Advanced manufacturing for personalised vascular grafts

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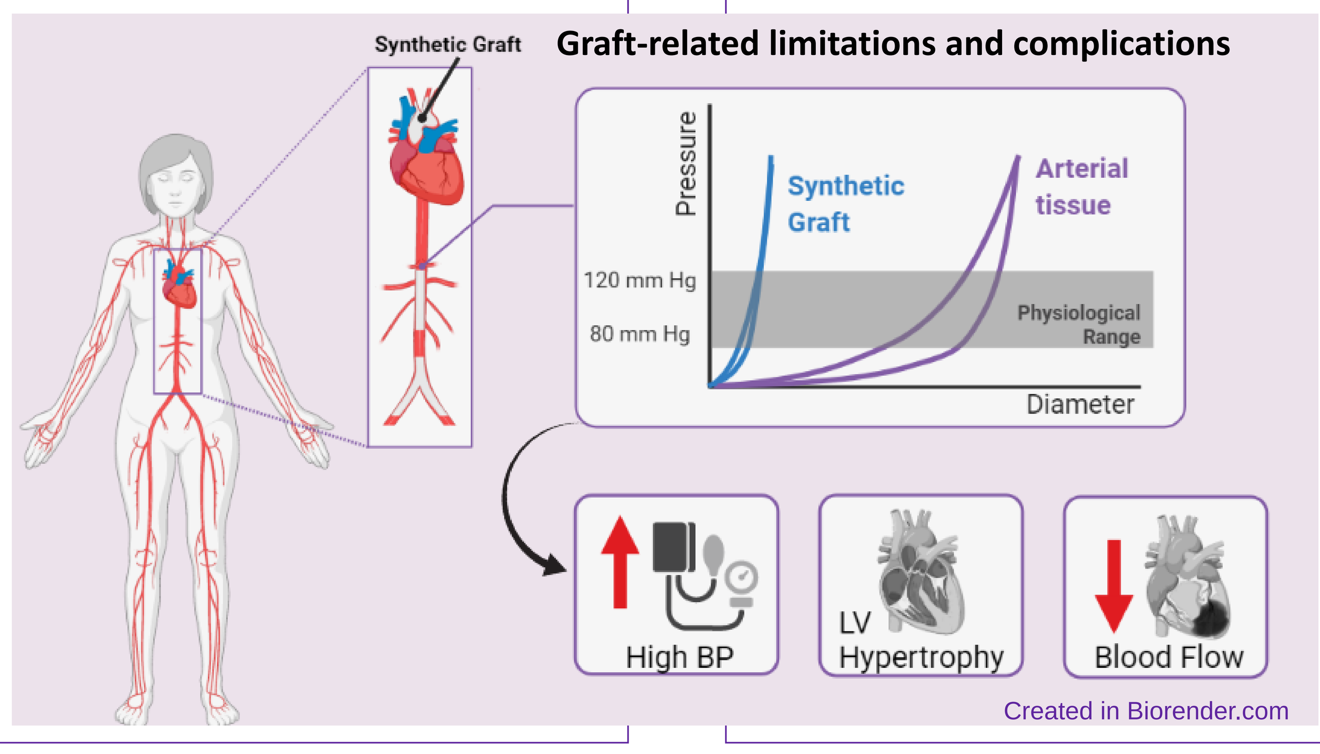
BACKGROUND

Surgical repair of the **aorta** – the major artery in the human body – utilises **synthetic grafts** made out of polyester fabric (**Dacron**). Despite being a life-saving procedure, the recurrence of **long-term graft-related complications** still remains. These have been linked with the graft material's **high rigidity** when compared to native aortic tissue creating a **mismatch in mechanical behaviour**. Additionally, Dacron grafts are fabricated as straight, thin-walled tubular conduits, thus varying significantly from the **anatomical geometry** of the human aorta. Therefore, novel aortic graft technologies are required.



