Biomechanical Validation of Additively Manufactured Polymeric Femora

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INTRODUCTION

- Current biomechanical models do not accurately represent altered bone structures resulting from primary or metastatic bone neoplasms.
- 3D printing technologies offer the potential for creating customized synthetic femurs with specific geometric and mechanical properties for biomechanical testing.
- This study aimed to develop and validate a 3D printed model of a normal human femur using polylactic acid (PLA) that can be adapted to variant anatomy.

METHODS

1) Material Selection and Characterization

a) A literature review was conducted to identify the material properties of human bone
b) PLA was selected due to its mechanical characteristics as well as to accomplish the goal of using a low cost and widely available material
c) Standard tensile, compressive, and torsional testing specimens were constructed and loaded to failure to evaluate the anisotropic mechanical properties of 3D printed PLA

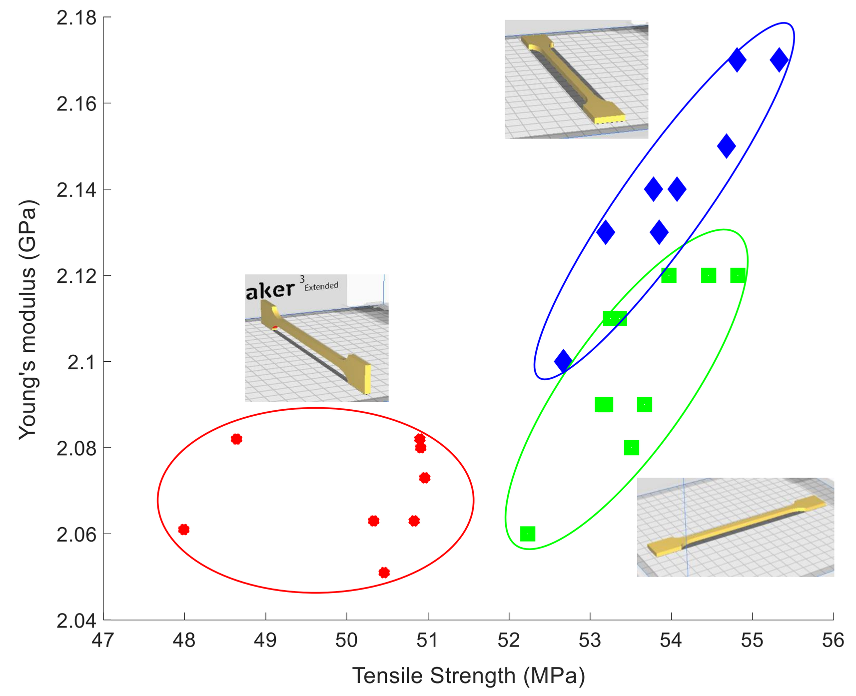
2) 3D Printing

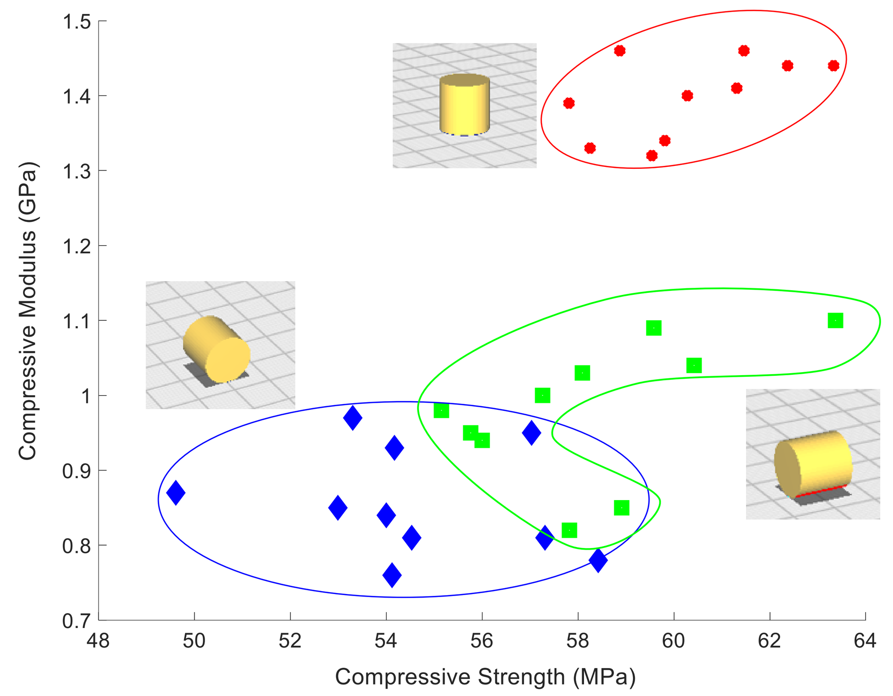
a) A digital model of a normal human femur was obtained from Sawbones and used to prepare 3D printed models with varying wall thicknesses and infill densities
b) The prepared models were 3D printed using a low-cost, widely prevalent fused deposition modeling printer (Original Prusa i3 MK3S+)

