2024-1 | 49th congress of the Société de Biomécanique
29-31 octobre 2024, Compiègne, France

Multidisciplinary Biomechanics Journal

Preliminary results on multimodal mechanical characterization of a haemostatic sponge used for sinus lift

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Received date: 05/04/2024
Accepted date: 28/06/2024
Publication date: 31/01/2025

Keywords: haemostatic sponge, compression tests, elastic properties, magnetic resonance elastography, sinus lift

1. Introduction

Heamostatic sponges made of collagen or gelatin can be used for sinus lift procedure (Sohn et al., 2010) that aims to increase the bone thickness above teeth for implant positioning. Success of such a surgery requires predictive tools in terms of volume of filling material as well as mechanical properties once implanted into the sinus cavity. Using thermo-hydraulic analogy, the volume after implantation can be predicted thanks to finite element analyzes (Soar et al., 2023). The change of volume occurs within few hours after surgery, then the surrounding cells colonize the sponge. Cell behavior as well as the volume integrity depends on sponge mechanical properties. Today used in clinical practice, Magnetic resonance elastography (MRE) is a non-invasive technique coupling low-frequency shear wave propagation and magnetic resonance imaging (MRI) to reconstruct local stiffness maps of tissues (Muthupillai et al., 1995).
This work aims to set a first result using MRE confronted to compression test on haemostatic sponge to demonstrate their complementarity for quantitative monitoring of the evolution of sponge colonization, with a view to optimizing their use.

2. Methods

2.1 Samples

3 cubic Hemocollagen® sponges (Spetodont®) were used to carry on 3 different mechanical tests. Their initial dimensions and mass were measured thanks to a caliper and a Sartorius CPA225D scale. Their values are in Table 1.

Table 1. Characteristic dimensions and mass of the samples.

	Mean Value	Standard Deviation
Width	14.84mm	2.12mm
Depth	14.37mm	0.44mm
Height	12.27mm	1.01mm
Mass	28.15mg	0.78mg

Credit: A Baldit.

Three conditions were then tested: dry, with 0.5mL phosphate buffer (PBS) and fully saturated of PBS. Once the sample was 0.5mL PBS hydrated its height decreased to 6.19mm.

2.2 Compression tests

Thanks to a Zwicky0.5 universal tensile machine (ZwickRoell, Ulm, Germany), plate-plate compression tests were performed on the two first conditions thanks to a 10N load cell driven by displacement at 1mm/s speed. Then a linear fitting was performed on the linear response close to 10% of strain imposed.

2.3 Magnetic resonance elastography

A sponge was hydrated with saline solution for 2.5 months prior being installed in agarose block for MRI exam. It was performed using preclinical 7T MRI (Bruker Biospsin, Germany) with 86 mm volume coil and 10mm surface coil, RF transmitter and receptor,

To cite this article: Alexis Da Rocha, Simon Chatelin, Chrystelle Po, Cedric Laurent, Olivier Perroud, Halima Kerdjoudj, Cédric Mauprivez, Adrien Baldit, Preliminary results on multimodal mechanical characterization of a haemostatic sponge used for sinus lift, *Multidisciplinary Biomechanics Journal*, 2024, vol. 1, p. 209-211, DOI: 10.46298/mbj.14508.

respectively. Vibrations were induced using a home-made MRI-compatible system integrating a multilayer piezoelectric plate bender (*CMBP05, CTS* Denmark). The actuator was triggered by an MRI EPI sequence. A local frequency estimation (LFE) algorithm, close to that used in clinical MRE, was implemented and used to extract the local wavenumber and then to reconstruct stiffness maps (shear modulus) from shear wave propagation encoded on the MRI phase images.

3. Results and discussion

The compression tests, on the two first samples, highlights after a short toe curve a linear mechanical response up to 10% of engineering strain (Figure 1). The effect of hydration is clear on sample stiffness with an 11.5-fold decrease of Young's modulus in between both conditions. Even if this behavior for Hemocollagen® sponge was already reported (Okley et al., 2020), it is really difficult to be measured with conventional compression test. Indeed, the sponge's structure tends to collapse even though it is not fully saturated of fluid, while once implanted within the human body the colonizing cells are confronted to the fully saturated mechanical behavior. Such a saturated state of the sponge structure can be observed through MRI.
Therefore, the use of MRE lead, on the third sample, to local measurements of the dynamic shear modulus. The use of agarose as substrate to conduct the mechanical shear waves through the sample appears to be efficient. As a first result, the optimal vibration frequency was 400Hz yielding shear moduli around 2.82kPa in average. Considering an incompressible material full of water, it gives a Young's modulus of 8.46kPa (E=3xG with ν=0.5). Hence, both tests lead to the same order of magnitude. The higher value obtained by MRE can be related to the viscous behavior of the saturated sponge. Added to this are the differences in strains by the different protocols. In view of these aspects and aside the limitation of the repeatability (only one sample), these preliminary results are most promising and should be taken into account, in particular by extending the frequency range, for the non-destructive analysis of the mechanical evolution of haemostatic sponges as a function of their hydration level.

