



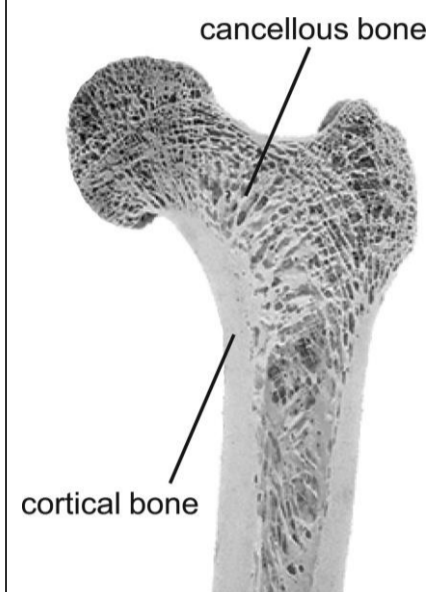
Cancellous Bone Structure for Implant Development

Brandon Honwad, Dennis Tercero, Kaleb Zhong, Jobanpreet Mutti
University of California Berkeley



Introduction

Human bones are composed of two tissue types: cancellous and cortical. Cancellous bone, often referred to as spongy bone, forms the internal matrix of skeletal structure, characterized by a lightweight lattice structure. This porous lattice structure aids in the storage of bone marrow, where red blood cells are created through erythropoiesis. In contrast, cortical bone, known as compact bone, comprises the dense outer layer with minimal porosity. Its role is to provide structural support to the skeletal framework



Despite advancements in medical technology, traditional bone implants encounter limitations in replicating the intricate structure of natural bone. Current-day implants, face challenges in replicating the strength and porosity compared to the natural bone they aim to replicate.

Utilizing 3D printing techniques, we analyzed samples of different geometry and density for their strength and porosity. These results can be used to guide continued research in further development of porous structures for bone implants that more closely align with the intricacies of natural bone, ensuring a clear improved strength, compatibility behavior, and a better overall performance.

Figure 1: Vincent Everts, et al. *The Microstructural and Biomechanical Development of the Condylar Bone*. The European Journal of Orthodontics, PubMed, 2013.

Abstract

Our primary research question is: How can we improve the strength and porosity of bone implants to better replicate the complex structure of natural bone through the incorporation of a porous structure similar to cancellous bone but having an appropriate balance between these variables making sure our implant is successfully accepted by a human body. For this experiment, 4 different types of infill geometries with different infill densities are studied and tested. For all the variations of these pieces, the [liquid] flow rate through their cavities was calculated to establish a correlation between actual implants and nutrients and other liquids inside the human body passing through these holes. At the end of our study, several results are presented verifying our hypothesis and determining the best geometry.



Figure 2: 3D Printed Bone with similar porosity (infill geometry) used in our studies

Materials and Software

- Φ Polylactic Acid (PLA)
- Φ Polyvinyl Alcohol (PVA)
- Φ 3D Printer
- Φ 3D Printer Slicer
- Φ Instron
- Φ MATLAB
- Φ Water
- Φ Bluehill 3 (Instron Software)
- Φ Digital Weight Scale
- Φ Solidworks
- Φ Microsoft Excel
- Φ Microsoft PowerPoint
- Φ 100 ml Beakers
- Φ Viscous Fluids
- Φ Digital Caliper
- Φ Others ...

Method

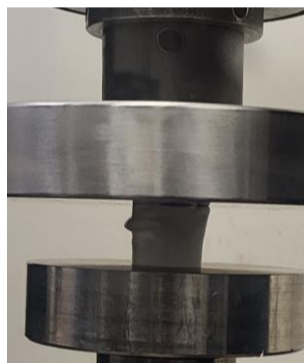
Tensile Mode Instron



Parameters used: 5 mm/min.

