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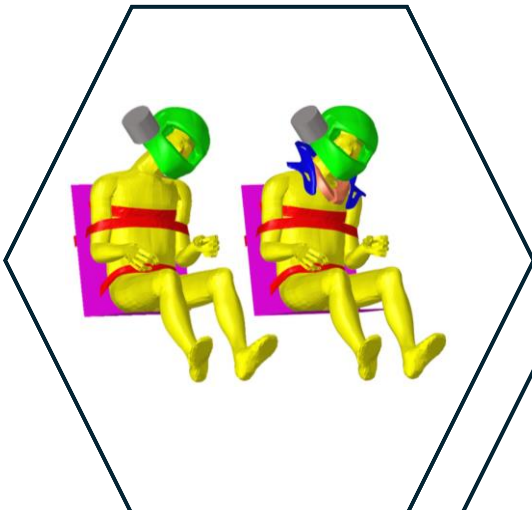

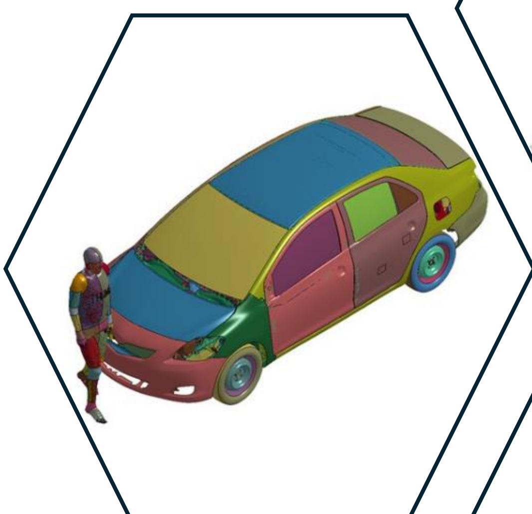

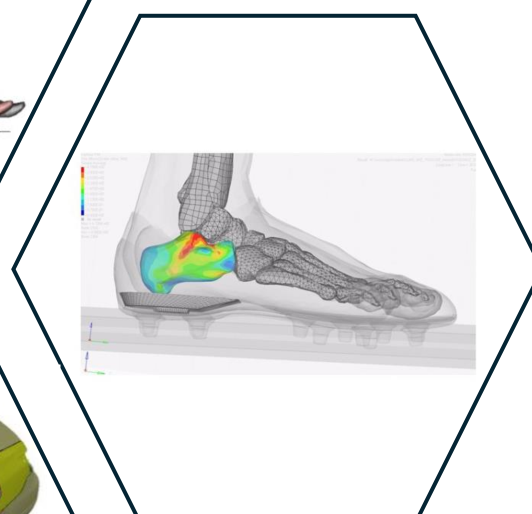

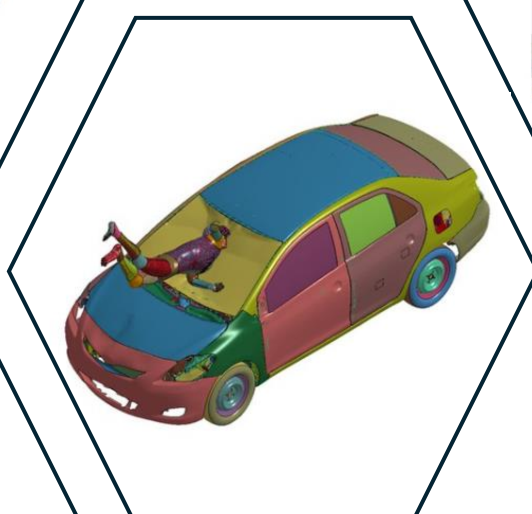

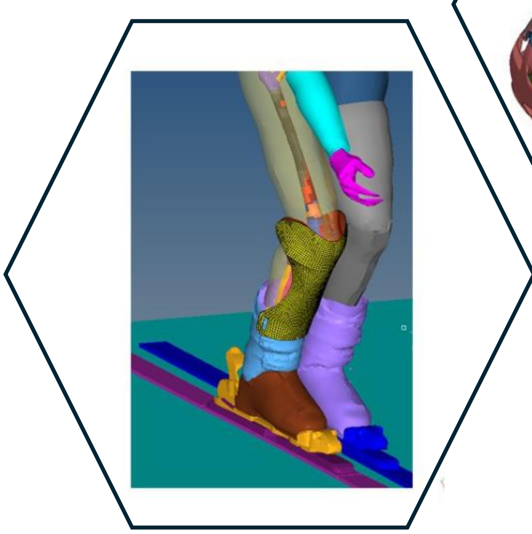

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abstracts

Design and Development of a Cellular Laminoplasty Plate

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ABSTRACT

Our research investigates the development and evaluation of cancellous-like laminoplasty plate designs, focusing on honeycomb structures with thicknesses of 0.4mm, 0.8mm, 1.0mm, and 1.2mm, as well as a solid design. Laminoplasty plates are essential in spinal surgery for stabilizing vertebrae and promoting bone healing. The study's objective was to evaluate the stiffness, strength, and flexibility of these designs under stress, which are crucial for both stability and adaptability within the spine's dynamic environment. Mechanical testing was conducted to determine the ultimate tensile strength (UTS) and flexibility of each design. The 0.4mm honeycomb design exhibited a UTS of 14.0±4.55 MPa and a strain of 0.131±0.0397 highlighting its strength but limited mechanical support in highly dynamic spinal environments. Although, the 0.8mm and 1.0mm honeycomb designs showed balanced stiffness and strength with UTS values of 12.57±3.58 MPa and 13.17±4.12 MPa, respectively, the 1.0mm design could withstand higher strains up to 0.156±0.0456 before failure, making it ideal for dynamic spinal regions where adaptability is crucial. The 1.2mm honeycomb design, despite its increased thickness, did not significantly outperform the 1.0mm design, indicating a potential limit to the benefits of increased thickness. The solid design, though less stiff than the honeycomb structure raised concerns about osteointegration and long-term bone healing. The results suggest that the 1.0mm honeycomb design offers the best balance between strength and flexibility, making it a promising candidate for laminoplasty applications.

Keywords: Laminoplasty Plate, Honeycomb Structure, Mechanical Properties, Spinal Surgery, 3D Printing, Design Optimization

INTRODUCTION

