2025-2 | 50th congress of the Société de Biomécanique
27-29 October 2025, Marseille, France

Multidisciplinary Biomechanics Journal

Mechanical characterization and computational modelling of a levitating hydrogel droplet to stimulate cells

Emilie Wiedemann-Fodé[a, b, c*], Anaïs Lavrand[b], Nicolas Louvet[c], Chrystelle Po[d], Simon Chatelin[d], Ophélie Caballina[c], Jessica Schiavi-Tritz[e], Kevin Moerman[f], Halima Kerdjoudj[b], Cédric Laurent[a]

a University of Lorraine, CNRS, LEM3, F-54000 Nancy-Metz, France
b University of Reims Champagne-Ardennes, BIOS, Reims Champagne-Ardenne, France
c University of Lorraine, CNRS, LEMTA, F-54000 Nancy, France
d University of Strasbourg, CNRS, ICube, Strasbourg, France
e University of Lorraine, CNRS, LRGP, F-54000 Nancy, France
f Department of Mechanical Engineering, School of Engineering, University of Galway, Ireland
* Corresponding author: cedric.laurent@univ-lorraine.fr

Received date: 05/04/2025
Accepted date: 27/06/2025
Publication date: 27/10/2025

Keywords: Wharton's Jelly, biomaterials, in silico modelling, material characterization, stem cell culture

Published by Société de Biomécanique

1. Introduction

In tissue engineering, *in silico* models are increasingly used to simulate the effect of mechanical stimuli on cellular responses, enabling the design of conditions that maximize tissue growth and regeneration. These models give access to stresses and strains that are challenging to measure experimentally. Among existing biomechanical systems, acoustic levitation is an emerging approach that enables biological samples to be stimulated in a contactless manner. Levitating droplets of biologically-based hydrogels, cyclic compressions are applied (Wiedemann-Fodé et al. 2025) **[Figure 1.a]**. Wharton's jelly (WJ) is a soft and gelatinous connective tissue found in newborn's umbilical cord, and constitutes a natural hydrogel highly promising for tissue engineering. While several computational studies have investigated the distribution of the acoustic pressure field within a levitator (B. Andrade et al. 2010), the characterization of strains and stresses distribution within a levitating droplet is still lacking. The development of computational models applied to WJ droplets in levitation requires knowledge on the WJ intrinsic properties, which constitutes the first objective of this work. The second objective is to use these material properties in a computational model of the droplet using Finite Element (FE) method to provide a deeper insight into the mechanical environment experienced by the embedded cells.

2. Methods

2.2 Mechanical characterization of Wharton Jelly

Wharton's Jelly-based hydrogels were prepared by BIOS Reims laboratory. Magnetic Resonance Elastography (MRE) tests were conducted using a T2 RARE sequence and a local estimator frequency algorithm at different frequencies (200-400 Hz by 100Hz steps) (Loumeaud et al. 2025) to determine the WJ shear modulus **[Figure 1.b]**. The samples were also subjected to oscillatory rotation tests at different angular frequencies (from 0.62 to 6.2 times × 10^2 Hz) at 20°C using a rheometer (AR2000 TA Instruments).This enables us to determine G' (storage modulus) and G" (viscous modulus),using $G'=\frac{\tau_0}{\gamma_0}.\cos\delta$ and $G'=\frac{\tau_0}{\gamma_0}.\sin\delta$ with τ_0 the shear stress amplitude, γ_0 the shear strain amplitude and δ the phase shift between the two amplitudes. Rheological models (Maxwell, Jeffrey, Prony series) were identified based on experimental data using optimization techniques.

2.2 Computational modelling of the levitating droplet

An *in silico* model based on the FE code FEBio was developed based on literature-based material

To cite this article: Emilie Wiedemann-Fodé, Anaïs Lavrand, Nicolas Louvet, Chrystelle Po, Simon Chatelin, Ophélie Caballina, Jessica Schiavi-Tritz, Kevin Moerman, Halima Kerdjoudj, Cédric Laurent, Mechanical characterization and computational modelling of a levitating hydrogel droplet to stimulate cells, *Multidisciplinary Biomechanics Journal*, 2025, vol. 2, p. 209–211, DOI: 10.46298/mbj.16174.

parameters (Baldit et al. 2022). The purpose was to study the behaviour of an acoustically levitated droplet subjected to cyclic compression by modulation of the input voltage, and therefore a varying applied acoustic pressure. In order to determine this pressure, an inverse approach based on experimental acquisition of the shape of WJ droplets during levitation was carried out **[Figure 1.a]**. Using the least-square method (minimizing node-to-node displacement between the simulated droplet and the experimental data), we aimed to determine the distribution of acoustic pressures. Computational simulations then gave access to displacements, strain and stress fields during levitation **[Figure 1.c and d]**, and thus enabled to compute equivalent mechanical stimuli known to control the cellular fate (Boaretti et al. 2022).

3. Results and discussion

MRE results were successfully obtained for the WJ sample [**Table 1**], with temperature ranging from 17.8°C to 19.4°C. Given that WJ exhibits thermoresponsive gelation, generally going into a gel state around 30-37°C and remaining fluid at lower temperatures, further studies would need to be carried out to assess whether the 2°C difference between the start and end of the experiment results in collagen self-assembly, which would explain the shear modulus values.

The Maxwell model was satisfyingly used to describe viscous behaviour, but was found to be not suitable for elastic behaviour. Its limitations highlight the need to explore alternative rheological models, such as Jeffrey or more complex viscoelastic models, better suited for biomaterials. Further adjustments are therefore needed to better characterize the WJ.