Figure 3: Tensile testing setup

Compression Mode



Parameters used: 2 mm/min

Figure 4: Compression testing setup

Porosity Measurement

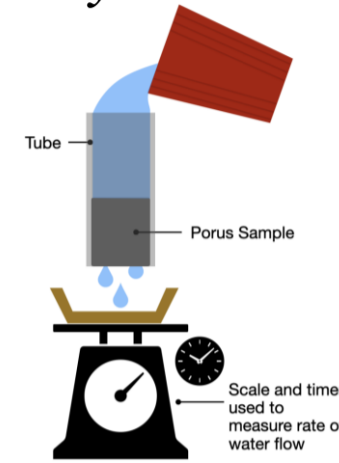


Figure 5: Current Porosity studies

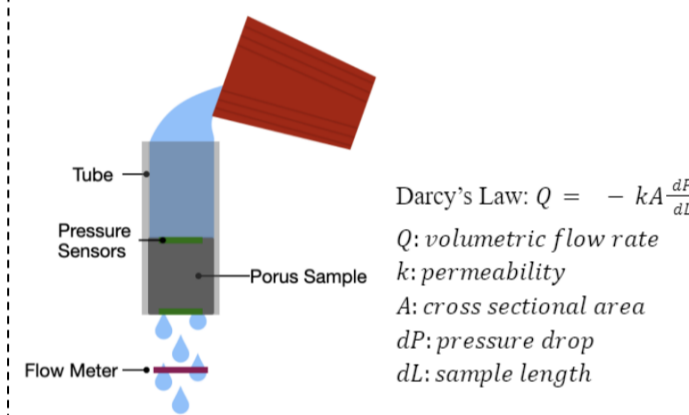


Figure 6: Current Porosity studies

Darcy's Law: $Q = -kA \frac{dP}{dL}$
 Q : volumetric flow rate
 k : permeability
 A : cross sectional area
 dP : pressure drop
 dL : sample length

Discussion



Figure 7: Dog Bone Pieces



Figure 8: Cylinder Pieces

Error Calculations For Instron Testing

Total Error (Stress)

$$u_{\sigma} = \sqrt{\left(\frac{d\sigma}{dF}u_F\right)^2 + \left(\frac{d\sigma}{dt}u_t\right)^2 + \left(\frac{d\sigma}{dw}u_w\right)^2}$$

$$= \sqrt{\left(\frac{u_F}{F}\right)^2 + \left(\frac{F u_t}{t}\right)^2 + \left(\frac{F u_w}{w}\right)^2}$$

Total Error (Strain)

$$u_{\epsilon} = \sqrt{\left(\frac{d\epsilon}{dt}u_t\right)^2 + \left(\frac{d\epsilon}{dl_0}u_{l_0}\right)^2}$$

$$= \sqrt{\left(\frac{u_t}{t}\right)^2 + \left(\frac{l u_{l_0}}{l_0}\right)^2}$$

Total Error (Modulus)

$$u_E = \sqrt{\left(\frac{dE}{d\sigma}u_{\sigma}\right)^2 + \left(\frac{dE}{d\epsilon}u_{\epsilon}\right)^2}$$

$$= \sqrt{\left(\frac{u_{\sigma}}{\sigma}\right)^2 + \left(\frac{\sigma u_{\epsilon}}{\epsilon}\right)^2}$$

Sample	u_{σ} [MPa]	u_{ϵ}	u_E [MPa]
Gyroid 25%	3.98E+04	3.14E-03	2.02E+07
Gyroid 35%	3.14E-03	5.17E+04	2.63E+07
3D Cross 25%	3.40E+04	3.14E-03	1.72E+07
3D Cross 35%	4.14E+04	3.14E-03	2.10E+07

Table 1: Tensile Error (Shortened, 1 Sample per Config.)

