Experimental Search for Determinants of Ligament Health

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OBJECTIVE

Identify knee ligament characteristics that determine mechanical health.

- Use magnetic resonance imaging (MRI) to observe ligament structure and geometry.
- Conduct mechanical testing to quantify ligament health.
- Determine correlations between MRI data and mechanical testing results.

INTRODUCTION

Background Problem

- The Anterior Cruciate Ligament (ACL) is one of four ligaments that help stabilize the knee during movement.

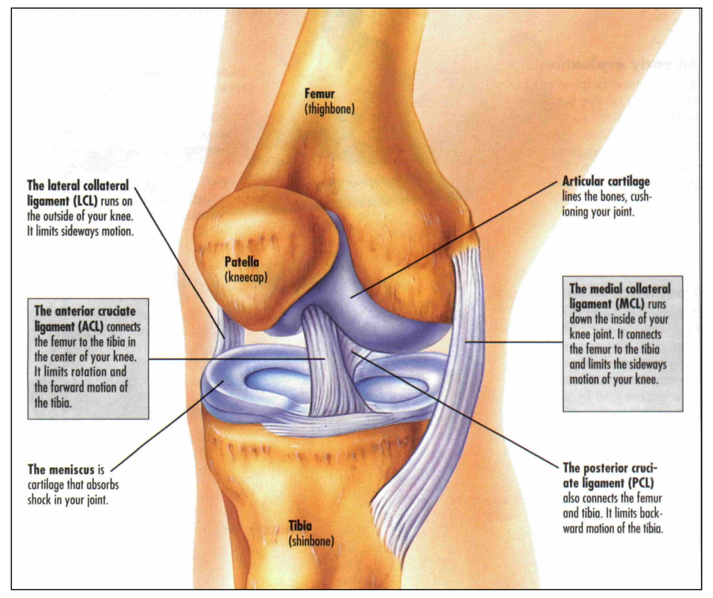


Figure 1: Knee Ligament Schematic [1]

- ACL injuries occur more than 200,000 times per year—through both contact and non-contact mechanisms [2].
- Identifying a relationship between MRI data and mechanical health can help medical professionals detect ligament injuries before tearing occurs.

Solution Approach

- Use porcine knees as analog to humans.
- Start with the Posterior Cruciate Ligament (PCL) for its large size and ease of measurement.
- Generate correlations by comparing MRI data to mechanical testing results.

METHODS

1. MRI Examination

- Use proton density sequences
- Measure PCL geometry
  - Length
  - Cross-Sectional Area

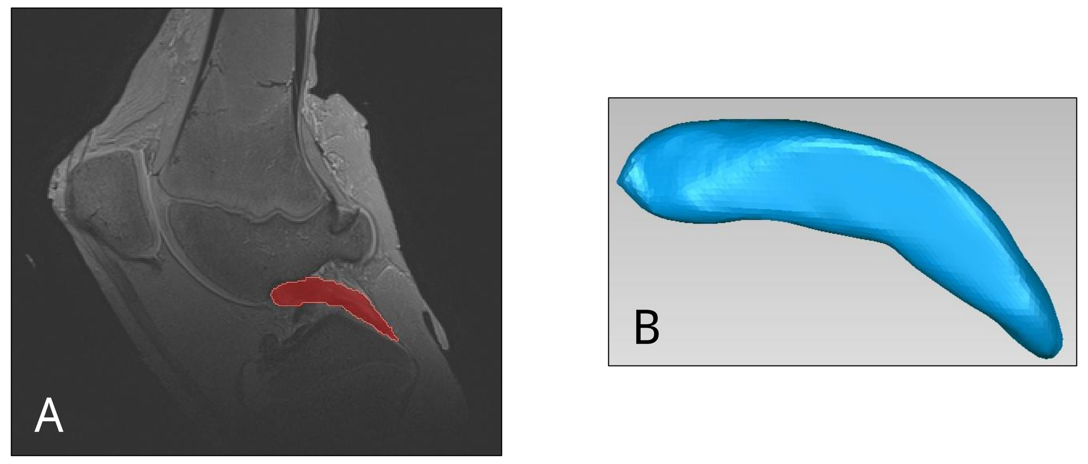


Figure 2: (A) Sagittal MRI of Porcine Knee, (B) Rendering of PCL

2. Mechanical Testing Setup

- Utilize load frame and potting fixtures to conduct tensile test on PCL
- Measure elasticity by calculating slope of stress-strain curve