Laminectomy and laminoplasty are critical spinal surgeries aimed at relieving compression on the spinal cord or nerves due to conditions such as spinal stenosis, herniated discs or spinal tumours [2]. These procedures often involve removing or altering portions of the vertebral lamina to reduce pressure on the spinal cord thereby reducing neurological claudication, halting clinical deficits and promoting functional ambulation [3]. However, in some instances problems can arise involving destabilization of the spinal column, potentially leading to post-surgery complications [2,7]. Open laminectomies are the standard traditional treatment for relieving spinal cord or nerve root compression [5], while such procedures are effective, there may be limitations in terms of structural integrity because of the alterations in the biomechanics of the spinal column associated with the procedure [1]. Traditional metal implants are typically used to provide structural support, yet issues like stress shielding and poor osseointegration remain significant challenges potentially leading to poor long term surgical outcomes [6]. To ensure the stability and proper healing of the spine after these procedures, biomedical implants, such as plates, are often used to provide structural support and facilitate fusion. However, the challenge remains to develop spinal plates that offer both mechanical stability and flexibility to accommodate the dynamic nature of the spine while promoting osteointegration.

This paper focuses on the design and mechanical testing of cellular laminoplasty plates with a honeycomb structure that mimics the flexibility and load distribution of bone tissue. Through 3D printing, prototypes were fabricated and tested for their mechanical properties, including ultimate tensile strength (UTS), to evaluate their suitability for clinical applications. The primary aim is to enhance patient outcomes by providing a plate that balances strength, flexibility, and biocompatibility

MATERIALS & METHODS

Plate Design

The study's core focus is the design of cellular hexagonal honeycomb structures using SolidWorks. The aim was to mimic the natural cancellous bone structure to optimize flexibility and mechanical support while promoting biological integration. Five designs were tested: honeycomb structures with thicknesses of 0.4mm, 0.8mm, 1.0mm, 1.2mm, and a solid design. The geometric considerations were driven by ensuring anatomical fit and biomechanical performance. The figure 1 shows the laminectomy plate design using SolidWorks.

