ISAKOS CONGRESS 2025 | MUNICH GERMANY June 8–11

NorthShore University HealthSystem

Axial and Torsional Loading: Comparative Effects on ACL Integrity in Porcine Adolescents

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Faculty Disclosure Information

- Nothing to disclose

Introduction

- ACL (Anterior Cruciate Ligament) injuries increasing in adolescents aged 10–13 due to high-impact activities.
- Majority (~75%) of ACL injuries result from non-contact, often involving torsional loads.
- Scarcity of adolescent cadaveric specimens limits biomechanical studies.
- Porcine knees are anatomically and biomechanically similar to human knees.

Hypothesis and Aim

- Evaluate biomechanical behaviour of adolescent porcine ACL under axial and torsional loads.
- Determine ACL deformation (strain), stiffness, and load-to-failure.
- Hypothesis: Torsional loading has greater detrimental effects than axial loading.

Methods

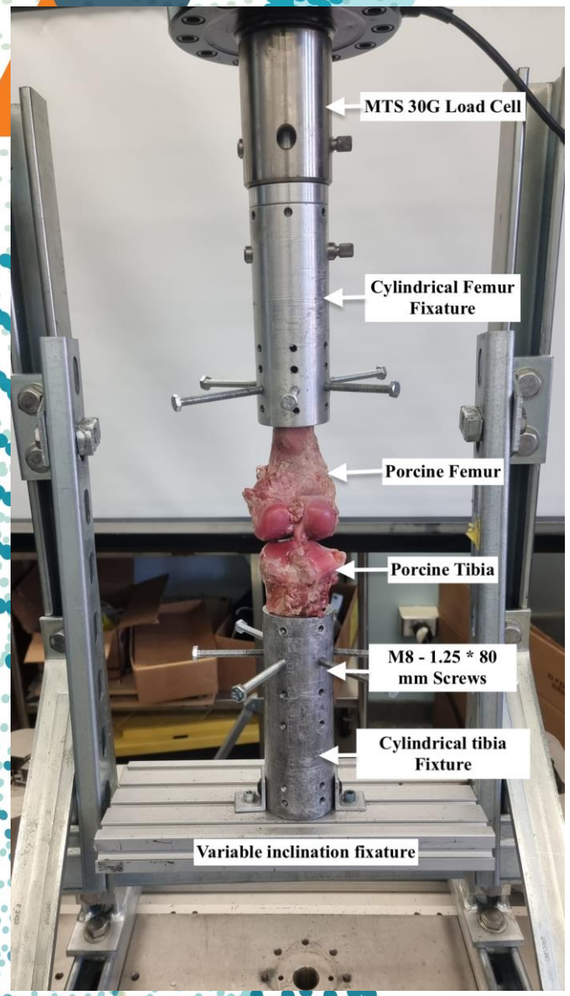
Specimen Preparation

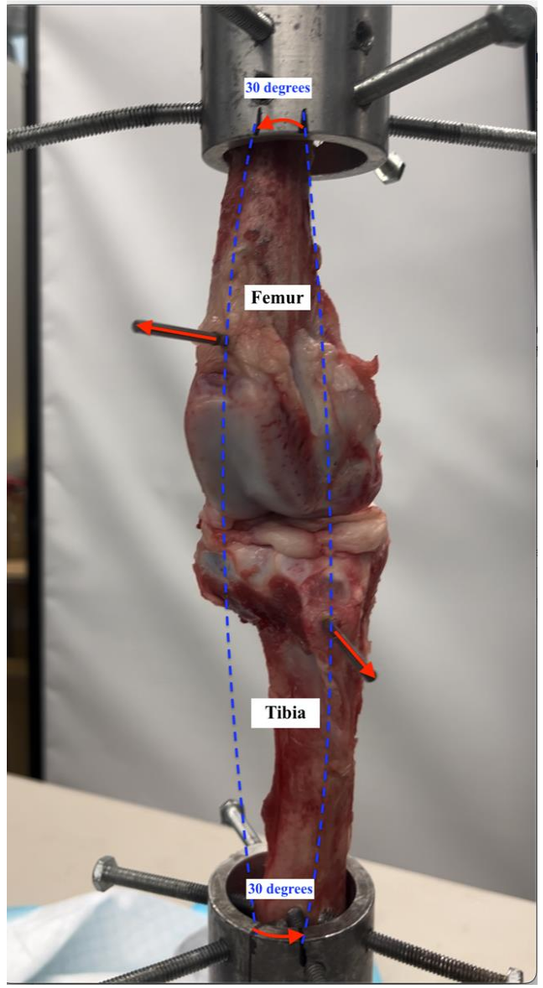
- Breed: Yorkshire
- The average age was 3 months (10 weeks to 15 weeks), which is the age of sexual maturity for the pig. This age resonates with human sexual maturity age, the adolescent (13-15 years) age range.
- Average weight: 90 pounds (60 – 120 Pounds)
- None of the knee samples showed patellar instability, knee injuries, cartilage damage, or arthritic deformities.