3) Mechanical Testing and Refinement

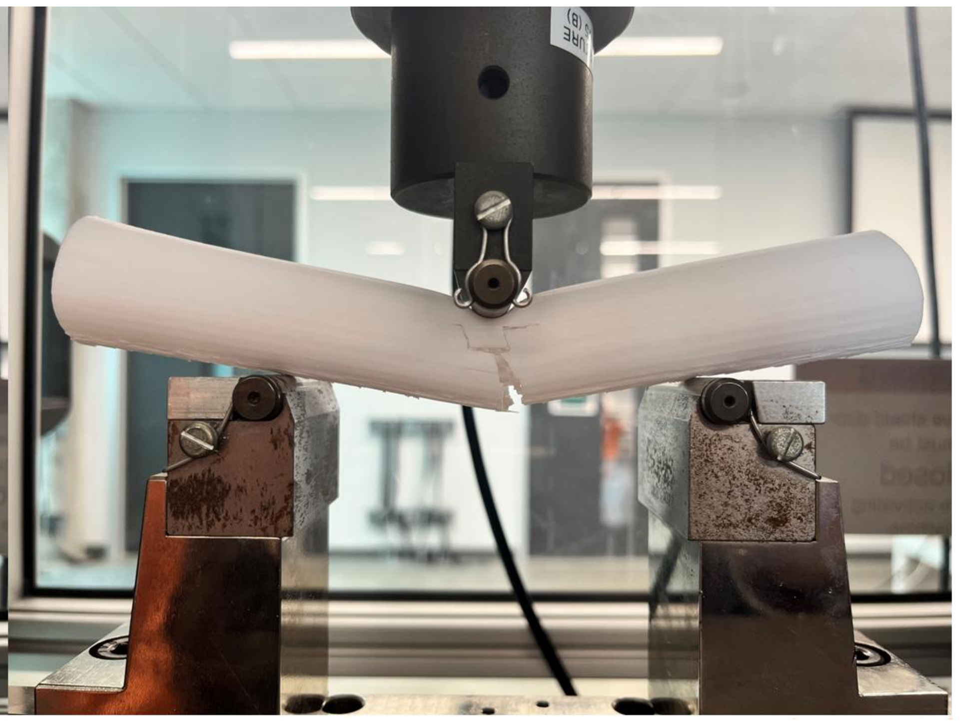
a) The 3D printed femurs were loaded in 3-point bending, and their flexural modulus and strength was determined from the stress-strain response curves
b) The results were compared with literature values of natural bone, allowing for refinement of the print parameters and optimization of the mechanical properties
c) This iterative process was performed until the desired flexural modulus was achieved, with ongoing efforts to optimize the flexural strength

RESULTS





Material Property	Literature Value	Tested Parts	Dogbone Specimens	Units
Flexural Modulus	11-20	7.46 – 18.35	N/A	GPa
Flexural Strength	140-220	342.4 – 832.7	N/A	MPa
Ultimate Tensile Strength	130	N/A	52.65 ± 1.90	MPa
Ultimate Compressive Strength	205	N/A	57.70 ± 3.23	MPa
Elastic Modulus	N/A	N/A	2.10 ± 0.03	GPa



CONCLUSIONS

In conclusion, the 3D printed anatomic human femur models have successfully replicated the flexural modulus of natural bone, showcasing the potential and effectiveness of the 3D printing process and materials used in this study. This achievement marks a significant step forward in the development of accurate and reliable 3D printed bone models for medical and educational purposes.

Although the flexural strength of the tested parts exceeded that of natural bone, it is important to note that reducing the flexural strength is a more straightforward task than increasing it. Efforts are currently underway to refine the design and 3D printing parameters, aiming to further improve the mechanical properties of the printed models and closely match those of natural bone.

Overall, this project has demonstrated considerable success in replicating the mechanical behavior of the human femur using an affordable and customizable manufacturing method and provided a solid foundation for future research. Further investigation into the microstructural geometry, printing parameters, and material properties of the 3D printed models will undoubtedly contribute to the ongoing advancements in this sector. Ultimately, our goal is to pave the way for the development of highly accurate, application-specific bone models in the near future.