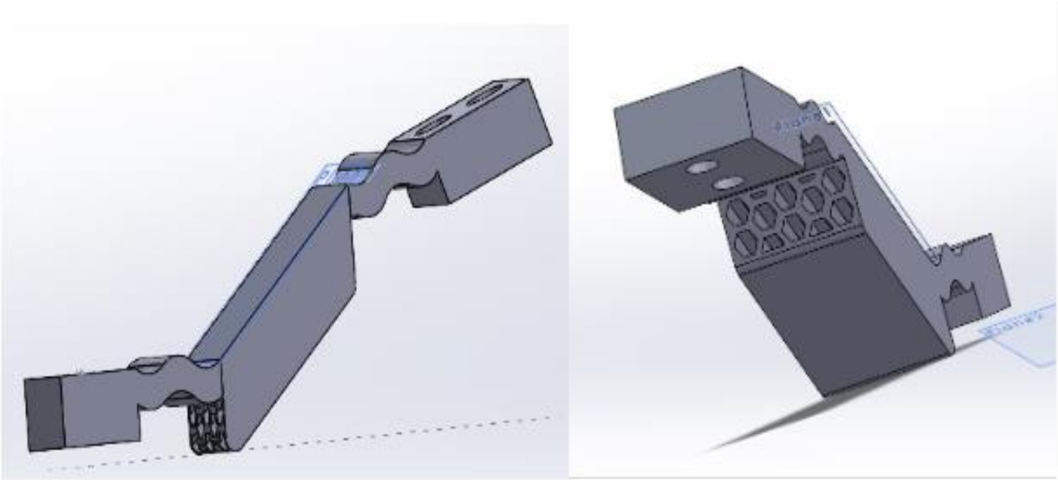

Figure1: The Laminectomy plate design using SolidWorks

3D Printing of Prototypes

The CAD-AM process allowed for the creation of complex geometries that would be difficult to achieve using traditional manufacturing methods. Multiple prototypes were printed for testing and comparison. Mechanical testing was conducted to evaluate the structural integrity of the plates in tension and compression and FEA was performed (SolidWorks) to make predictions. The aim was to determine the plate's capacity to withstand physiological loads while maintaining structural stability.

The prototypes were printed using PLA polymer with a density of 1.24g/cm^3 on an Ultimaker 2+ Extended printer. The 3D printing process was optimized to achieve a balance between mechanical integrity and lightweight design, utilizing a grid infill pattern at 20% density. The process settings, including a nozzle diameter of 0.4 mm and a printing temperature of 200^{0}C, were carefully selected to maintain precision during the fabrication of the intricate honeycomb designs.

Mechanical Testing

Mechanical testing was conducted using a Universal Testing Machine (EZ50) to determine the stiffness, UTS, and Young's modulus of each plate. Tensile tests were conducted to assess how the plates performed under simulated physiological loads. The aim was to compare experimental data with finite element simulations to ensure the designs met clinical standards for spinal implants.

Table1: The strain and the Ultimate tensile strength, UTS (MPa)

Honeycomb size (mm)	Ultimate Tensile Strength (MPa)	Strain
0.4	14.00 ± 4.55	0.131 ± 0.0397
0.8	12.57 ± 3.58	0.128 ± 0.0375
1.0	13.17 ± 4.12	0.156 ± 0.0456
1.2	12.30 ± 3.68	0.116 ± 0.0336
Solid	12.70 ± 3.58	0.163 ± 0.0474

RESULTS AND DISCUSSION

Experimental Findings

The tensile strength testing of various laminoplasty plate designs, including honeycomb structures (0.4mm, 0.8mm, 1.0mm, and 1.2mm) and a solid design, revealed distinct mechanical properties in terms of strength, and flexibility. The 0.4mm honeycomb design demonstrated the highest stiffness and load bearing capacity, with a UTS of 14.0±4.55 MPa and a strain of 0.131±0.0397, making it ideal for high-load applications with minimal deformation but limited flexibility as shown in figures 2 and 3. Although, the 0.8mm and 1.0mm honeycomb designs showed balanced stiffness and strength with UTS values of 12.57±3.58 MPa and 13.17±4.12 MPa, respectively, the 1.0mm plate, had a higher load bearing capacity, and demonstrated increased strain tolerance (up to 0.156±0.0456) making it adaptable for dynamic spinal regions. The solid plate had the highest strain at failure (0.163±0.0474), and it was more flexible than the rest, but may be prone to stress shielding.