PROJECT AIMS

This project aims to address the **mechanical and geometrical mismatches** of existing aortic grafts by investigating alternative materials (**hydrogels**) and advanced fabrication methods (**3D printing**) to develop a novel synthetic vascular graft that:

(1) Closely mimics the **mechanical behaviour** of aortic tissue,

(2) Is **patient-specific** to ensure optimal anatomical compatibility, and

(3) Enables **cell ingrowth** and long-term **bio-integration.**

METHODS

1 Material preparation

Initial investigations identified **alginate** – a natural monomer derived from seaweed – as a suitable candidate for this application. However, alginate on its own exhibits **weak mechanical properties** when compared with aortic tissue. Therefore, the alginate was reinforced via the addition of a secondary polymer creating an **interpenetrating polymer network (IPN).**

Alginate-Polymer IPN hydrogels were prepared by mixing sodium alginate with a photocurable polymer. Hydrogel formation involved two steps:

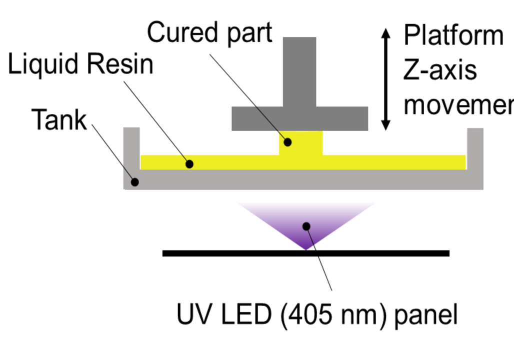
(1) exposing the solution to UV (365 nm) or visible light (405 nm) to gel the photocurable polymer, and

(2) transferring the quasi-solidified gel into a salt solution to gel the alginate.

2 Hydrogel fabrication

Gels were prepared via **moulding** and/or **3D printing** to obtain dog-bone shaped structures for material mechanical characterisation, and tubular structures to mimic sections of the aorta.

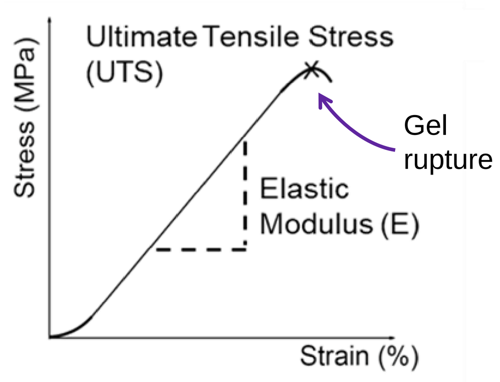
A light-based 3D printer was used to fabricate structures in a layer-by-layer manner. Tubular structures were designed and printed with geometries similar to the human abdominal aorta.



3D printing mechanism.

3 Mechanical characterisation

Hydrogel dog-bone shaped samples were **stretched to failure** at a rate of 1mm/min to obtain values for **strength (UTS)** and **stiffness (E)** of the material. The **tubular structures** were **compressed** between 2 plates at 1mm/min up to 50% of their original outer diameter to investigate radial load capacity.

