Characterizing Uniaxial Mechanics of Single AF Lamella

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Introduction

- Low back pain is a widespread public health issue [1]
- Lumbar intervertebral disc (IVD) degeneration is recognized as the origin of low back pain [2]
- IVDs are located between the vertebrae of the spine, Figure 1
- IVD is composed of the annulus fibrosus (AF) and the nucleus pulposus, Figure 2
- Healthy AF has 15-25 distinct lamellae [3]
- AF fiber orientation alternates by approximately ± 30^0 in adjacent layers [4]
- Lumbar IVD bears large biomechanical stresses [5]
- Mechanical behavior of AF lamella is very important
- Investigation of material properties of IVD will improve modeling and understanding of IVD
- Only handful of studies done on characterizing mechanical properties of single AF lamella [6,7,8]

The objective of this study is to investigate material properties of human, cadaveric, single annulus fibrosus lamella in uniaxial loading.

Figure 1. Sample Geometry in Spinal Segment
(image modified from www.smartimagebase.com)

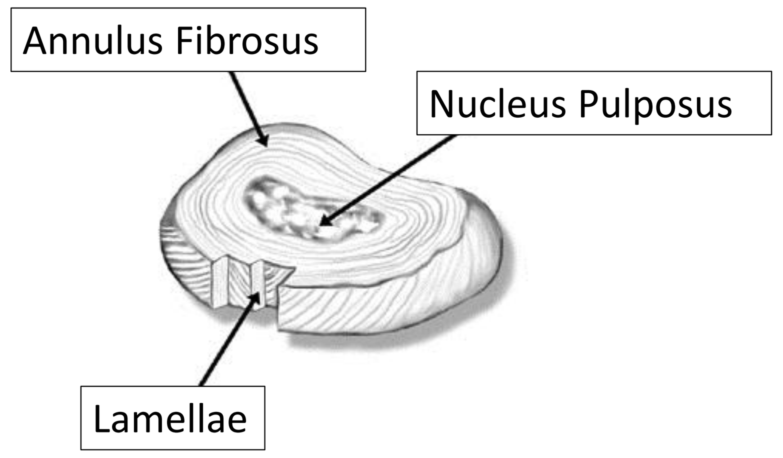


Figure 2 Schematic Representation of the Intervertebral Disc
(image modified from www.MagedHamza.com)

Methodology

Dissection:
- 3 Freshly frozen human cadaveric L1-L2 and L3-L4 discs
- Dissection to single, anterior, inner AF lamella sample

Uniaxial Tensile Testing:
- Measure the sample
- Speckle using Verhoeff's Stain
- Immerse the sample in the saline bath
- Apply 0.2N preload
- Uniaxial Testing Protocol 1 --- Sample (A) and Sample (C)
  - Precondition at 10% equibiaxial strain over 10 sec, 7 times
  - Test at 1%/sec equibiaxial strain until sample failure
- Uniaxial Testing Protocol 2 --- Sample (B)
  - Precondition at 7% equibiaxial strain over 5 sec, 7 times
  - Test at 7% equibiaxial strain