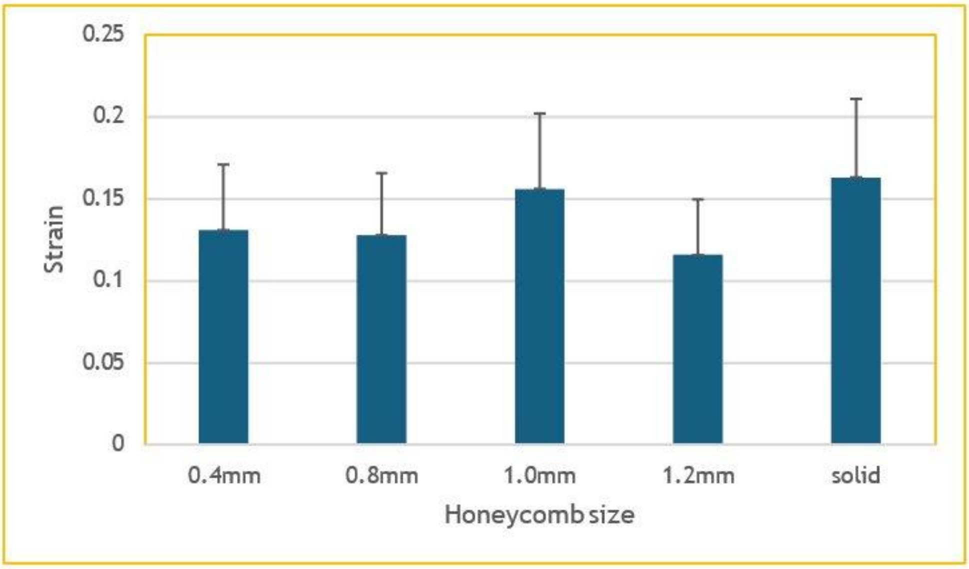

Figure 2: Bar Chat representative of the strain for the Honeycomb Designs

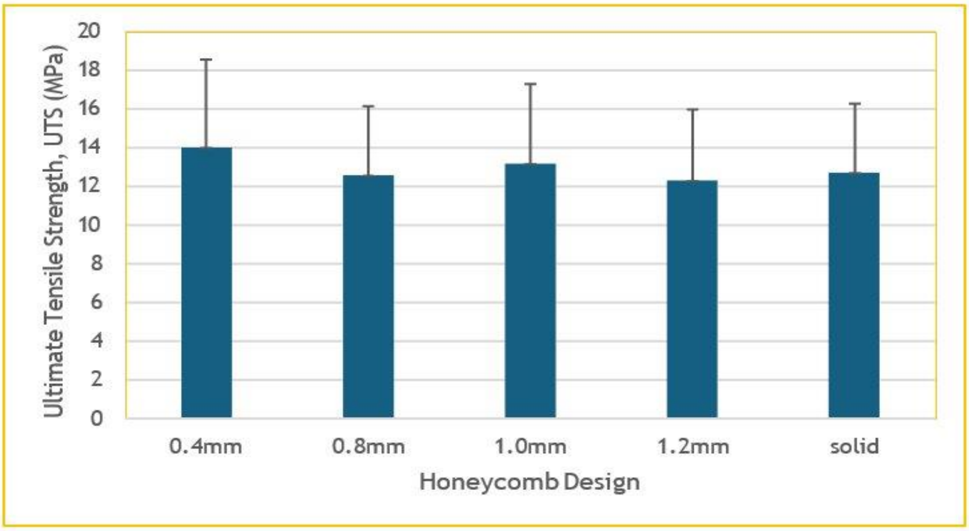

Figure 3: Bar Chat representative of the UTS for the Honeycomb Designs

Finite Element Analysis

Finite element analysis was performed to simulate the mechanical behaviour of the plates under realistic loading conditions. In figure 4, the simulations showed that stress distribution was optimized in the honeycomb designs, particularly in the case of 1.0mm plate, which closely matched the experimental results. The stress concentration was well within acceptable limits for clinical applications, reinforcing the suitability of the 1.0mm design

