Designing Better Organs-on-Chips: CFD-Driven Optimisation and Validation for 3D Tissue Systems

Erick Solorio González [1-3], Amanda Guitián-Caamaño [1-3], Philip Cardiff [1,3], Fiona E. Freeman* [1-7]

[1] School of Mechanical and Materials Engineering, Engineering and Materials Science Centre, University College Dublin, Ireland
[2] Conway Institute of Biomolecular and Biomedical Research, University College Dublin, Ireland
[3] UCD Centre for Biomedical Engineering, University College Dublin, Belfield Dublin 4, Ireland
[4] Trinity Centre for Biomedical Engineering, Trinity Biomedical Sciences Institute, Trinity College Dublin, Ireland
[5] Department of Mechanical Manufacturing, and Biomedical Engineering, School of Engineering, Trinity College Dublin, Dublin , Ireland
[6] Advanced Materials and Bioengineering Research Centre (AMBER), Royal College of Surgeons in Ireland and Trinity College Dublin, Dublin, Ireland
[7] CÚRAM Research Ireland Centre for Medical Devices, Biomedical Sciences, University of Galway, Galway, Ireland

Corresponding Author: Tel: +353-1-7161831, email: fiona.freeman@ucd.ie

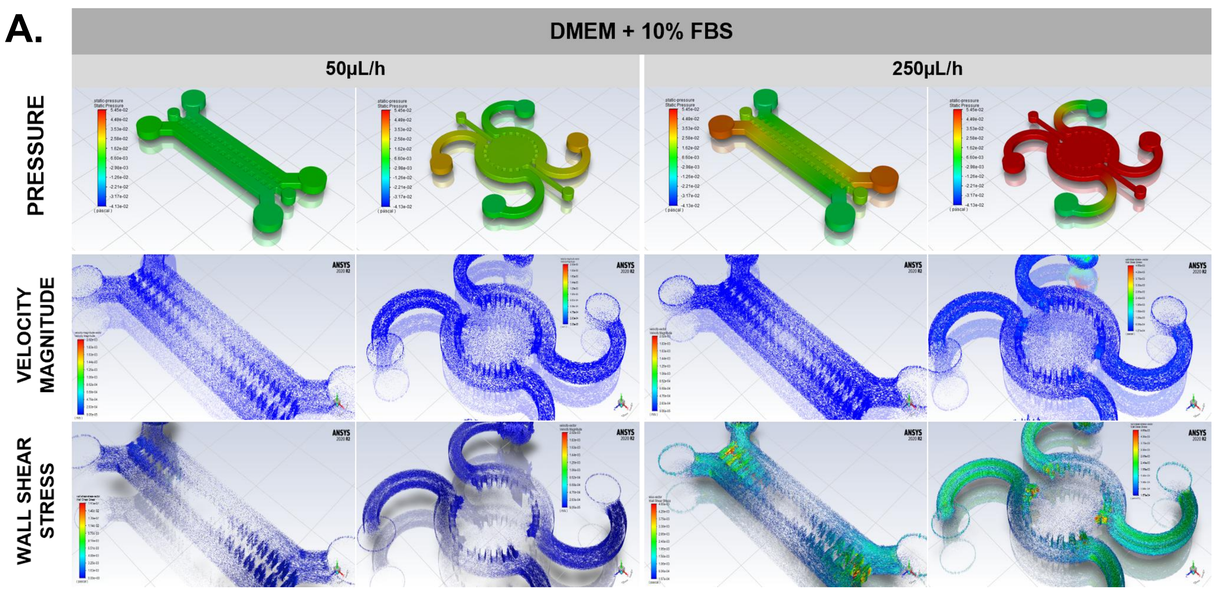
INTRODUCTION

Organ-on-Chips (OoCs) are microfluidic devices containing cells or organoids designed to replicate human organ function. While OoCs have been developed for many tissues, the wide variety of designs makes it challenging to identify which features make one model more suitable than another. Optimal OoC design depends on several key factors, including cell type, chip architecture, material properties, mechanical stimulation, and perfusion. A successful design should replicate the target tissue's structural and functional features while remaining reproducible, scalable, and analytically compatible.

In this study, using computer-aided design (CAD) and ANSYS Fluent simulations, we optimizes device geometry to enhance nutrient transport and minimise shear stress. High-resolution moulds were fabricated via digital light processing (DLP) 3D printing and used to cast the OoC designs in polydimethylsiloxane (PDMS).