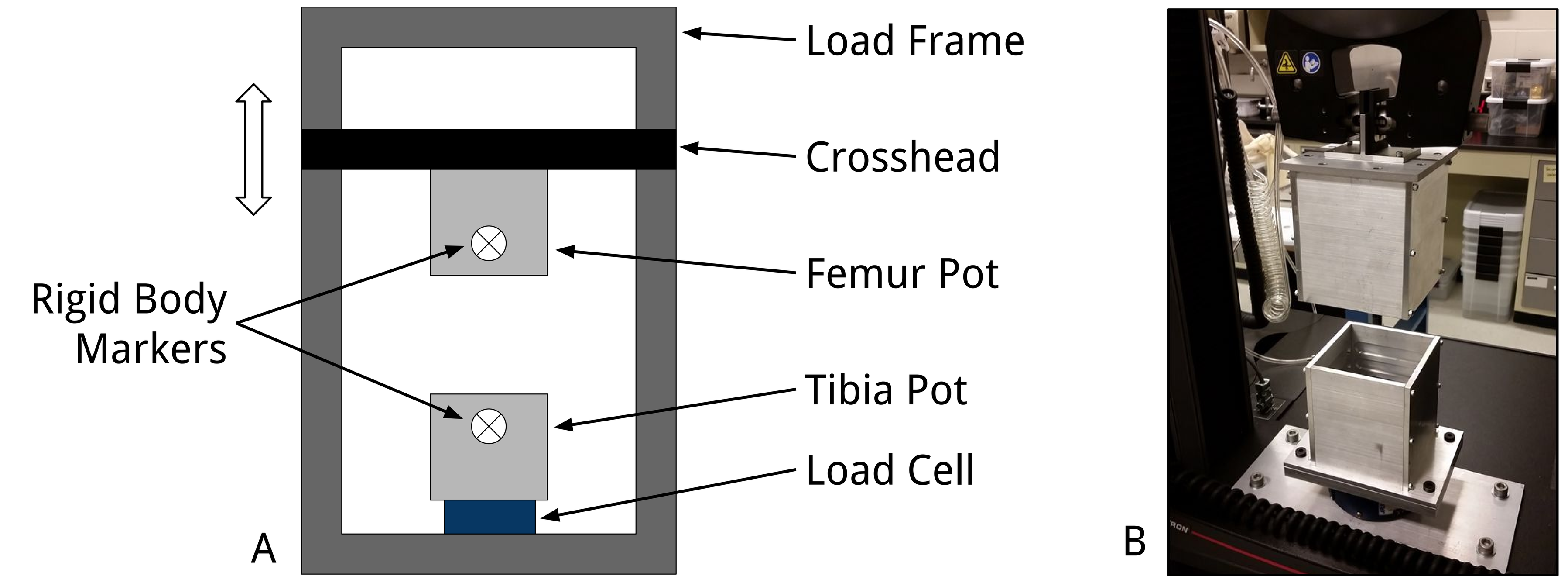


Figure 3: (A) Load Frame Schematic, (B) Load Frame Equipped with Fixtures

3. Experimentation

- Dissect knee to leave femur-PCL-tibia complex intact and and pot bones into test fixtures
- Run test using load frame, force/torque sensor, and motion capture system

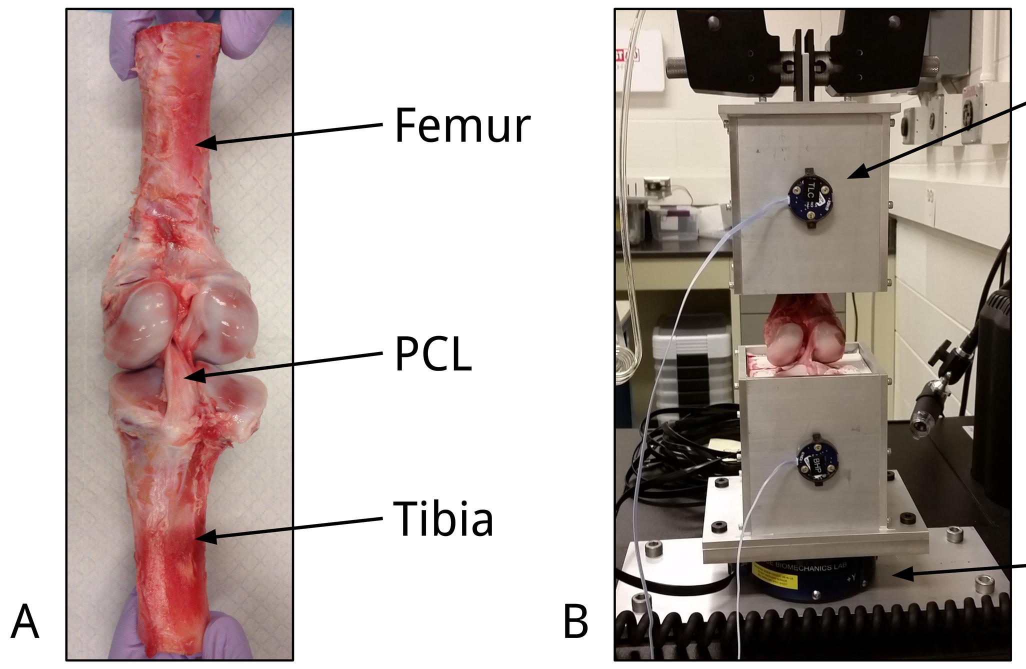


Figure 4: (A) Posterior View of Dissected Pig Knee (B) Experimental Setup with Potted Knee