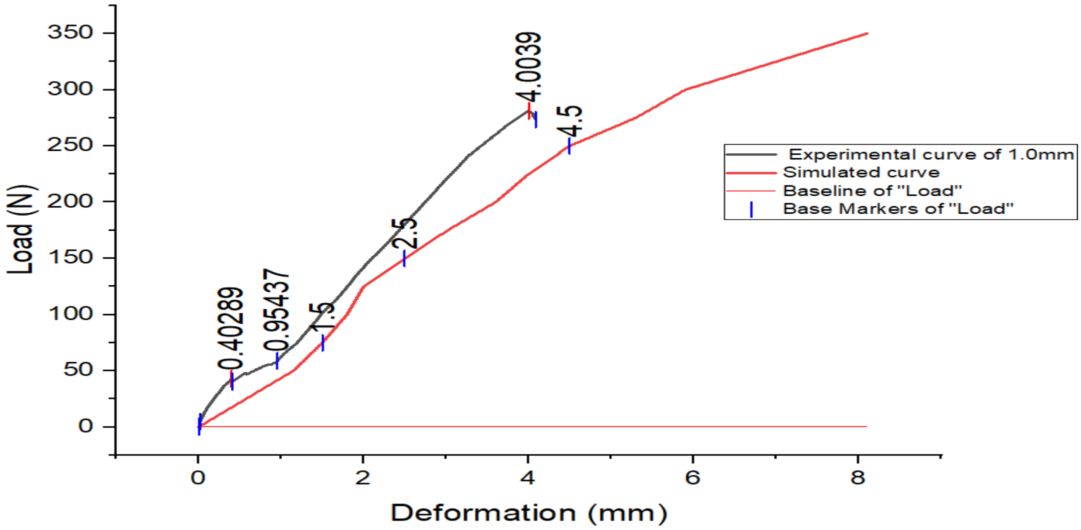

Figure 4: Simulated Load-Deformity curve for 1.0mm plate and Experimental curve

The study demonstrated that honeycomb structures offer distinct mechanical advantages over traditional solid plates. The 1.0mm honeycomb design struck the optimal balance between mechanical strength and flexibility, essential for use in spinal surgery where the implant must support biomechanical loads while adapting to movement. The design also showed potential for promoting osteointegration due to its porous nature. Figure 5 shows the commercial plate in-situ and the design of a custom-made cellular body 3D printed plate with a honeycomb cellular structure.

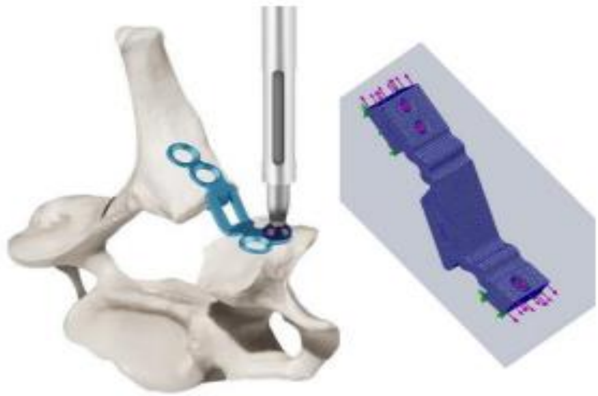

Figure 5: Commercial plate [4] in-situ and our design of a custom-made cellular body 3D printed plate with a honeycomb cellular structure.

While the study showed promising results for the 1.0mm design, further research is needed to explore its long-term biological performance, particularly in terms of bone growth and integration. Additionally, testing on a broader range of materials, including biocompatible metals and composites, could yield further improvements in the design's clinical viability.

CONCLUSIONS

Our research presents an approach to laminoplasty plate design by incorporating cellular honeycomb structures, which mimic the mechanical properties of natural bone. The results suggest that the 1.0mm honeycomb design offers the best combination of strength and flexibility, making it a strong candidate for future clinical application in spinal surgery. Further research will focus on long-term in-vivo testing and material enhancements to optimize osteointegration and mechanical performance.

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