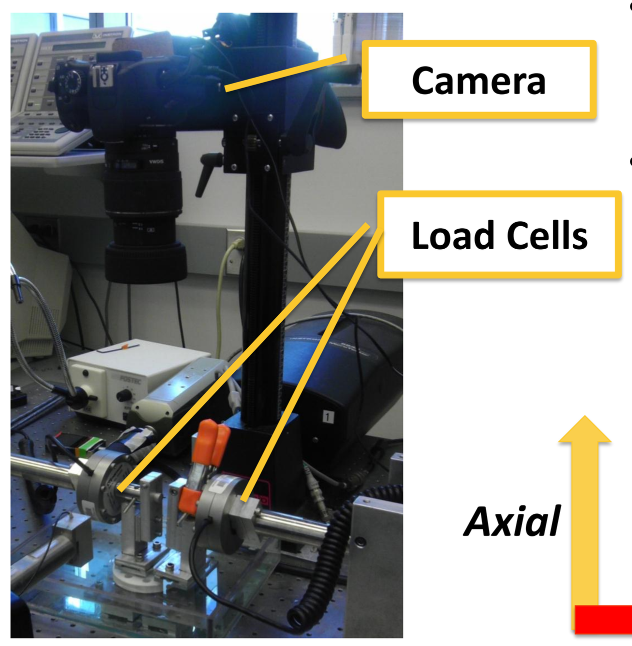


Figure 3. Instron-Sacks Biaxial Testing Apparatus

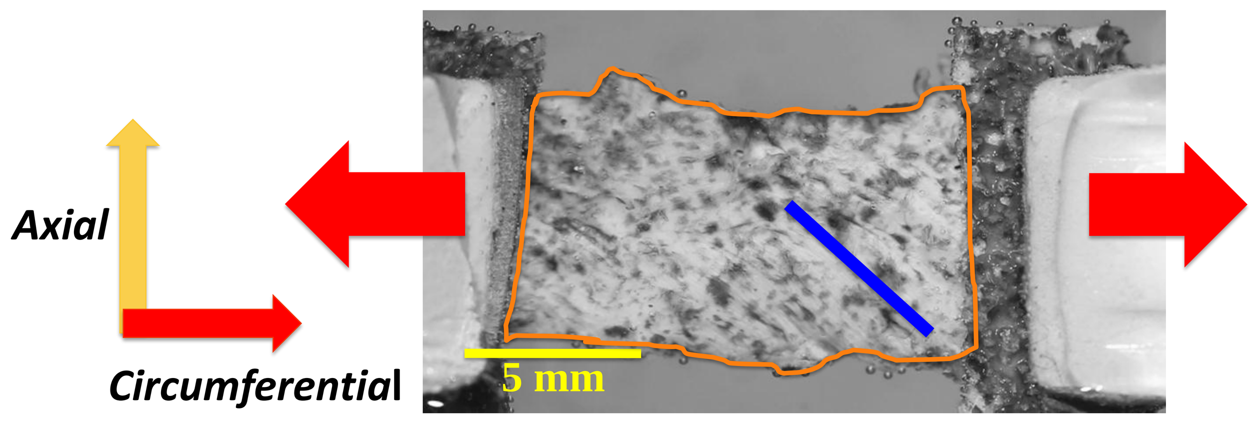


Figure 4. AF Lamella Sample Geometry
The orange field was tracked. The blue line denotes tissue fiber alignment.

Data Analysis:
- Sample thickness approximated to 0.9448 mm
- Calculated strain field (E_{cir}) for samples (A) and (B) by digital image correlation
- Calculated 1st Piola-Kirchhoff Stress
- Plotted Stress-Stretch curve and calculated elastic modulus (E)

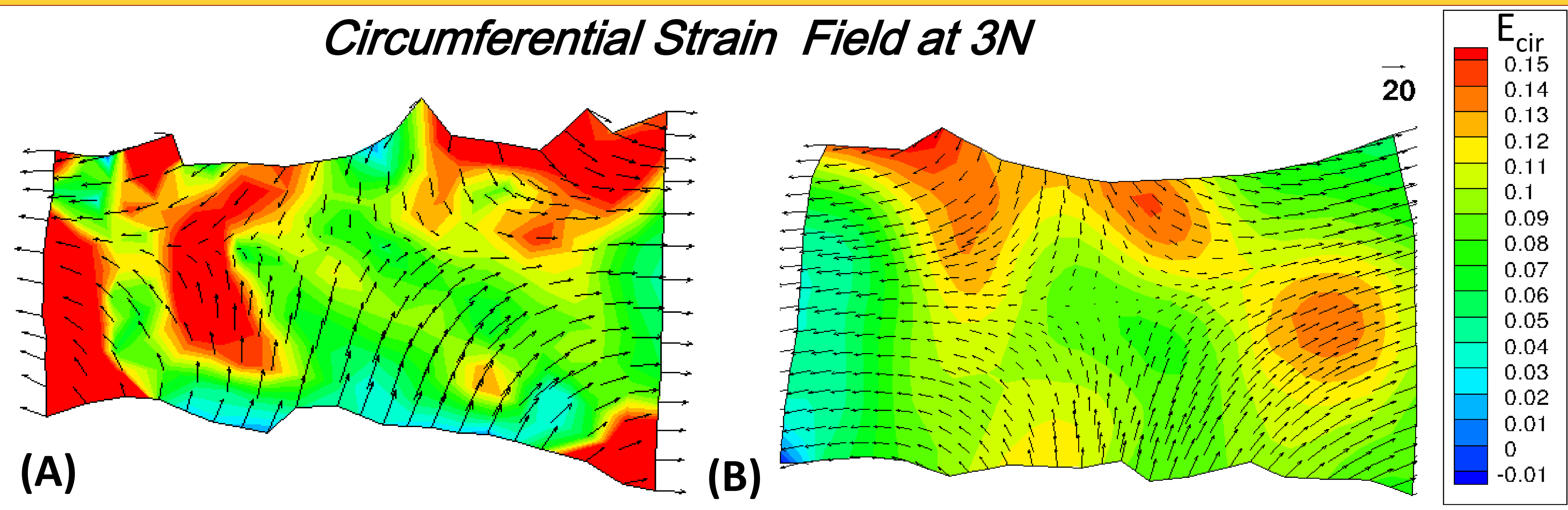
$$\frac{F}{A_0} = \sigma$$

1st Piola-Kirchhoff Stress

Results

- Similar strain patterns
- Higher strains in sample A
- Larger strains along reference fiber orientation
- Heterogeneous strain fields
- Average surface strain approximately equivalent to grip strain