Results and Conclusion

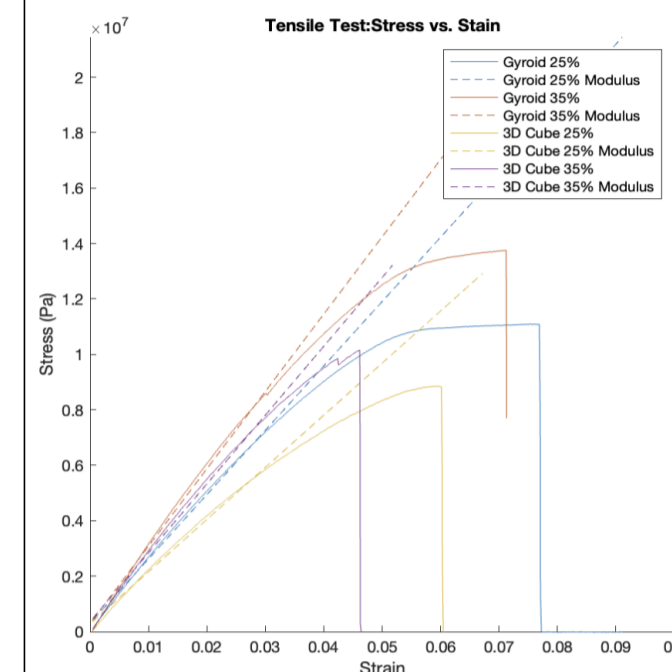


Figure 9: Tensile Stress vs. Strain Graph

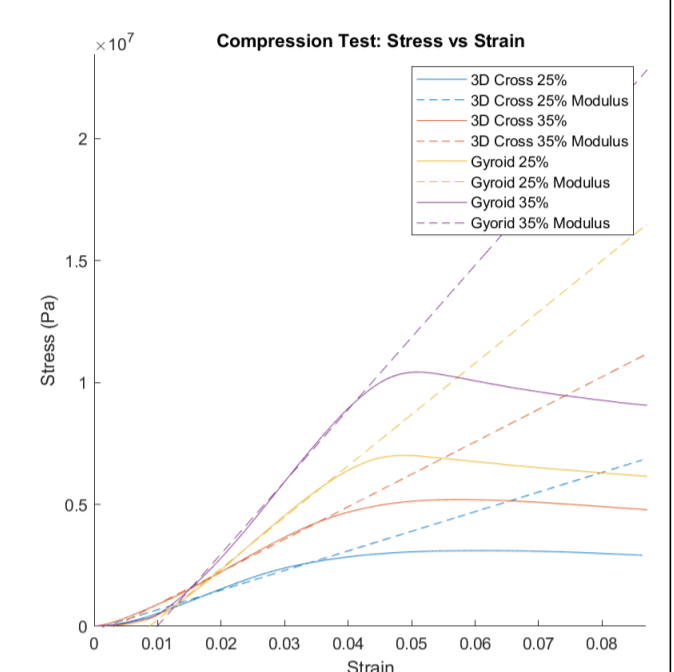


Figure 10: Compression Stress vs. Strain Graph

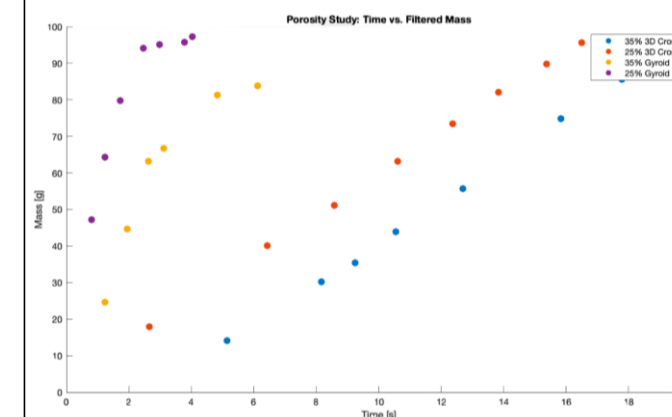


Figure 11: Porosity Study: Time vs. Filtered Mass

Configuration	Average Tensile Modulus [Pa]	Average Compression Modulus [Pa]	Porosity Study Time to reach 80% Water Passage [s]
Gyroid 25%	2.31E+08	2.11E+08	2.02
Gyroid 35%	2.84E+08	3.22E+08	4.53
3D Cross 25%	1.99E+08	7.77E+07	13.02
3D Cross 35%	2.45E+08	1.33E+08	16.66

Table 2: Summary table of Porosity Study

From our studies, we can conclude that the infill geometry "Gyroid" has a higher stiffness level, and it aligns better with our expectation of having a good balance between porosity and structural integrity/strength. This is because Gyroid Geometries are more isotropic than the 3D Cross geometries. Gyroid has a higher density and therefore a higher modulus. Overall, it performed better than the infill geometry "Cross". We would recommend using this type of infill to produce implants with good structural integrity and porosity (fluid flow) resulting in implant compatibility. There is no clear end to the linear region due to the plasticity of the material. Even then, the modulus shows a clear increase in stiffness as the infill density increases.

References

1. Carpenter RD, et al. *Effect of Porous Orthopedic Implant Material and Structure on Load Sharing with Simulated Bone Ingrowth*. Journal of the Mechanical Behavior of Biomedical Materials, DOI: 10.1016/j.jmbbm.2018.01.017, April 2018.
2. Yu Chen, et al. *Linear Viscoelasticity of Bio-based Composites of Polylactic Acid and Regenerated Cellulose Fibers*. Science Direct Journal, DOI 10.1016/j.compositesa.2023.107580, January 2023.

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