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► To cite this version:

Charles Jayyosi, Karine Bruyère-Garnier, Michel Coret, Jean-Michel Affagard, Stéphane Bancelin, et al.. Comparison between experimental and affine reorientation of collagen fibers in plane fibrous tissues. 22nd Congress of the European Society of Biomechanics, Jul 2016, Lyon, France. hal-04246656

HAL Id: hal-04246656

<https://hal.science/hal-04246656>

Submitted on 17 Oct 2023

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COMPARISON BETWEEN EXPERIMENTAL AND AFFINE REORIENTATION OF COLLAGEN FIBERS IN PLANE FIBROUS TISSUES

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Introduction

In order to better understand the biological tissues micromechanics, structural constitutive models have been developed which allow including considerations about tissues microstructures. A key aspect of this kind of modeling is to link the behavior between the microscopic and macroscopic scales, and especially to determine how the macroscopic strain will be transmitted to the microstructural organization. In most existing models, the affine assumption is taken to perform the connection between scales. It relies on the hypothesis that the microscopic strain can directly be derived from the macroscopic strain through the tissue transformation [1]. Here this hypothesis is taken to compute a theoretical reorientation of the collagen fiber network in plane connective tissues subjected to uniaxial and biaxial loading. Using the experimental data on liver capsule [2] and on skin [3], this theoretical reorientation is compared to the observed reorientation during these experimental campaigns to assess the validity of the affine assumption.

Material and methods

The collagen fibers orientations used here come from the experimental data published in [2] and [3]. Briefly, the histograms of collagen fibers orientation have been collected during mechanical loading on plane connective tissues. Uniaxial tensile tests have been conducted on mice skin and equi and non-equibiaxial bulge tests have been performed on human liver capsule, both coupled with imaging using multiphoton microscopy. Therefore the evolution of collagen fibers orientations during mechanical loading has been assessed. The theoretical reorientation of collagen fibers can be calculated [4], as derived from the initial fibers orientations distribution and the transformation gradient tensor by:

$$\Gamma_1(\beta) = \Gamma_0(\theta) \frac{\mathbf{M}^T \times \underline{\underline{C}} \times \mathbf{M}}{\det \underline{\underline{F}}} \quad (1)$$

where $\Gamma_0(\theta)$ is the orientation distribution in the reference state and $\Gamma_1(\beta)$ is the orientations distribution in the deformed state (associated to an angle β after deformation). $\underline{\underline{F}}$ is the transformation gradient tensor, $\underline{\underline{C}}$ the dilatation tensor and \mathbf{M} the direction of a fiber family defined by θ in the reference configuration.

Results

Globally speaking, we notice that this model of reorientation based solely on geometric considerations is not able to reproduce the observed reorientation. For the samples which exhibited an important reorientation during loading, for instance during non-equibiaxial bulge tests (figure 1), the reorientation predicted by the affine model is not important enough to successfully account for the experimentally observed reorientation.

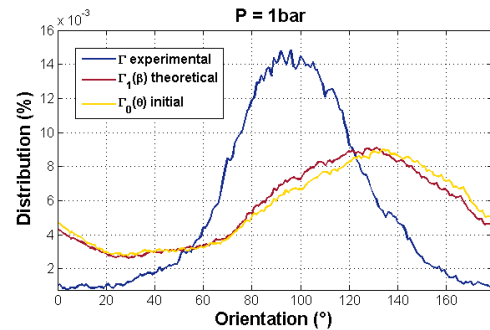


Figure 1: Initial (yellow), experimental (red) and theoretical (blue) orientation distributions of collagen fibers in a liver capsule sample subjected to non-equibiaxial bulge test.

Discussion

The reorientation of the fibers network seems to depend on other factors than just the applied strain. Indeed, the structural interactions neglected in the affine models appear to have a crucial importance in the network reorganization. Therefore, the validity of the affine assumption has to be investigated by identifying the force transmission mode in the tissue, especially among collagen fibers.

References

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Acknowledgements

The authors wish to thank Pr Mathias Brieu for useful discussions. This work was partly supported by the Programme Avenir Lyon Saint-Etienne (ANR-11-IDEX-0007) of Université de Lyon, within the program "Investissements d'Avenir" operated by the French National Research Agency (ANR).

