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# First results on poro-mechanical characterization of temporomandibular joint disc through multiple testing

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## Abstract

### Introduction

The human temporomandibular joint (TMJ) connects the skull to the mandible and contributes to a series of fundamental functions such as speech and chewing. Several pathologies can affect its proper functioning, impacting 34% of world's population (1). The joint possesses a fibrocartilaginous disc that acts in force distribution and movement guidance of the mandible. TMJ dysfunctions are frequently associated with problems linked to the disc and the understanding of its mechanical behavior is essential for improving TMJ simulations and therefore proposing new solutions to pathologies. Since the TMJ is a synovial joint with low vascularization, it is also interesting to understand the fluid diffusive phenomena inside the tissue which play a major role on cell metabolic waste and nutrient distribution within the disc.

The mechanical behavior of the disc has been minimally explored in the literature, resulting in a limited current knowledge about its biphasic nature and consequently in a lack of effective solutions to its dysfunctions. The disc tissue is a porous medium that undergoes large deformations and is primarily composed of water (66 to 80%), with its dry mass consisting mainly of collagen fibers (68 to 80%). The biphasic theory enables the inclusion of fluid pressurization and flow influence in the material's viscous and nonlinear mechanical response through its permeability. The limited data currently available for the disc tissue was mainly obtained thanks to curve-fitting of confined compression tests (2). The present study aims to perform the poromechanical characterization of a same temporomandibular joint disc by means of three different methods: i) finite element analysis parameter identification on spherical compression data, ii) direct permeation measurement and iii) confined compression creep test, enabling a direct comparison of the permeability values as well as solid phase mechanical properties for two methods.

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## Materials and Methods

For this preliminary work, a porcine TMJ disc central part underwent multiple experimental tests. Starting with spherical compression tests (3), the curves were compared to (i) an axisymmetric finite element model of a disc compressed by a rigid sphere, in a coupled pore fluid diffusion and stress analysis (Abaqus 2022, Dassault Systèmes France). Using Ogden hyperelastic material definition with initial parameters for solid phase obtained from two models existing in the literature (3,4), an optimization process was performed to determine the permeability value and solid phase mechanical parameters that fitted experimental data.

The second part of the work consisted in testing a 10mm diameter cylinder cut from the central part of the same disc, to be tested in a direct permeation device designed on purpose. A constant pressure was applied to drive physiological fluid through the material, enabling the estimation of its permeability by (ii) direct fluid flow measurement. This allowed the measurement of the TMJ disc material's permeability through the direct application of Darcy's law, dissociating it from the compression of the material.

Finally, confined compression tests were conducted on the same sample, enabling the comparison between the three permeability measurement methods. The specimen was positioned on a porous base within a laterally restricted chamber and compressed by a porous piston, which allowed fluid exudation during the compressive process of a creep test. Like for the previous tests, the sample was kept at all times in saline solution at 37°C and the stress-strain curve was fitted to the biphasic theory through an optimization procedure minimizing the mean square errors (RMSE), also enabling the determination of (iii) permeability and solid phase parameters.

## Results and Discussion

The finite element spherical compression model allowed testing the parameters defined in the literature for the solid phase of the material, showing a large difference with the experimental results for these cases (RMSE = 6.44e-3 for (3) and RMSE = 3.97e-1 for (4)). The optimization process allowed determining parameters that best fitted the experimental data (RMSE = 1.12e-3), with a final definition of shear modulus of 40.0kPa and bulk modulus of 36.7kPa. The permeability of the material was eventually obtained equal to 8.22e-15 m<sup>4</sup>/Ns.

The permeability measurement by direct permeation was performed for the first time on this material, leading to a value of 9.56e-16 m<sup>4</sup>/Ns. The same sample, when subjected to confined compression, provided a permeability value of 2.20e-15 m<sup>4</sup>/Ns and aggregate modulus of 99.0kPa, both in the same order of magnitude as in (2), which also performed confined compression tests. Besides, a shear modulus of 21.5kPa and bulk modulus of 30.0kPa were obtained, consistent with that observed for the spherical compression identification results.

## Conclusion

The aim of this work was to characterize the TMJ disc, contributing with valuable insights to the currently limited literature available on its poromechanical definition. According authors knowledge, this work represents the first permeability measurement by direct permeation on this tissue, enabling cross-referencing of results from multiple methods on the same sample, which are typically applied individually and rarely compared. Looking ahead, the aim is to conduct the same tests on additional discs, confirming the preliminary results and further enriching the database. Magnetic resonance imaging is also being conducted to examine the tissue's microstructure and measure local water diffusivity.

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