Crimped and Cross-Linked Collagen Fibre Structure May Lead to Auxetic Behavior in Soft Tissues

Chenghe Piao, Simon Le Floc'h, Patrick Cañadas, Christiane Wagner-Kocher & Pascale Royer
LMGC, Univ. Montpellier, CNRS, Montpellier, France. E-mail: chenghe.piao@umontpellier.fr, simon.le-floch@umontpellier.fr, Patrick.canadas@umontpellier.fr, pascale.royer@umontpellier.fr

Auxetic materials have a negative Poisson's ratio. When stretched, they become thicker perpendicularly to the loading direction; and when compressed, they become thinner perpendicularly to the loading direction. The auxetic behavior in biological tissues have been discovered in skin tissue[1][2], carotid arteries[3], cornea strip[4], tendons[5] and annulus fibrosus tissue[6][7][8]. Gatt et al.[5] proposed that the crimped fibre structure may be the reason of the negative Poisson's ratio in the tendon. In the present work, we consider a fibre structure which include both fibre corrugation and cross linking to explain auxetic behavior in collagen-rich soft tissue.

We consider the crimped collagen fibres as helical structures which are cross-linked by means of straight fibres. The helix fibre is set up as a symmetrical arrangement. Our proposed fibre structure is shown in Figure 1 (a), where red and blue indicate straight fibres in different planes. A finite element analysis is conducted to operate a tensile test for the fiber structure being considered. The proposed structure is set to the same material which is a hyperelastic material with equivalent Young's modulus of Neo-Hookean model 100MP a and Poisson's ratio 0.49. The bottom surface is constrained to displacements along the y-axis and a loading of 50% strain along the y-axis is applied on the top surface.

When the given fiber is stretched 50% along the y-axis, the outline of the fiber is expanded to both sides compared to the position before stretching. We take λ_i, where $\lambda_i = L_i/L0_i$ (with L_i and $L0_i$ representing the stretched length and original length respectively, and i standing for the component along the x,y,z axis), to describe the dilatation relation. The horizontal and vertical dilatation relations are shown in Figure 1 (b). As shown in Fig 1 (b), when the λ_y increases, λ_x and λ_z increase at the same time, which shows that the fiber structure under consideration has an auxetic behavior until 50% stretching. In conclusion, the helix-like cross-linked collagen fibre structure may be a cause of auxetic behavior in soft tissue.

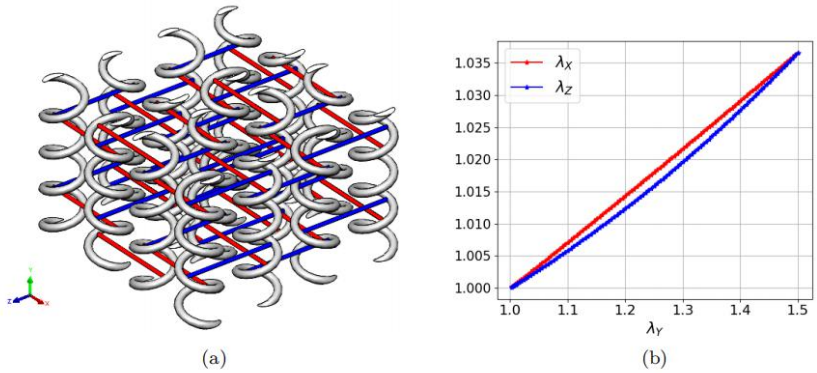

Figure 1. (a) 3D perspective of the fiber structure. (b) Transverse dilations in the transverse direction x and z as a function of the dilation along the direction of traction y.

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