Healthcare Innovations
How practice has changed

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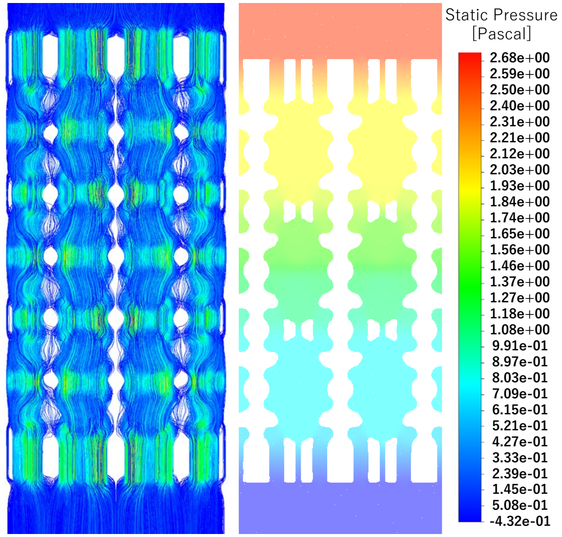
Morphological Orthopaedic Scaffolds could be plug 'n' print?

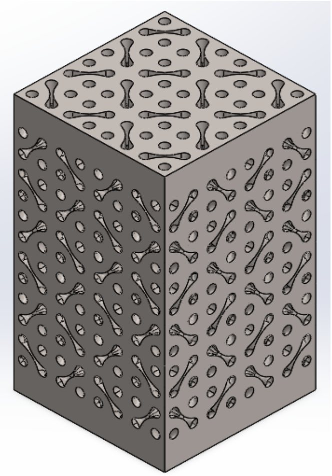
Purpose: Biocompatibility and customisation are key components in orthopaedic implants. Employing additive manufacturing (AM), titanium based porous scaffolds can be developed using unit cell (UC) structures with customisable pore size and properties that can be optimised for specific clinical applications. A key feature of biocompatibility is Fluid-flow dynamics within the porous structure as it is closely related to the supply of nutrients essential for cell activity. In this study, the scaffolds were assessed for permeability to improve the biological performance and bone in-growth by encouraging nutrient flow to cells.

Methods: A porous UC was developed based on a novel design proposed by a medical professional using computer aided design (CAD). Orthopaedic scaffolds with open structures were generated from this UC and scaled to size. Preliminary testing was undertaken on scaffolds (titanium alloy) for Force-Displacement relationship at varying scaffold porosities (approx. 50, 70 and 90%) using Finite-element analysis (FEA). Fluid flow was also tested at specific levels of porosity and pore diameter using Computational fluid dynamics (CFD). Data from CFD analysis was then used to optimize the design of scaffold structure by adjusting parameters such as pore diameter, channel width and internal surface smoothing to improve CFD simulations until satisfactory results were achieved.

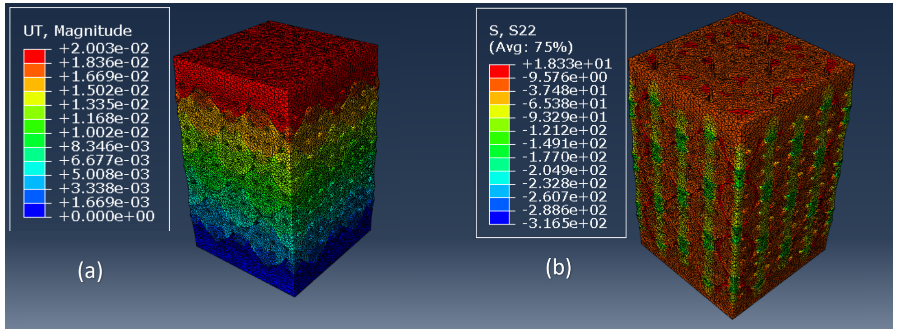
Results: Current UC design (semi-closed structure) with cell size 10 mm, pore diameter 2.5 mm and a 50.3% porosity gives a permeability of 3.73×10^{-8} m^2. FEA for Scaffolds (Open Structure) at 107 GPa (Titanium alloy) was tested under compression for varying porosities as shown below. For 53.5% porosity, 11.97 kN of force was required for a displacement of 0.1 mm. This data was compared to mechanical testing data yielding average error of 12.68% (from all displacements for 53.5% porosity).



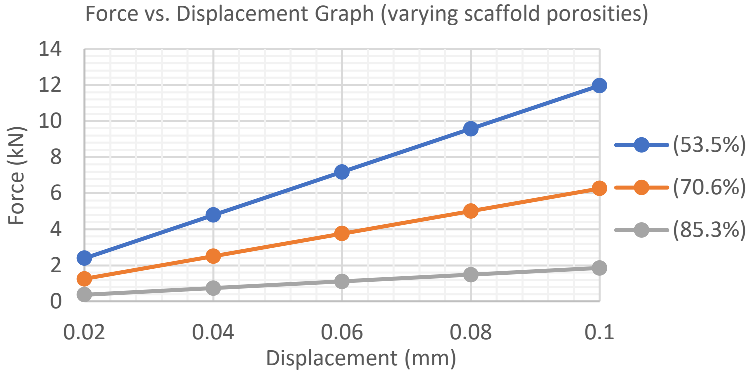
Scaffold – Fluid Flow (Semi-Closed)



Scaffold – 53.5% porosity, 25mm scaffold size (Scaled) (Open structure)



53.5% porosity scaffold a) Displacement b) Stress distribution



	Force (kN)		
Displacement (mm)	**53.50%**	**70.60%**	**85.30%**
0.02	2.394	1.253	0.371
0.04	4.789	2.506	0.742
0.06	7.183	3.759	1.113
0.08	9.577	5.011	1.484
0.1	11.97	6.264	1.855

Conclusions: Human trabecular bone permeability was found to be 5.13 x 10-9 m2, which is a lot smaller than the designed scaffold permeability which has permeability of 3.74 x 10-8 m2. Even the result in CFD is significantly larger, the rough surface in the actual printed scaffold contributed a lot to fluidic performance. For further investigation, a micro-CT scan of the printed scaffold can be computationally simulated in order to achieve a more accurate result. FEA testing has provided preliminary data that describes the rate of displacement, but more data is required at higher displacements to predict behaviour more accurately. This will then be provided for CFD analysis until the scaffold design is optimised and ready for implementation as orthopaedic implants.

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