Dissection

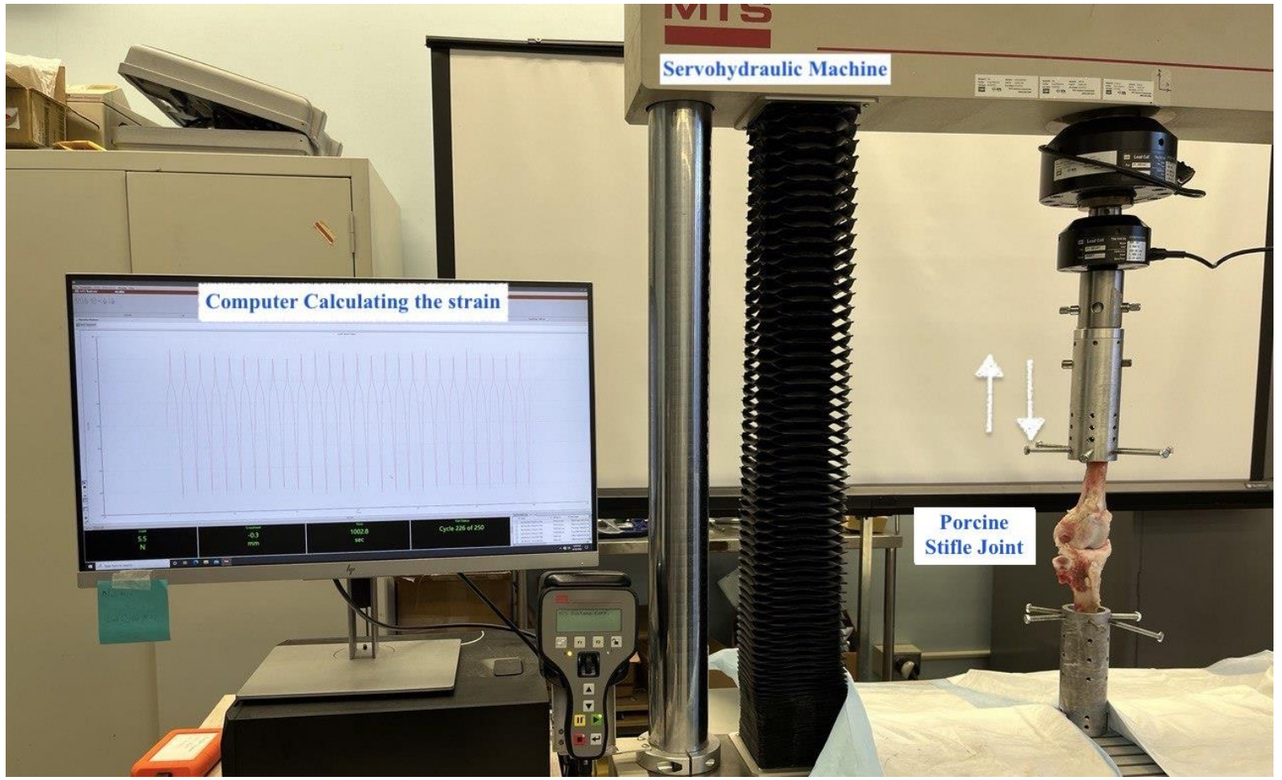
- All samples were stored at -22°C in the deep freezer after the procurement and thawed for 24 hours at room temperature before using it for the experiment.
- The dissection of the stifle joints was performed, removing all tissues except for the ACL, meniscus, and the ligaments that stabilize the meniscus.

Biomechanical Testing





The prepared samples were placed in a servo-hydraulic material testing machine (MTS, Eden Prairie/MN, USA), aligning the tibia's longitudinal axis with the load sensor at a 20-degree angle between the femur and tibia.



