A PARAMETRIC CELL STRESSES ANALYSIS DURING EXTRUSION BIOPRINTING PROCESS BASED ON A FSI APPROACH

Gianluca Santesarti (1), Giuseppe Vairo (1), Francesco Viola (2), Roberto Verzicco (3), Michele Marino (1)

1. Department of Civil Engineering and Computer Science, University of Rome "Tor Vergata", Italy;
2. Gran Sasso Science Institute, L'Aquila, Italy;
3. Department of Industrial Engineering, University of Rome "Tor Vergata", Italy;

Introduction

In extrusion bioprinting the cell viability and the quality of the printed scaffold are highly influenced by several process variables, such as the extrusion velocity, the bio-ink properties, and the nozzle dimensions [1, 2, 3]. The introduction of the in-silico (computational) models would allow to reduce the experimental optimization costs and to speed-up the innovation of the bioprinting process. So far, the theoretical and numerical models used are not specific enough to give a quantitative assessment of the main cell damage causes such as the shear stress and exposure time [4]. They often consider very specific fluid behaviors (at most, power laws) and ignore the interaction between cells and the surrounding fluid. The aim of this work is to present a computational model for the extrusion of non-Newtonian hydrogel-based bioinks that explicitly considers the detailed 3D geometry of traditional nozzles used in bioprinting and the presence of cells.

Methods

To analyze the complex fluid-structure interaction (FSI) occurring in the nozzle between the hydrogel and cells, as well as among cells themselves, we have realized a multi-physics solver based on the immersed boundary technique [5] to accurately reproduce cell extrusion process. The dynamics and deformations of cells are solved using a spring-network structural model based on the Fedosov's interaction potential approach [6].

Results

The parametric study addresses the cell stress analysis on a standard convergent nozzle geometry with different needle diameters and multiple immersed cells.

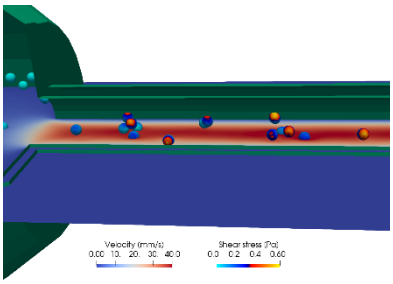

Figure 1: Velocity field along a symmetry plane and shear stress field in the nozzle during the simulation.

In Fig. 1, the computed velocity field of the hydrogel in the convergent area of the nozzle and the shear stresses acting on cell surface are reported. Numerical results demonstrate that cells locally modify the hydrogel velocity field, and that cell shear stresses and deformations are highly influenced by interactions with other cells.

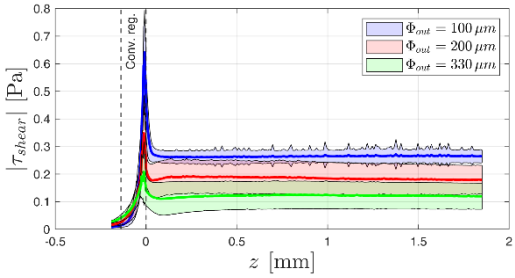

Figure 2: Cell shear stress analysis along the nozzle axis (solid line: mean value; shaded area: standard deviation) for different needle diameters.

In Fig. 2, the probability distribution of the load history of cells for the three diameters considered is shown, which indicates a maximum shear stress peak occurring in the nozzle convergent region.

Discussion

The planning of a bioprinting protocol requires to find a delicate balance between biological requests and engineering constraints. The proposed in-silico model opens for a systematic virtual optimization of hydrogels material properties, nozzle geometries and cell densities in extrusion bioprinting.

References

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