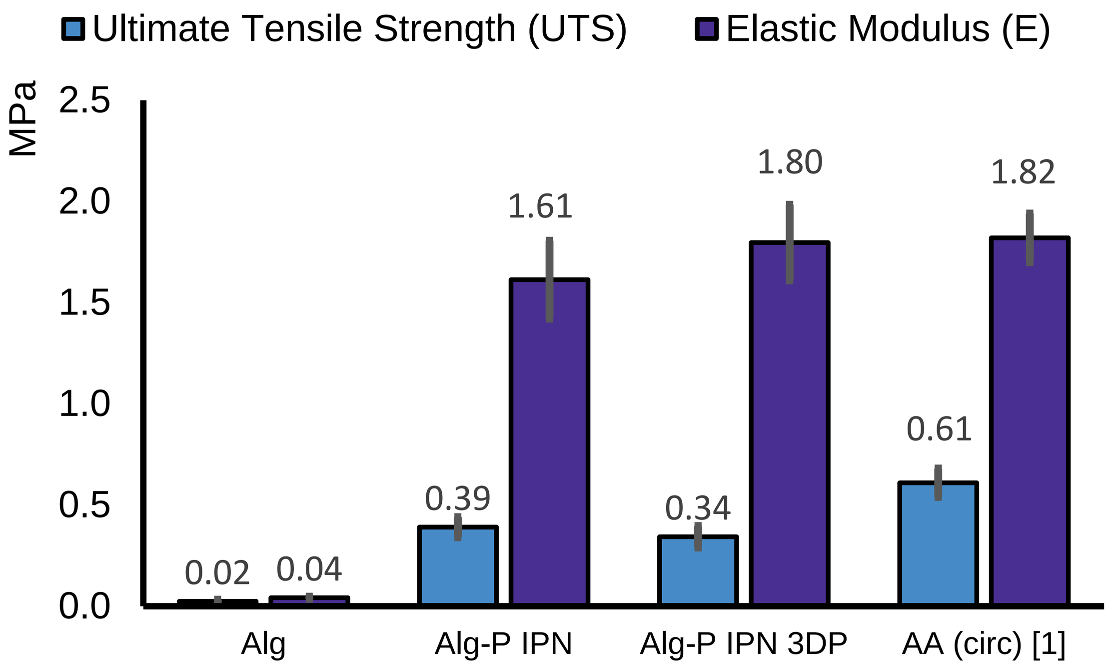


Tensile testing stress-strain curve.

MAIN FINDINGS

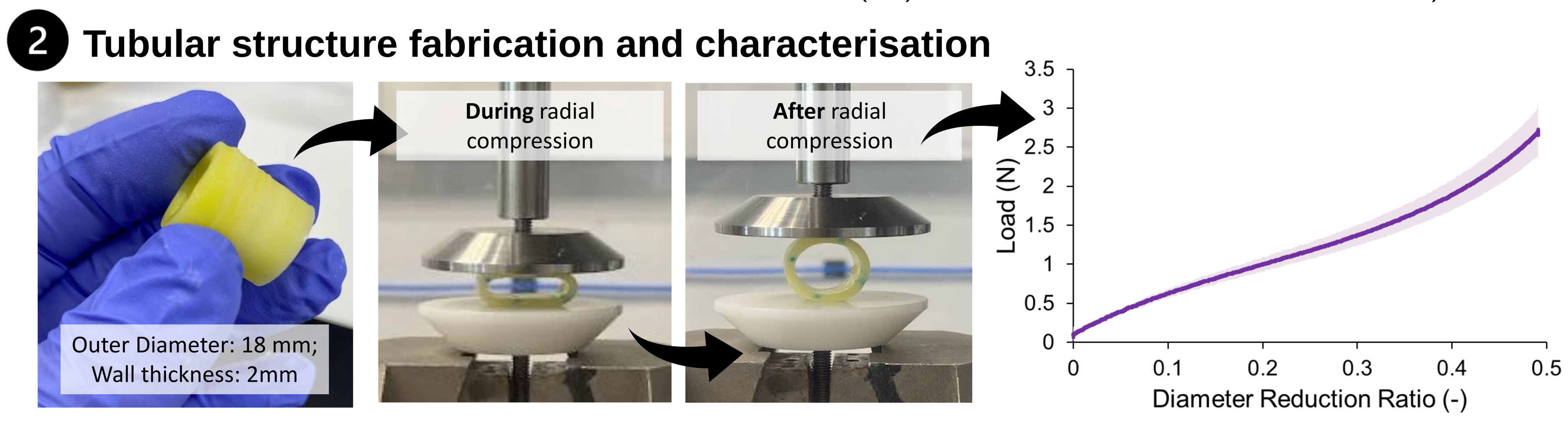
1 Material characterisation

- Uniaxial tensile tests showed that **alginate-Polymer IPN** exhibits superior **strength** and **stiffness** than **alginate** on its own**.**
- The **alginate-polymer IPN** exhibited **closer** mechanical properties to **aortic tissue** data reported in the literature.
- No significant differences in the mechanical properties were observed between **moulded and 3D-printed hydrogels**.



