COMPARING UNIAXIAL AND BIAXIAL STRAIN RESPONSES OF THE PORCINE ANNULUS FIBROSUS

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INTRODUCTION

The annulus fibrosus is primarily a collagenous tissue that is required to withstand tensile forces during various loading and postural scenarios. This is especially true for the outer annulus, which is comprised of type I collagen fibres, similar to those found in tendons and ligaments (Lo et al., 2002, Pritchard et al., 2002). However, to date, the tensile loading properties of the annulus fibrosus have only been examined uniaxially, while the annulus is likely loaded in all directions *in vivo*. Due to the structural organization of the annulus, each layer is subject to vertically orientated strains as well as circumferentially orientated strains. Therefore, it is important to determine the response of the annulus fibrosus under multiple axis loading. The purpose of the current study was to compare the force-displacement profile of porcine annulus layers under uniaxial and biaxial tension.

METHODS AND PROCEDURES

Ten 5mm by 5mm annulus samples (average thickness 0.52mm, S.D. 0.16mm) were dissected from the outer anterior portion of the intervertebral discs from four C3/4 and six C5/6 porcine functional spinal units. These functional units have been shown to be morphologically and functionally similar to human lumbar functional units (Yingling et al., 1999, Oxland et al., 1991). Each tested sample consisted of two adjacent annular layers and were dissected such that the orientation of the fibres of the superficial layer were running in a vertical orientation and therefore the fibre orientation of the adjacent layer was approximately 30 degrees deviated from vertical. Each sample was subjected to 20% uniaxial strain (applied transversely to the orientation of the vertical fibres) at a strain rate of 2%/s, and subjected to biaxial strain (20% in both the transverse (perpendicular to fibre orientation) and vertical (parallel to fibre orientation)) at a rate of 2%/s. The order in which these strains were presented were randomized. Samples were strained using a custom biaxial testing system (BioTester 5000, CellScale, Waterloo Instruments Inc, Waterloo, ON). Variables of interest (all in the transverse direction) were peak force, peak displacement, and stiffness. A two-way ANOVA (uniaxial versus biaxial, and functional unit type, i.e. C3/4 versus C5/6) was conducted in order to determine any main effects on the previously mentioned variables. An alpha level of 0.05 was used in order to determine significance.

RESULTS

As expected, the biaxial strained tests resulted in significantly higher stiffness values (uniaxial average (S.D.) stiffness: 1.79 N/mm (0.86); biaxial stiffness: 3.44 N/mm (1.36); $p<0.0001$) as well as peak force values (uniaxial average (S.D.) peak force: 0.71N (0.36); biaxial peak force: 1.39N (0.59); $p=0.001$). Figures 1a and 1b depict the stiffness and peak forces values,

respectively. It is also important to note that the peak displacement for the uniaxial versus biaxial tests were not significantly different (p=0.831). In addition, the stiffness, peak force, and peak displacement were not significantly different between the C3/4 and C5/6 functional unit specimens (p=0.326, 0.273, 0.297, respectively).

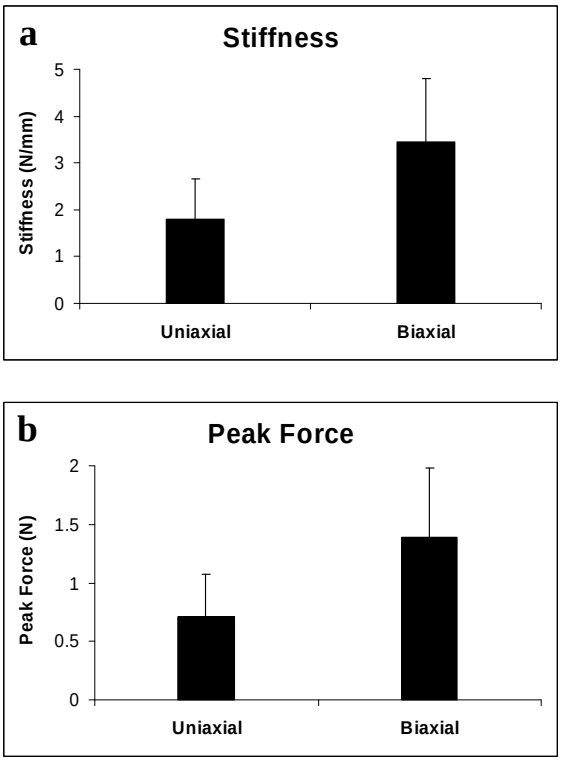

Figure 1. a) Average stiffness (p<0.0001) and b) average peak force (p=0.001) for the uniaxial and biaxial tensile tests to 20% strain. Error bars represent standard deviation.

DISCUSSION

Prior to the current study, the annulus fibrosus had only been studied under applied uniaxial tensile loads *in vitro*. However, it is generally accepted that the annulus, and most biological tissues, undergo multi- directional tensile loads. Therefore, it is important to determine how these tissues respond to multi-directional strains. The current study showed that the annulus fibrosus requires almost double the force to strain to the same magnitude when under biaxial tensile load as compared to uniaxial tensile load. Further, the tissues are approximately twice as stiff under biaxial tension as compared to uniaxial tension. Therefore, the annulus fibrosus experiences a higher stress for a given strain during multi-directional tension, which is a more physiological scenario, then what has been previously documented uniaxially. This is important for determining tissue tolerance levels as well as the injury potential of various tensile loading situations, as currently these tissue tolerances are based solely on uniaxially applied strains.

SUMMARY

This study was the first to document biaxial tensile loading for the annulus fibrosus. The most important finding is that the annulus fibrosus experiences much higher stress levels (approximately 95% higher peak forces) at a given strain magnitude when under biaxial tension as compared to uniaxial tension, which is a far more biologically relevant scenario.

REFERENCES

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