2026-4 | 51th congress of the Société de Biomécanique
27-29 October 2026, Montpellier, France

Multidisciplinary Biomechanics Journal

Numerical Investigation of Acoustic Streaming-Induced Shear Stress in 3D-Printed Bone-Mimicking Scaffold

Lucille Allègre[a*], Philippe Laysagues[b], Victor Fournié[c], Julie Foncy[c], Laurent Malaquin[c], Carine Guivier-Curien[a], Cécile Baron[a]

a Aix-Marseille Univ., CNRS, ECM, IRPHé UMR7342, Marseille, France
b Aix-Marseille Univ., CNRS, ECM, LMA UMR7031, Marseille, France
c LAAS-CNRS, UPR8001, Toulouse, France
* Corresponding author: lucille.allegre@univ-amu.fr

Received date: 03/04/2026
Accepted date: 25/06/2026
Publication date: 27/10/2026

Keywords: numerical modelling, acoustic streaming, porous scaffold, wall shear stress

© 2026 The Authors
Licence CC-BY 4.0
Published by Société de Biomécanique

1. Introduction

The interaction between ultrasonic (US) waves and bone cells may potentially trigger a bone remodeling response. However, this US mechanotransduction phenomenon remains poorly understood, and efforts are ongoing to better characterize and understand it. Osteocytes are considered the primary cell regulators of bone remodeling, acting as the bone's mechanosensors. They are fluid shear stress sensitive.

These dendritic cells are widely distributed throughout the bone extracellular matrix (ECM), where they form an intricate 3D network at the micrometer scale immersed in the interstitial fluid (IF). The main assumption is to consider that US waves can induce acoustic streaming in IF leading to shear stress on osteocytes thereby triggering a biological cascade.

Since it has been demonstrated that cells cultured in 2D do not exhibit the same responses as those in 3D (Bicer, 2021), it is crucial to integrate a biomimicking 3D microenvironment to test our assumption. The aim of this study is to develop a numerical model of a 3D-printed scaffold that mimics the osteocyte environment (microstructure and mechanical properties) and which is subjected to ultrasound insonification, to investigate the resulting fluid mechanical loads within it.

2. Methods

2.1 Scaffolds

Since the long-term goal of this study will be to test cells in biological culture, specific scaffold was therefore designed and printed by stereolithography at LAAS-CNRS. This scaffold stands out because its acoustic and mechanical properties are close to those of bone (density: 1.21g/cm³, Young's modulus: 5.25GPa, Poisson's ratio: 0.36). Geometrical (pore dimension around 200µm), acoustical and mechanical characteristics of these scaffolds were used to build an equivalent numerical model.

2.2 Numerical model

COMSOL Multiphysics (v. 6.4) was used to conduct numerical investigations. To evaluate the acoustic streaming, the Navier-Stokes equations were solved inside the pores of the scaffold using the perturbation method. It allows to calculate the acoustic streaming velocity V2 (time average of the 2nd order term) and to deduce the resulting wall shear stress (WSS) applied at the pore walls interface of the scaffold. In detail, *Thermoviscous Acoustics* physics in the frequency domain was used to assess first-order fields (pressure and velocity) describing the wave propagation in the fluid. This was coupled with *Solid Mechanics* to model elastic wave propagation in the resin as an isotropic medium (Alexander & Hoople, 2019).

Due to the microscopic-scale geometry and low fluid velocities (Re<1), acoustic streaming was modeled via *Laminar Flow* driven by acoustic source terms (Bach, 2020). This study was performed on a Representative Elementary Volume (REV) of the scaffold, utilizing symmetry conditions on lateral sides to represent the structure as a whole. Perfectly Matched Layers (PML)

To cite this article: Lucille Allègre, Philippe Laysagues, Victor Fournié, Julie Foncy, Laurent Malaquin, Carine Guivier-Curien, Cécile Baron, Numerical Investigation of Acoustic Streaming-Induced Shear Stress in 3D-Printed Bone-Mimicking Scaffold, *Multidisciplinary Biomechanics Journal*, 2026, vol. 4, p. 175–177, DOI: 10.46298/mbj.19174.

were added to prevent wave reflection (Fig. 1a). A first-order oscillating velocity, $V_1(f)=i2\pi f d_0 e_z$, parallel to the Z-direction was imposed at the bottom scaffold interface to model a harmonic acoustic wave at a frequency (f) of 1 MHz with a displacement amplitude (d_0). Three d_0 values were tested to investigate its influence on the WSS measured on the scaffold surface (royal blue Fig. 1a).