Table 1. MRE results for the WJ sample, with shear moduli (Pa) and temperature (°C) at each shear wave frequency value (Hz)

Freq.	200	300	400
Shear m.	41.05±9.9	60.79±5.9	86.53±24.5
Temp.	19.4	18	17.8

Credit: Simon Chatelin.

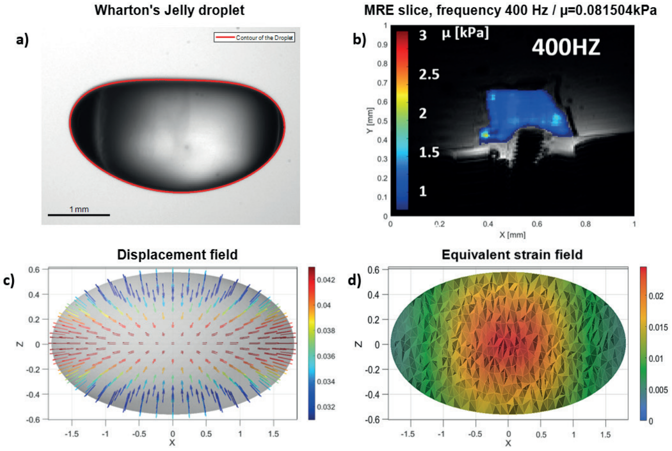

Figure 1. a) Experimental levitating droplet of WJ, **b)** MRE slice at 400 Hz, **c)** Displacement field and **d)** equivalent strain field obtained by simulation.

Credit: Simon Chatelin and Emilie Wiedemann-Fodé.

The inverse method used in FE modelling enabled to determine a pattern of the applied acoustic pressure based on an analytical pressure field of the form $P = P_0 + A(|\sin\theta|)$, with P_0 a base pressure and A the pressure variation, defining the highest pressure at the poles ($\theta = 0, \pi$) and the lowest at the equator ($\theta = \frac{\pi}{2}$). Gravity was not yet implemented in the code, which explains the discrepancy between the experimental and simulated droplets. However, it will be included in further refinements of the model's boundary conditions.

FE calculations enabled to determine stress and strain distributions associated with tension modulation during levitation, therefore providing insights of how the local mechanical environment within the droplet will be distributed and transferred to embedded cells. Such results will establish a macro-micro link at the cellular level, *i.e.* how the mechanical environment influences cellular responses.

4. Conclusions

The present study constitutes the first attempt to model the mechanical state of a droplet of WJ during acoustic levitation, and thus represents a major step forward in the understanding and development of this approach to mechanically stimulate cells. From the knowledge of the mechanical environment experienced by cells, a better definition and description of the macro-micro link would make it possible to provide comprehensive interpretation of the forthcoming results of cellular culture in levitation, and thus to optimize the parameters for modulating cyclic compression towards promoting cell response.

Acknowledgements

Thanks to the Metro'NRJ platform for the rheological measurement of the samples used in the present study.

MRE tests were performed with the support of the IRIS platform in Strasbourg.

Contributor Roles

EWF: Data curation, Formal analysis, Investigation, Software, Visualization, Writing original draft; AL: Methodology, Resources; NL: Data curation, Investigation, Methodology, Resources, Visualization; OC: Methodology, Resources; CP: Methodology, Resources, Visualization; SC: Data curation, Investigation, Methodology, Resources, Visualization; JCT: Writing-review and editing; KM: Software, Methodology; HK: Resources, Writing-review and editing; CL: Software, Supervision, Validation, Writing-review and editing, project administration.

Funding

This research was funded by HyCareMat Project-ANR-23-CE51-0039 ; MECHABOOST ANR JCJC project ANR-23-CE51-0048 and a CNRS PhD fellowship.

Data, software, code availability

https://www.gibboncode.org/Documentation/
https://febio.org/knowledgebase/

References

Andrade, M. A. B., Buiochi, F, & Adamowski, J. C. (2010). Finite element analysis and optimization of a single-axis acoustic levitator. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 57*(2), 469–479. https://doi.org/10.1109/TUFFC.2010.1427

Baldit, A., Dubus, M., Sergheraert, J., Kerdjoudj, H., Mauprivez, C., Rahouadj, R. (2022). Biomechanical tensile behavior of human Wharton's jelly. *Journal of the Mechanical Behavior of Biomedical Materials, 126*, 104981. https://doi.org/10.1016/j.jmbbm.2021.104981

Boaretti, D., Wehrle, E., Bansod, Y. D., Tourolle Né Betts, D. C, & Müller, R. (2022). Perspectives on *in silico* bone mechanobiology: computational modelling of multicellular systems. *Eur Cell Mater, 44*, 56–73. https://doi.org/10.22203/eCM.v044a04

Loumeaud, A., Po, C., Wach, B. F., Bensamoun, S., Pagé, G., Doblas, S., Garteiser, P., Grenier, D., Tse Ve Koon, K., Beuf, O. et al. (2025). Preclinical multi-organ Magnetic Resonance Elastography (MRE) at 7T: an original piezoelectric actuator design with dedicated sequences. *Multidisciplinary Biomechanics Journal* [Internet]. [accessed 2025 Apr 4] *49th congress of the Société de Biomécanique*. https://doi.org/10.46298/mbj.14507

Wiedemann-Fodé, E., Laurent, C., Schiavi-Tritz, J., Kerdjoudj, H. (2025). Acoustic levitation: a new process to stimulate stem cells for regenerative medicine. *Multidisciplinary Biomechanics Journal* [Internet]. [accessed 2025 Mar 26] 49th congress of the Société de Biomécanique. https://doi.org/10.46298/mbj.14502