RESULTS

CFD SIMULATIONS



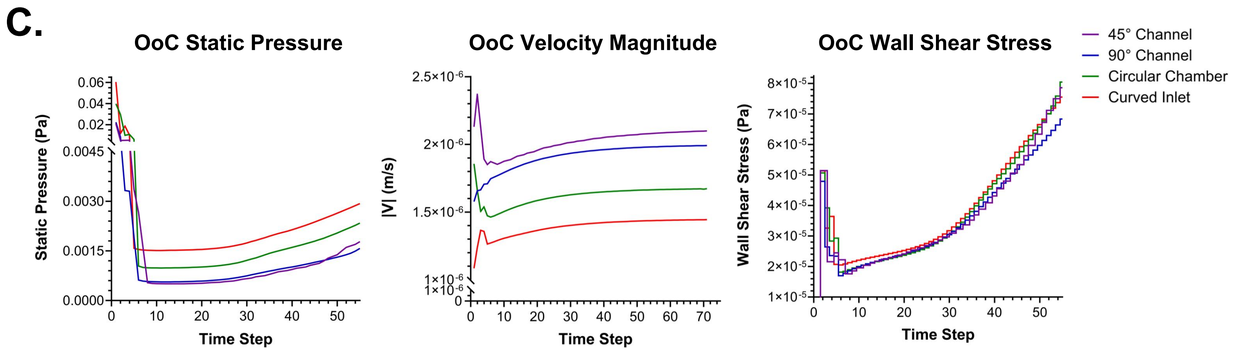


Figure 1. (A) Color contour results for pressure distribution through flow patterns, and vector magnitude gradients for flow velocity and wall shear stress presented on rectangular and circular hydrogel chamber designs. Results show the flow simulation for both glucose [top] and DMEM solutions [bottom] at the two range limits of flow rate (50-250µL/h). (B) Comparative volume fraction analysis across the microfluidic platform designs. Capturing the resulting fluid dispersion patterns within chambers, showcasing differences in flow behaviour and flow distribution. (C) Graphs show the impact of each design for each parameter to be evaluated (static pressure, velocity magnitude and wall shear stress, respectively).

In Vitro – CELL VIABILITY

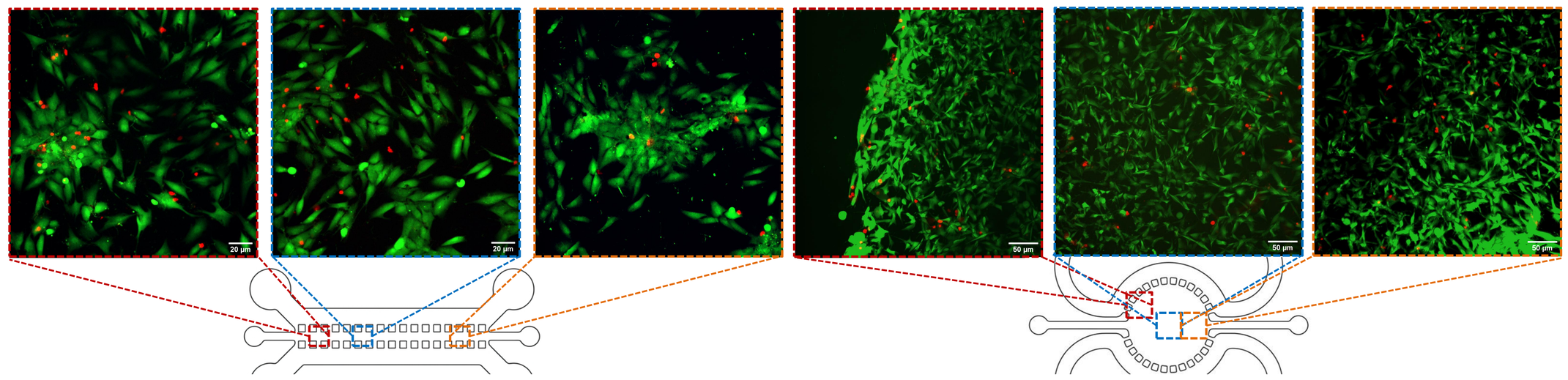


Figure 5. LIVE/DEAD assay performed using Calcein/PI staining to evaluate the bio-compatibility in the designed microfluidic platforms. The highlighted regions indicate the sampling locations for fluorescent imaging. The predominance of green fluorescence indicates the cell viability and successful integration within the chips' microenvironment.

FABRICATION

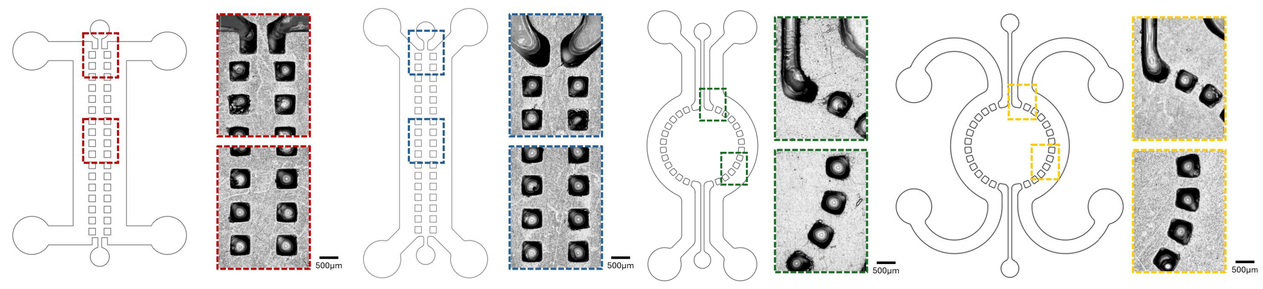


Figure 2. Representative CAD layout illustrating the chip designs and highlighted sections replicated in PDMS via soft-lithography. The architecture features a dedicated central chamber for fibrin-hydrogel encapsulation, flanked by symmetric inlets to ensure uniform shear stress distribution