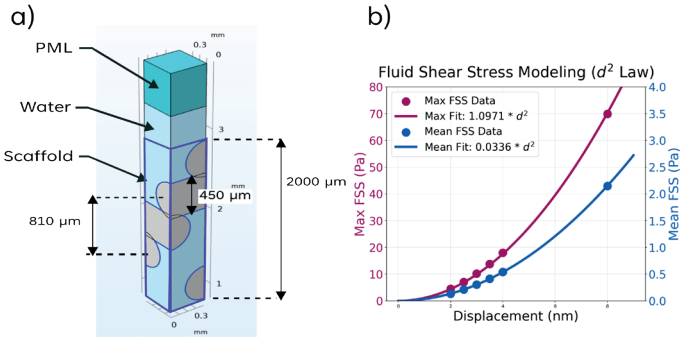

Figure 1. a) Numerical simulation of the Representative Elementary Volume (REV), b) Wall shear stress [Pa] in function of displacement.

Credit: L.Allegre.

3. Results and discussion

The numerical simulations provided an estimation of the fluid mechanical loads induced by acoustic streaming within the 3D scaffold. The mean, respectively maximum, WSS recorded is in a range of [0.026;1.20], respectively [0.249; 39.130] depending on d_0 value (Fig. 1b and Table 1). The mean WSS range includes the value that triggers the osteocyte response, as identified by Weinbaum (1994), which is 0.8 Pa. The results show a trend where the WSS increases in proportion to the square of d_0. This observation suggests that the model could be used to relate the incident US pressure to the internal mechanical excitation of the supporting structure. This would make it possible to adjust the input pressure to achieve a range of shear stresses capable of triggering a biological response. Conversely, for a given experimental setup in which biological effects are observed, this model may provide an estimate of the shear stress levels experienced by the cells.

However, the scaffold's larger pore size makes osteocyte-sensed phenomena like pore pressure less dominant than in bone. Consequently, a future parametric study on pore size would be relevant to assess these effects.

Table 1. Evolution of WSS according to displacement amplitude d_0.

d_0 (nm)	Mean WSS (Pa)	Max WSS (Pa)
2	0.135	4.531
4	0.539	18
8	2.149	69.960

4. Conclusions

This study presents a preliminary numerical model aimed at estimating the fluid mechanical loads within a 3D-printed scaffold designed to approximate the osteocyte microenvironment. By employing a perturbation method within COMSOL Multiphysics, the investigation explored the potential relationship between acoustic streaming and WSS.

Our initial results show that it is possible to measure internal WSS values corresponding to a potential biological trigger resulting from the application of a harmonic acoustic wave. Therefore, this model may serve as a preliminary tool for approximating the ultrasonic parameters needed in 3D cell culture experiments and helps to advance the hypothesis regarding mechanotransduction.

Funding

The authors acknowledge the support of the French Agence Nationale de la Recherche (ANR), under grant ANR-22-CE51-0038-01 (project INVICT-US).

Contributor Roles

AL: Methodology, Investigation, Writing – original draft. PL: Methodology, Writing – review & editing. VF: Methodology, Writing – review & editing. JF: Methodology, Writing – review & editing. LM: Methodology, Writing – review & editing. CGC: Methodology, Validation, Writing – review & editing, Supervision. CB: Funding acquisition, Conceptualization, Methodology, Validation, Writing – review & editing, Supervision.

References

Alexander, E., & Hoople, G. D. (2019). Anisotropic behavior of ultrasonic waves in 3D printed materials. *American Journal of Undergraduate Research*, *16*(3). https://doi.org/10.33697/ajur.2019.027

Bach, J. S. (2020). *Theory of acoustic fields and streaming with viscous boundary layers in microsystems (PHD Thesis)*. Department of Physics, Technical University of Denmark.

Bicer, M., Cottrell, G.S., & Widera, D. (2021). Impact of 3D cell culture on bone regeneration potential of mesenchymal stromal cells. *Stem Cell Res Ther, 12*, 31. https://doi.org/10.1186/s13287-020-02094-8

Weinbaum, S., Cowin, S. C., & Zeng, Y. (1994). A model for the excitation of osteocytes by mechanical loading-induced bone fluid shear stresses. *J Biomech. 27*(3), 339-60. https://doi.org/10.1016/0021-9290(94)90010-8