FREEZE DRIED WHARTON'S JELLY MECHANICAL RESPONSE CHANGE WITH HYDRATION

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Introduction

Perinatal tissues such as Wharton's jelly (WJ) are investigated especially for regenerative medicine applications [1]. Assessing mechanical behavior as function of hydration is crucial to provide sound experimental characterization reducing discrepancies and to build predictive models fulfilling quality by design requirements. The hydration effect was already reported on mechanical strength and toughness [2]. It modifies the interaction between tropocollagen molecules such as direct electrostatic interactions, hydrogen bonds or water bridges. Molecular dynamics simulation of collagen microfibrils provides a complementary data to experiments to characterize tropocollagen molecules during the hydration process [4]. This work aims to propose a link in between both states, dry vs hydrated, at micro and macro scales.

Methods

WJ parts were isolated from human umbilical cords, washed in PBS and freeze dried. The tensile tests were carried out thanks to a Zwicky 0.5 equipped with a 10N load cell. To reproduce close physiological conditions ([NaCl]=9g/L, 37°C), a tank has been adapted to the machine. The hydration effect (d) has been characterized similarly to a damage parameter:

$$d = 1-(E_h/E_d) \qquad (1)$$

where Eh and Ed are linear elastic moduli respectively for dry and hydrated conditions. Besides, all-atom molecular dynamics simulations of model collagen type I were performed using the microfibrillar X-ray crystallographic structure [4]. Up to 48,000 water molecules were added to reach 220% hydration using package NAMD on 160 CPUs.

Results

Engineering stress-strain curves are plotted in Fig. 1 in both conditions for a representative sample Elastic moduli strongly decreased from Ed=11.10±1.43MPa to Eh=0.64±0.14MPa leading, for a fully saturated sample, to a hydration effect parameter of d=0.94±0.02 (n=6). At lower scales, and for low hydration (57%, Fig 2), we observed two regimes with a transition around 30nm that decreased while hydration increased.

Discussion

The strong decrease of elastic modulus in between both states at macro-scale is consistent with the literature [2] and a single parameter allows predicting the hydration effect. On the other hands at micro-scale, increasing the hydration level reduces mechanical strength as water molecules act rather as a lubricant. Extending this work to larger strain is under progress [3] while linking micro and macro scale parameters.

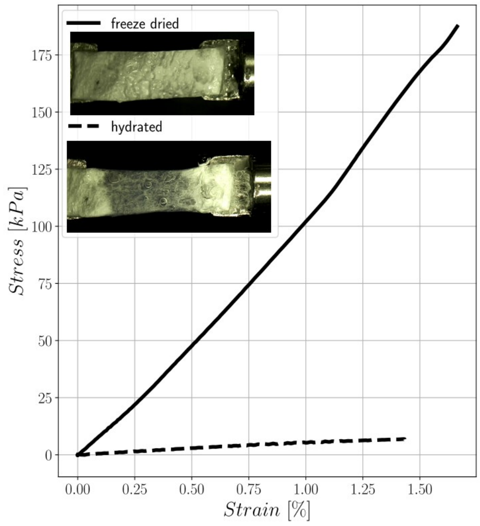

Figure 1: Stress-strain curves obtained for the same sample. The insert shows sample's appearance at the beginning of the mechanical load with the same scale.

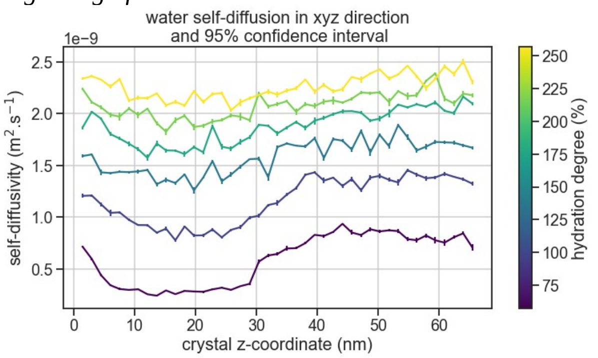

Figure 2: Variations of the self-diffusion coefficient with the position along the long z-coordinate of the crystal (c-axis) and with the hydration level (mass water/mass protein).

References

1. Dubus et al, Front Bioeng Biotechnol, 10, 828424, 2022.
2. Bose et al, J Mech Behav Biomed Mater, 111, 103983, 2020.
3. Baldit et al, J Mech Behav Biomed Mater, 126, 104981, 2022.
4. Orgel et al, PNAS, 103, 9001-9005, 2006