Optotrak Camera System
- Rigid body markers track location of femur pot and tibia pot
- Imaginary markers associate location of PCL insertion sites
- Three-camera system tracks 3D motion over time

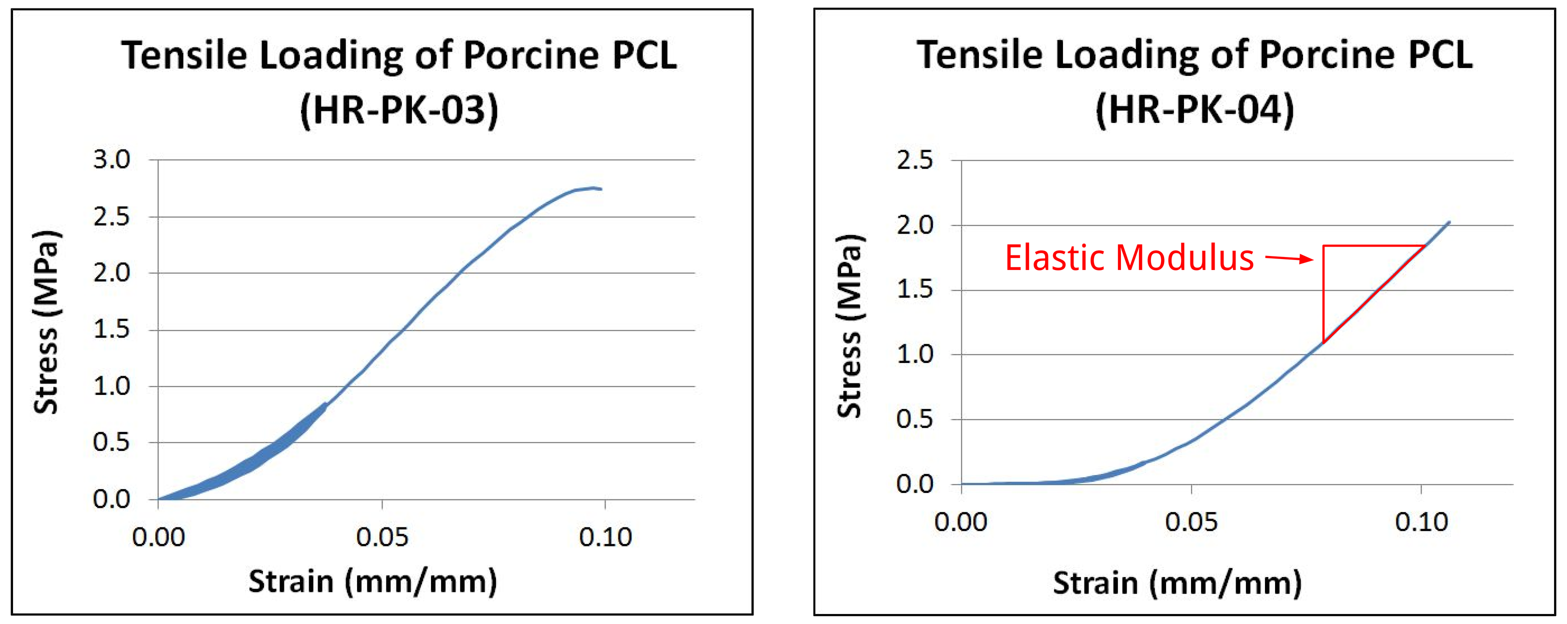
Force / Torque Sensor
- Measures force in x, y, and z
  - Identifies overall load on PCL
- Measures torque about x, y, and z
  - Detects any non-axial loads

Instron Load Frame
- Applies tensile extension:
  - Precycles 5 times to exercise ligament
  - Extends ligament until elastic limit to avoid plastic deformation

RESULTS / ANALYSIS

Table 1: Geometry and Performance Data for Two PCL Specimens

	Initial Length	Cross-Sectional Area	Stiffness	Elastic Modulus
	mm	mm^2	N/mm	MPa
HR-PK-03	40.36	38.54	38.11	39.91
HR-PK-04	37.81	40.81	36.09	33.44



- Samples yielded similar stiffness values
- Samples yielded somewhat different elasticity values
- Error in dimensional measurement explains variability in elasticity
  - 1 mm of uncertainty in width, thickness, and length yields an uncertainty of 8.4 MPa in elastic modulus
- Elastic limit identified
  - Yield Stress: 2.0 MPa (80 N load)
  - Yield Strain: 0.07 mm/mm (2.8 mm extension)

CONCLUSIONS / FUTURE WORK

- Ligament geometry measurement is critical and should be improved
- Future work includes inspection of collagen fiber microstructure via Second-Harmonic Generation (SHG) imaging

REFERENCES

[1] http://sportskneetherapy.com/acl-rehab-video-everything-you-need-to-know-about-your-torn-acl/

[2] "Anterior Cruciate Ligament Injury (ACL)." *Department of Orthopaedic Surgery.* University of California, San Francisco, n.d. Web. 02 Dec. 2015.

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