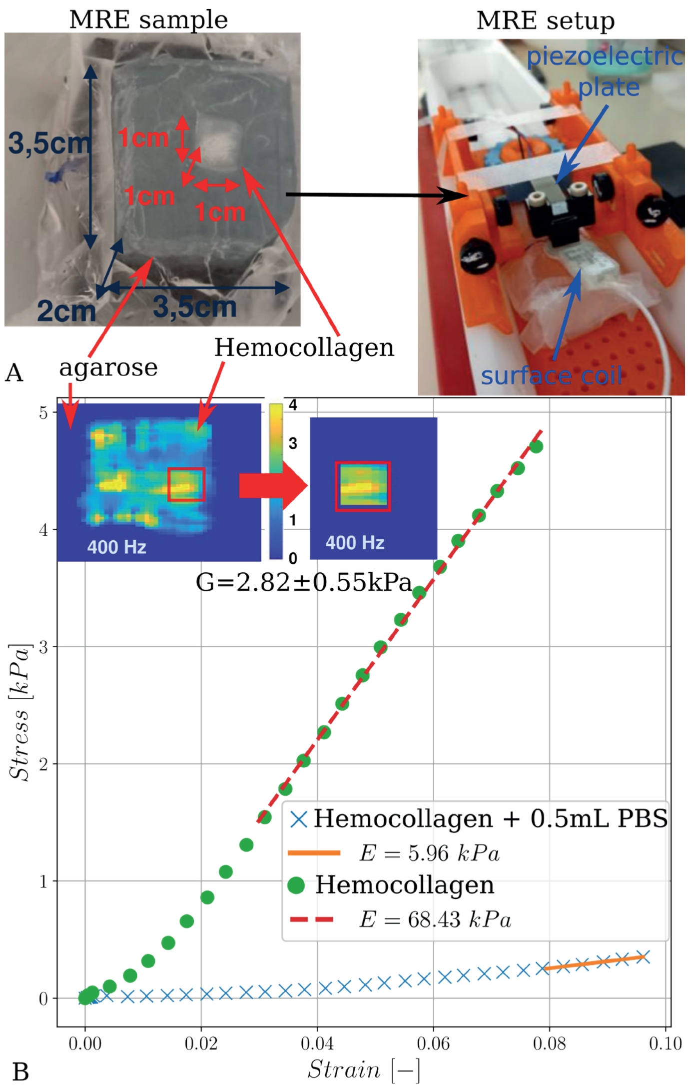

Figure 1. A) MRE sample and setup. B) Engineering stress strain curves of Hemocollagen® sponges undergoing compression. The inset shows a shear modulus field obtained by MRE.

Credit: A Baldit.

4. Conclusions

This work is a first step for the perspective of using MRE to quantify non-invasively the mechanical properties of a haemostatic sponge once fully saturated of physiological solution and close to *in vivo* conditions. This preliminary study confirms that non-invasive MRE combined with classical compression test gives outlooks with respects to patient specific modelling. Eventually, combined to cone beam tomography as well as the finite element analyses, these mechanical properties measurement will lead to predictive specific models.

Acknowledgements

The authors warmly thank Philippe Garteiser, Gwenaël Pagé and Sabrina Doblas (Center for Research on Inflammation, UMR Inserm 1149, Université Paris-Cité, ERL CNRS 8252, Paris, France) for providing the MRE EPI sequence, Jonathan Vappou and Aude Loumeaud (University of Strasbourg, CNRS, Inserm, ICube, UMR7357, Strasbourg, France) for the LFE algorithm and conception of the MRE vibration setup, respectively.

Funding

This study was supported by SEPTODONT for providing sponge samples, IMCOLL and IMSPONGE France Life Imaging projects (ANR-11-INBS-0006), HyCareMat project (ANR-23-CE51-0039-01) and IdEx Unistra (ANR-10-IDEX-0002) with the IRIS technology platform.

Conflict of Interest Statement

None.

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