Circumferential Strain Field at 3N



Stress– Stretch Curves

- Non-linear response
- Different strain energy density between Protocol 1 and 2
- Low E standard deviation

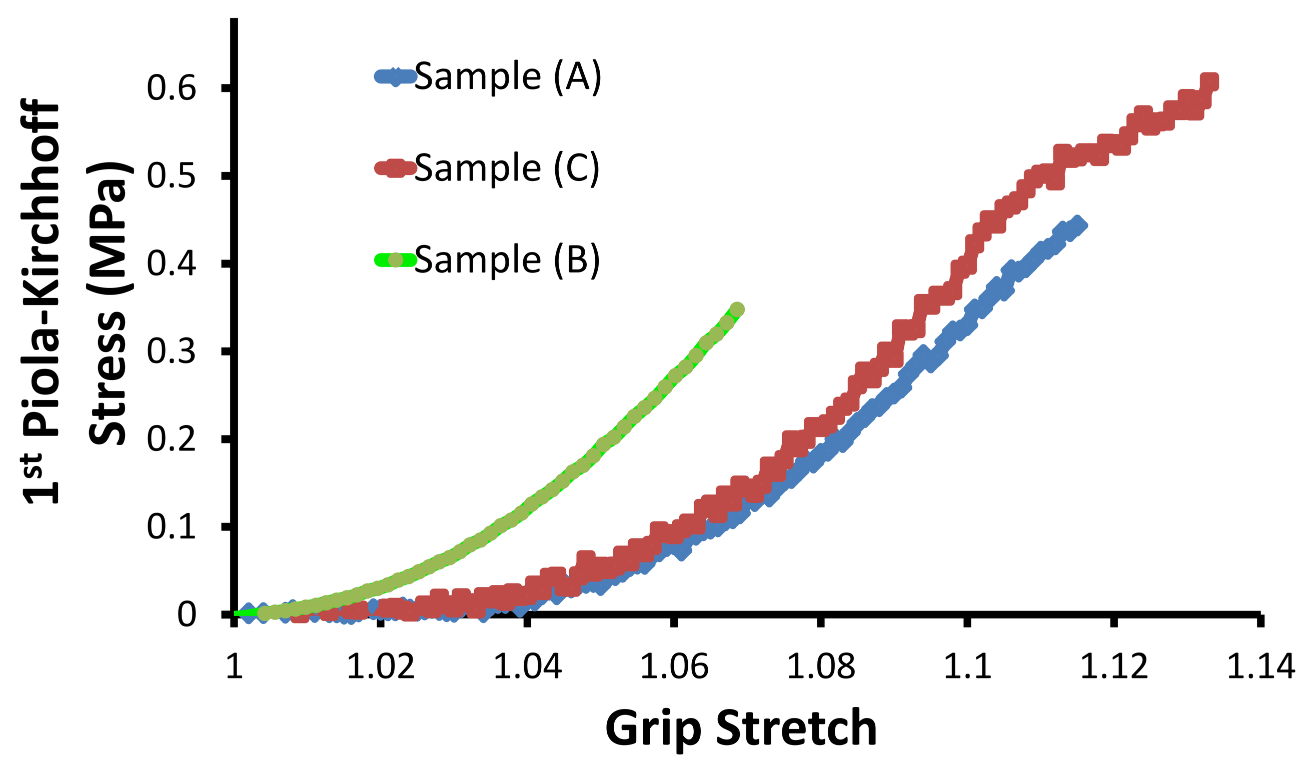


Table 1: Elastic Moduli

	E (ϕ=30°, MPa)	
	Average	Standard Dev.
Golman et al. n = 3	7.88	0.758
Ebara et al. n =15	8.53	5.42

Discussion

- Heterogeneous strain fields shows the anisotropy of the single AF lamellae.
- Stress-strain nonlinearity is a product of the aligned fibrous nature of AF lamellae.
- Differences in gripping technique and protocol produce distinct stress-stretch curves with similar elastic moduli.
- The average elastic modulus was similar to that obtained by Ebara et al. [9] with lower standard deviation.
- The average elastic modulus was within the published range of fiber orientations, ϕ = 0°, ϕ = 90° [6,7].
- Future work will focus on increasing the sample size and standardizing the testing protocol.

Conclusion : This study constitutes a first step towards characterizing AF material properties from uniaxial tensile tests.

References

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Acknowledgements

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