Centre for Doctoral Training in Medical and Biological Engineering

Characterisation and Comparison of Human and Ovine Spinal Ligaments

UNIVERSITY OF LEEDS

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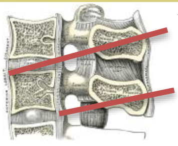
Study Aims

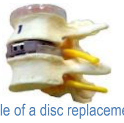
- Develop a methodology to test and compare the stiffness of ovine and human spinal ligaments.
- Devise a methodology for specimen-specific modelling of ligaments.
- Combine experimental & computational approach to mechanically characterise ALL & PLL spinal structures.

Introduction

- Spinal ligaments provide passive stability to the spine particularly the anterior longitudinal ligament (ALL) and posterior longitudinal ligament (PLL) play a major mechanical role in extension and flexion respectively[1].
- The literature on the physical and mechanical properties of spinal ligaments span a large range and these values have been used extensively in finite element models of the spine, assuming uniaxial behaviour i.e. using mean values for cross sectional area (CSA) and length (L)[2,3].



Lateral view of a functional spinal unit with ligaments[4]


Example of a disc replacement device to treat degenerated discs

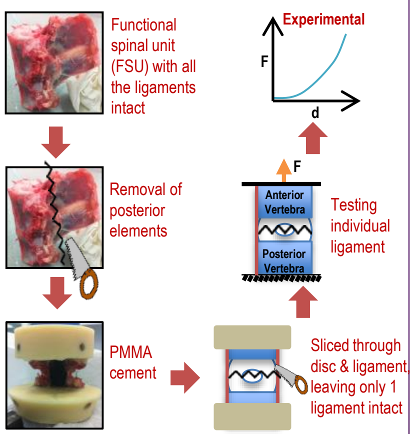
- Ovine spine models are commonly employed in preclinical research studies as a precursor to clinical trials for the evaluation of interventions and devices. However, limited studies have been conducted to characterise the mechanical properties of ovine spinal ligaments to justify the use of ovine spine as an alternative model for the human spine.

Significance

- Demonstrates the mechanical differences between human and ovine spinal ligaments.
- Marks a step change from the current state-of-art where ligament properties and geometry are derived from widely varying data in literature.
- Enables the mechanical contribution of the ligaments to be more realistically represented in future FE models

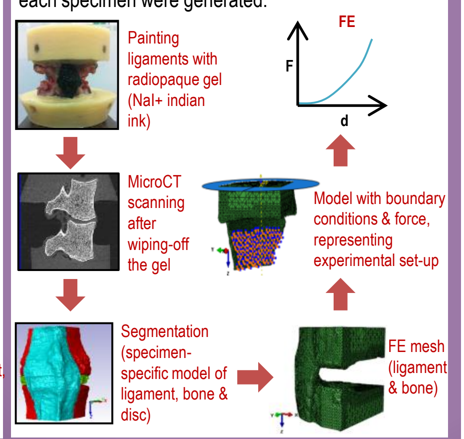
Experimental Approach

Ovine (N = 2x6) and human (N=2x7) ALL and PLL were tested in vitro.



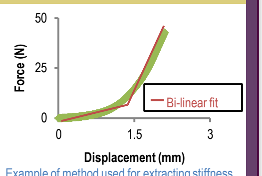
Computational Approach

Specimen-specific finite element (FE) models of each specimen were generated.



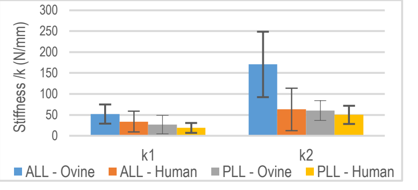
Data Analysis & Results

- Stiffness of the ligaments was consistently extracted, giving initial 'toe region' (k1) and final 'linear region' (k2) values using a systematic data analysis method[5].



Example of method used for extracting stiffness

- significant difference (p<0.05) between the human and ovine linear region stiffness.



Comparison of Mean Bilinear Stiffness for ALL and PLL

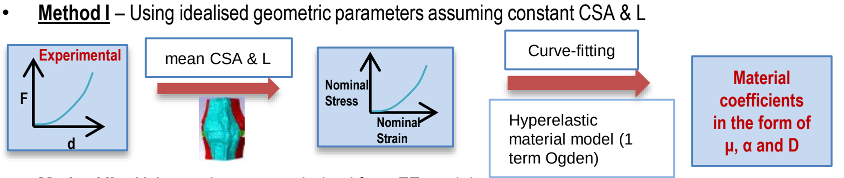
- Poor agreement between the material parameters derived from FE models and values derived assuming uniaxial behaviour.

Specimen	Assuming constant CSA and L				Derived from FE model		
	μ/GPa	α	D/GPa^{-1}	% diff.	μ/GPa	α	D/GPa^{-1}
1: T2-3	3.9E-04	6.3	2339	56.8	7.9E-04	9.4	1170
1: T4-5	7.4E-04	5.6	1244	35.4	9.9E-04	7.9	933
2: T2-3	1.4E-03	3.0	682	36.8	1.9E-03	3.8	477
2: T4-5	1.6E-03	5.1	559	56.5	3.0E-03	7.4	308
2: T8-9	1.5E-03	6.6	602	15.5	1.5E-03	9.2	602
3: T4-5	1.5E-03	4.9	596	73.1	4.4E-03	8.3	209
3: T6-7	1.8E-03	6.2	522	97.9	3.9E-03	8.9	235

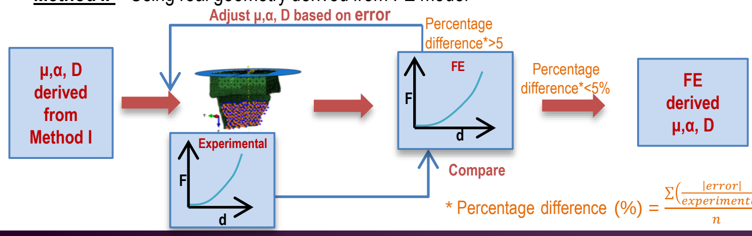
Material model constants for the human ALL

Methods of Calculating Material Coefficients

- **Method I** – Using idealised geometric parameters assuming constant CSA & L



- **Method II** – Using real geometry derived from FE model



$$\text{* Percentage difference (\%)} = \frac{\sum\left(\frac{|error|}{experimental}\right)}{n} * 100\%$$

Conclusion

- The differences in the material properties between human and ovine ligaments should be borne in mind when making a transition from the ovine model to the human spine.
- A specimen-specific image-based approach needs to be applied to derive the elastic properties of the ligaments due to its non-uniform shape and cross-sectional area.

References

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