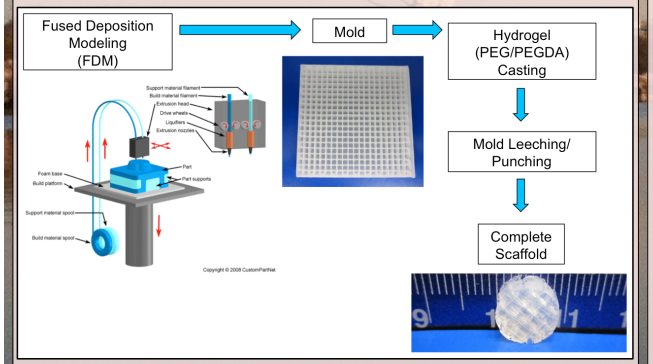


**Figure 1.** Flow chart representing the printing and casting process used to make each scaffold [3]. Mold and scaffold images are for the homogeneous model with low pore density, scaffold 2 in other figures.

- Cell adhesion was executed by covering each scaffold with a solution of human bone marrow mesenchymal stem cells (MSC) in media.
- Scaffolds were removed after 4 hours and cells lifted with Trypsan.
- These cells were then counted using a spectrometer to determine cell adhesion values for each scaffold.
- Each scaffold also went through compression testing.

## Results

**Table 1.** 3D scaffold pore dimensions and distribution.

| Scaffold | Pore Distribution | Vertical Pore Spacing (μm) | Horizontal Pore Spacing (μm) | Interfacial Spacing (μm) |
|---|---|---|---|---|
| 4 | Homogeneous | 500 | 1450 | N/A |
| 2 | Homogeneous | 550 | 745 | N/A |
| 4/2 | Biphasic | 550 | Phase 1 – 750<br>Pahse 2 - 1500 | 600 |
| 4/3/2 | Triphasic | 500 | Phase 1 – 700<br>Phase 2 – 950<br>Phase 3 - 1200 | Phase 1,2 – 550<br>Phase 2,3 - 550 |

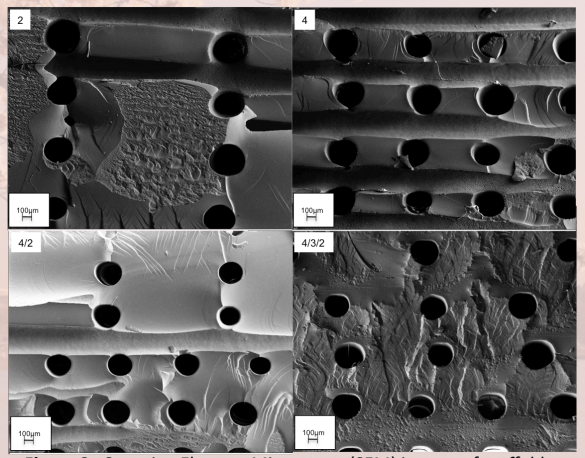


**Figure 2.** Scanning Electron Microscope (SEM) images of scaffolds. Images highlight differences in pore distribution and uniformity.

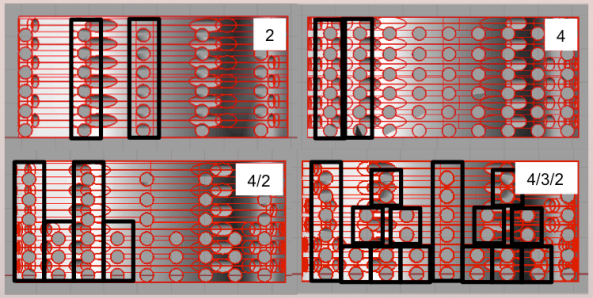


**Figure 3.** Computer Aided Design (CAD) models of scaffolds used to calculate scaffold surface areas. This image also highlights pore distribution and uniformity in the different models.

## Results

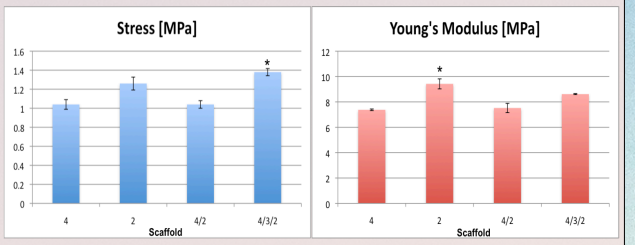


**Figure 4.** Mechanical testing on PEG/PEG-DA scaffold; data are average ± StdEM, n=5; *p<0.05 when compared to all other samples .

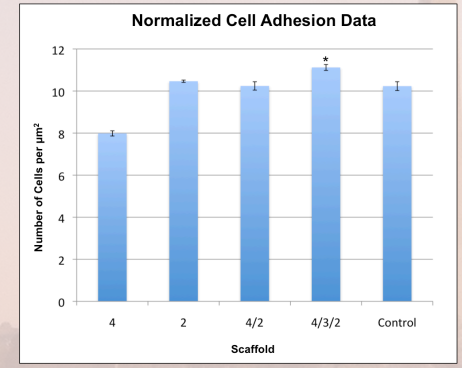


**Figure 5.** Cell adhesion, normalized by surface area, on PEG/PEG-DA scaffold; data are average ± StdEM, n=9; *p<0.05 when compared to all other samples.

## Conclusions

- The MSC adhesion results show promise for improved cell adhesion in scaffolds with discontinuous pore distribution; the triphasic scaffold outperformed all others significantly.
- Compression testing uncovered highest peak stresses in the triphasic scaffold; this is likely due to a discontinuous pore distribution disrupting crack propagation.
- Compression testing uncovered highest modulus of elasticity in the homogeneous sample with low pore density; this is likely related to deformation but more research is required to better define contributing factors.

## References

[1] Buckwalter, J.A. and J.A. Martin, *Osteoarthritis.* Adv Drug Deliv Rev, 2006. **58**(2): p. 150-67.
[2] Hootman, J.M. and C.G. Helmick, *Projections of US prevalence of arthritis and associated activity limitations.* Arthritis and Rheumatism, 2006. **54**(1): p. 226-229.
[3] FDM Image, copyright CustomPartNet, 2008.