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RESIDUAL STRESS IN PIG INTERVERTEBRAL DISCS

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Introduction

The intervertebral disc (IVD) growth, which is at the heart of the development of the juvenile idiopathic scoliosis, constitutes an example of biological growth influenced by mechanical loads. In order to better understand the early development of this pathology, we propose to study a marker of tissue growth which are the residual strains and stresses generated through the biological growth process of the IVD.

Materials and methods

Two lumbar discs (L4L5 and L5S1, graded I) were harvested from cadavers of domestic pigs obtained from a local slaughter house. The lumbar spine was excised and stored in a -12°C freezer. IVD were separated from the vertebral bodies by blunt dissection. Annulus fibrosus was separated from the nucleus using a surgical knife. Then, the stresses due to growth of the annulus fibrosus were released by cutting the sample at the left posterior part. The opening angles were measured by a similar method proposed by [Michalek, 2012], see figure 1. After cutting, samples were stored for 1 hour in physiological conditions, i.e., in a 0.15 M NaCl solution at $T=37^{\circ}\text{C}$.

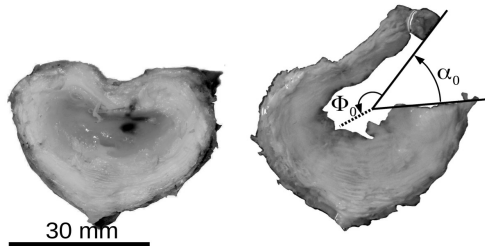


Fig. 1: Opening angle measured on L4L5 disc harvested from a domestic pig.

In addition to measured opening angle, we characterized the mechanical properties of the IDV tissue at 6 and 3 different locations (i.e. samples) for the L4L5 and L5S1 discs respectively, using uni-axial traction tests in the circumferential direction. The procedure, well described in [Baldit, 2014], was to

estimate the 5 mechanical parameters of the hyperelastic strain energy potential :

$$W = \frac{G}{2}(\bar{I}_1 - 3) + \frac{K}{2}(J - 1)^2 + \frac{K_1}{2K_2} \sum_{i \in \{1,2\}} \{ \exp(K_2 [k_{disp} \bar{I}_1 + (1 - 3k_{disp}) \bar{I}_{ai} - 1]^2) \} \quad (1)$$

The mechanical properties of the different samples together with the opened “stress-free” geometries allowed us to evaluate numerically the residual strains and stresses fields using a numerical closing procedure similar to [Ohayan, 2007].

Results and discussion

For the L4L5 and L5S1 pig discs, we measured opening angles α_0 of respectively 22° and 49° , corresponding to Φ_0 angles of 169° and $155,5^{\circ}$. The estimated mechanical parameters for L4L5 and L5S1 discs are respectively : $G = 47,9 \pm 43,3 / 46,7 \pm 26,6$ kPa, $K = 506 \pm 528 / 817 \pm 965$ kPa, $K1 = 1,36 \pm 2,04 / 3,5 \pm 1,89$ kPa, $K2 = 1610 \pm 1560 / 853 \pm 397$, $k_{disp} = 2,8 \cdot 10^{-2} \pm 3,36 \cdot 10^{-2} / 3,92 \cdot 10^{-2} \pm 1,58 \cdot 10^{-2}$.

Compared to a study on bovine discs [Michalek, 2012], our first preliminary results seem to indicate a smaller opening angle. Such an opening behavior correspond to a residual extension of the external layer of the annulus fibrosus (stretch of 1,05) and a residual compression of the internal layer of the annulus fibrosus (stretch of 0,85), see fig. 2.

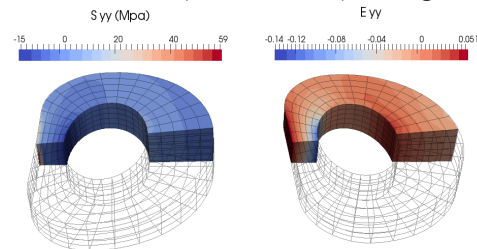


Fig. 2: Reconstructed residual strain and Cauchy stress for L4L5 disc harvested from a domestic pig.

Conclusion

Our preliminary results ($n=2$ discs) show that pig intervertebral discs present residual

strains and stresses, as other biological tissues grown under physiological mechanical loads. Further experiments and numerical reconstruction of residual strains and stresses, with sample-specific mechanical properties, will allow us to better understand disc growth and generation of residual stresses.

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