Three Groups

Control

10 Specimens underwent Load-to-Failure *without any cyclic load*

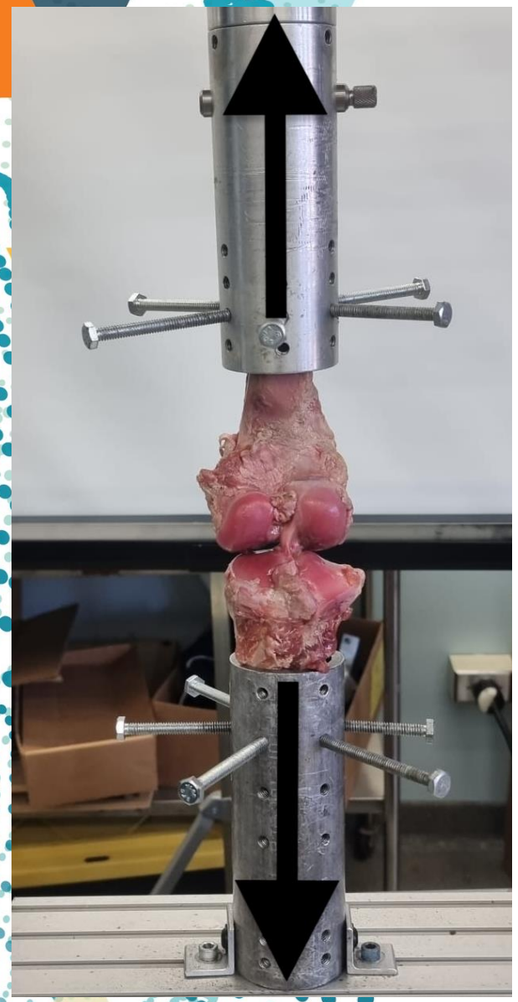
Experimental Group 1

10 Specimens underwent Axial load of 100 cycles at 520N (5 times BW of porcine) and then subject to load to failure

Experimental Group 2

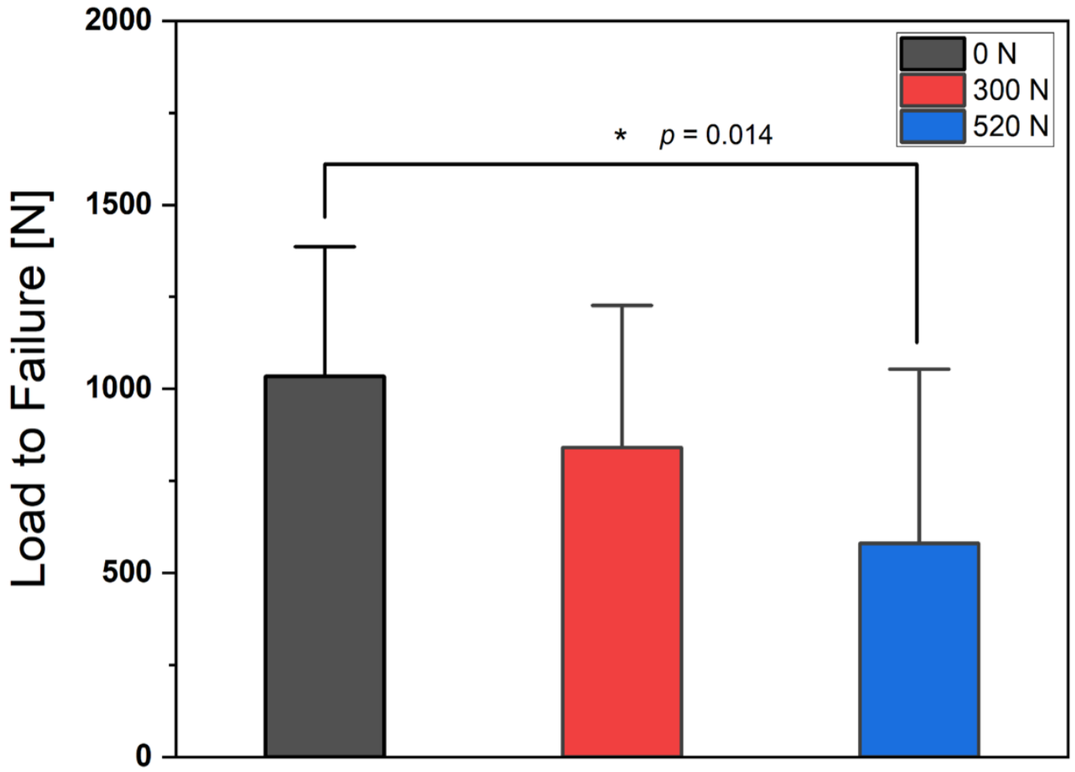
10 Specimens underwent 30 degrees Torsion load of 100 cycles at 520N (5 times BW of porcine) and then subject to load to failure

Load to failure



- Samples were subjected to unidirectional tensile loading at 1 mm/sec
- Data on load and displacement were captured at a frequency of 100 Hz
- Ultimate force exerted was directly measured from the load–displacement curves
- Comprehensive anatomical evaluation of the torn ACL was performed following the test

Result



- Control group had highest load-to-failure (Avg: 1034.7 N).
- Axial load group reduced to Avg. 829.8 N,
- Torsion load group further reduced to Avg 486.0 N.