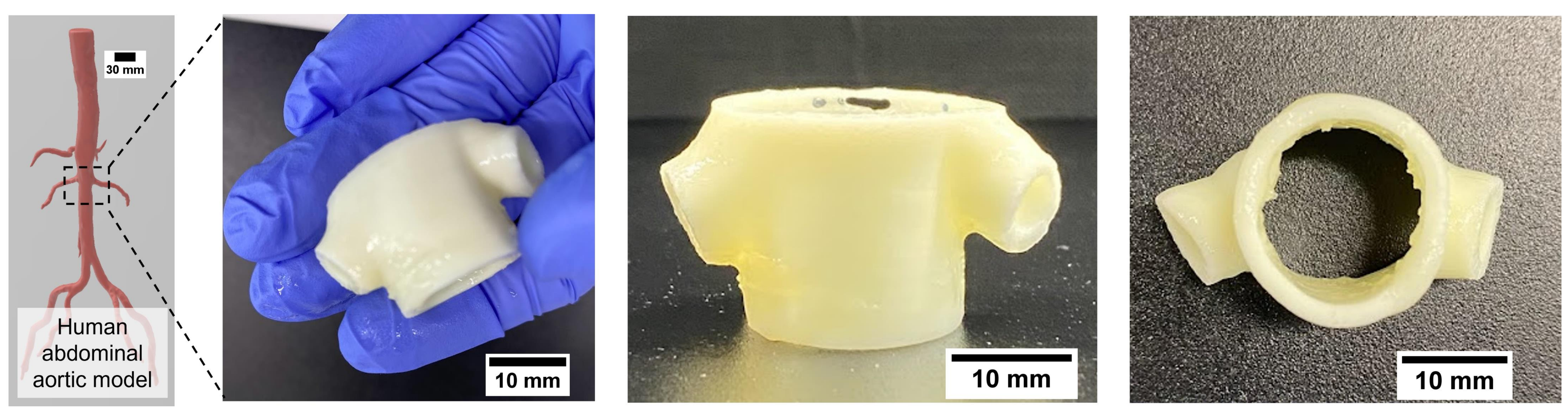
Ultimate tensile strength and **elastic modulus** for different hydrogel formulations (n=5 ± S.D.) in comparison with the aortic tissue [1].
(Alg: alginate, Alg-P IPN: alginate-Polymer interpenetrating network, 3DP: 3D printed, AA(circ): abdominal aorta tested in the circular direction)

2 Tubular structure fabrication and characterisation



When compressed radially to 50% of the original diameter (n=2 ± S.D.), the tubular structures could withstand a maximum load of approximately 3N. Upon load removal, **shape recovery** was observed.

3 Fabrication of patient-specific vascular grafts: branched aortic segment



CONCLUSIONS & FUTURE WORK

- An **alginate-based hydrogel** formulation with similar mechanical properties to the native aorta was developed as an alternative biomaterial to existing Dacron grafts.
- Aortic tissue-mimicking tubular conduits were successfully fabricated via **3D printing.**
- Ongoing work is looking at enhancing the cell compatibility properties of the material to ensure cell ingrowth.

REFERENCES

[1] S. R. Vallabhaneni, G. L. Gilling-Smith, T. V. How, S. D. Carter, J. A. Brennan, and P. L. Harris, "Heterogeneity of Tensile Strength and Matrix Metalloproteinase Activity in the Wall of Abdominal Aortic Aneurysms," *The Journal of Endovascular Therapy*, vol. 11, no. 4, pp. 494-502, 2004, doi: 10.1583/04-1239.1.

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