µPIV FLOW VALIDATION

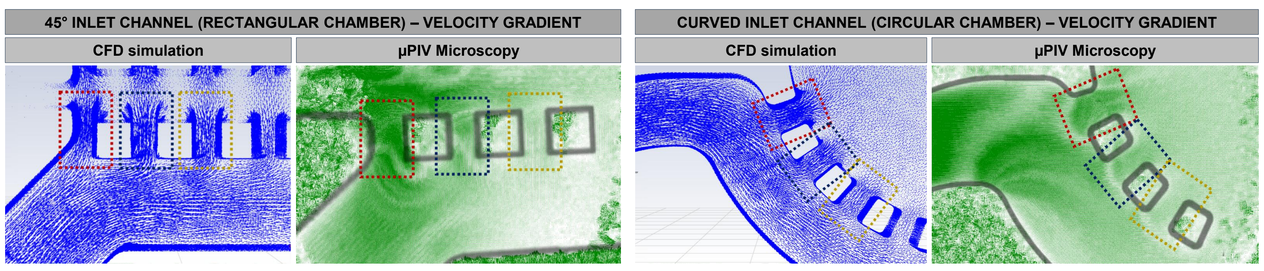


Figure 3. Comparison of velocity profiles between ANSYS CFD simulation and experimental µPIV results, confirming the similarity in flow trajectories and velocity magnitudes between the numerical models against the experimental data

In Vitro – CELL SEEDING

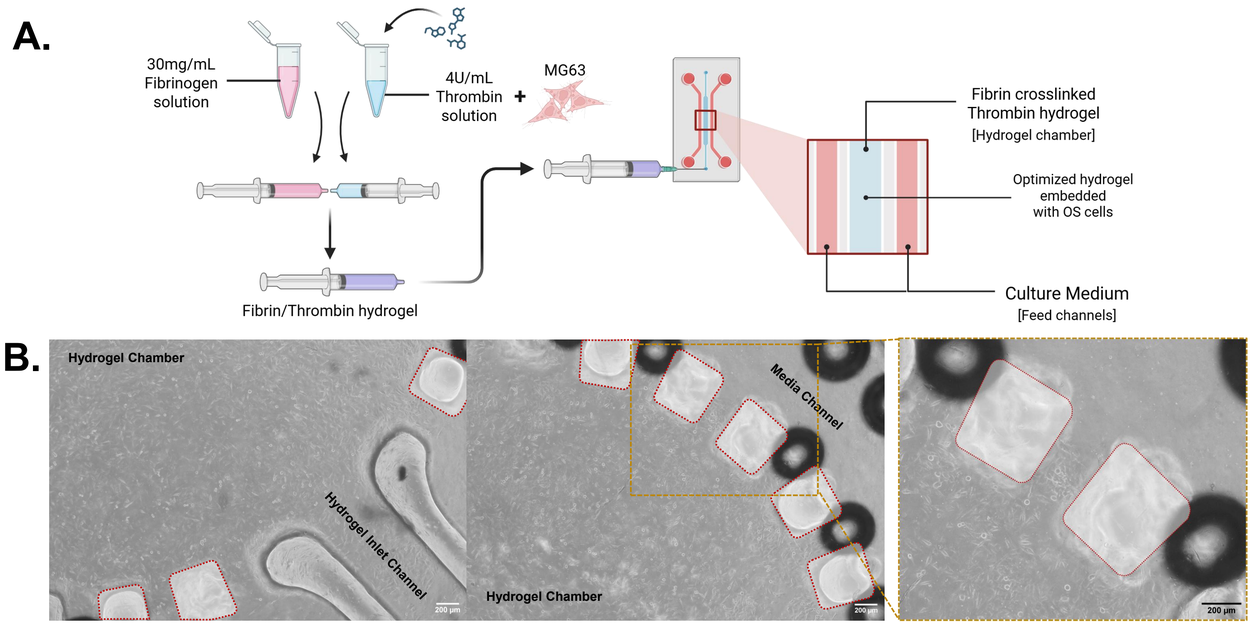


Figure 4. (A) Schematic representation for the preparation and seeding of cells in Fibrin hydrogel in microfluidic platform. (B) Bright Field images showing the cells being seeded inside the hydrogel chamber and restraining cells in the respective area.

DISCUSSION

CFD simulations using ANSYS Fluent showed that a **circular central chamber with side feed channels outperformed the traditional rectangular OoC design** by ensuring uniform nutrient delivery and **reducing harmful shear stress**. These models were key to optimising device geometry through analysis of static pressure, velocity magnitude, and wall shear stress. Successful PDMS casting of the optimised design further supports the practicality of this approach. The µPIV Microscopy showed that the CFD results would match the in-real life experimentation, **validating the computational models**. With this, MG63 cells were seeded in the hydrogel chamber on a Fibrin hydrogel crosslinked with Thrombin to further validate the viability and biocompatibility of the system, showing promising results for future studies on cancer research.

Acknowledgements

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