- ANOVA yielded statistically significant differences in the maximum failure force among the various loading conditions ($p = 0.018$)

- Post hoc analyses using the Tukey HSD test showed a statistically significant difference between the control and 520N loading groups ($p = 0.014$)

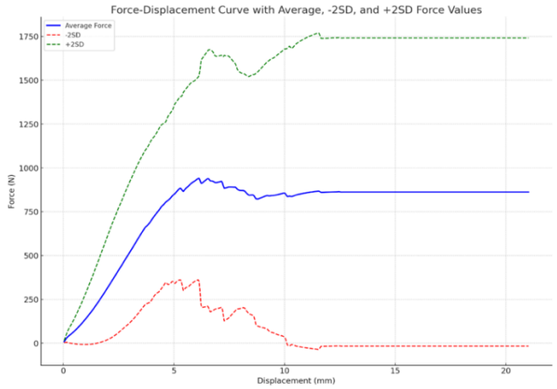
Failure patterns

- Axial loads caused ACL tibial insertion avulsion; torsional loads caused femoral growth plate separation.

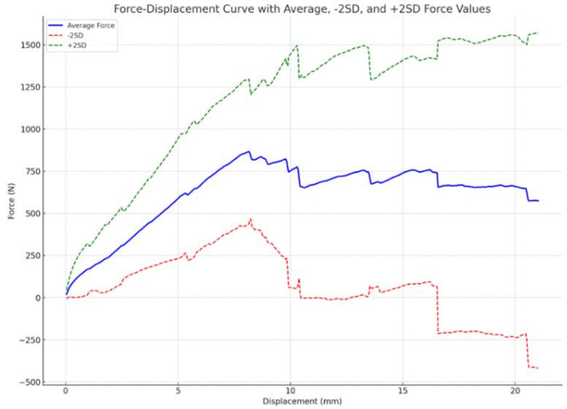
Stiffness

Torsional loading induced greater ACL strain and structural damage compared to axial loading.

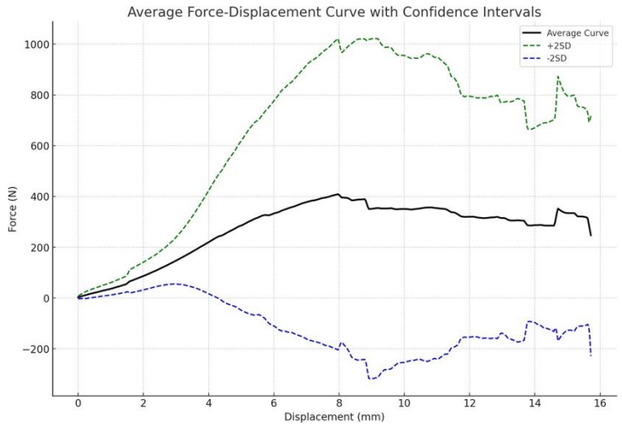
	0 cycle (control)	100 cycles with Axial 520N Load	100 cycles with Torsion 520N Load
Avg. stiffness (N/mm)	152.46 N/mm	86.90 N/mm	48.78 N/mm
SD	82.20 N/mm	72.53 N/mm	SD = 34.78
P value (T-test)	0.075 (Control vs. 100 cycles with Axial 520N Load)		
		0.032 (100 cycles with Axial 520N vs Torsion 520N Loads)	
	0.0012 (Control vs 100 cycles with Torsion 520N Load)		



Control



Axial Loads



Torsion Loads

Discussion

- Torsional loads equally or more harmful than axial loads for ACL.
- Results confirm importance of considering torsion in ACL injury prevention.
- Growth plates weaker than ligaments, reflecting pediatric injury patterns. Adolescent porcine model highly relevant to human ACL biomechanics studies.
- Porcine model validated as reliable for studying adolescent ACL injuries.
- Emphasizes the need for ACL injury prevention strategies focusing on: 1. Torsional load reduction 2. Neuromuscular conditioning 3. Proper recovery periods

Conclusions & Future Directions

- Adolescent porcine ACL effectively models human adolescent ACL biomechanics.
- Significant stiffness reduction under torsional loading highlights injury mechanisms.
- Supports further studies on preventive interventions and rehabilitation protocols.
- Future research: impact of neuromuscular training, sex differences, and protective equipment.

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