Preliminary Material Properties of Human Pelvic Cortical Bone

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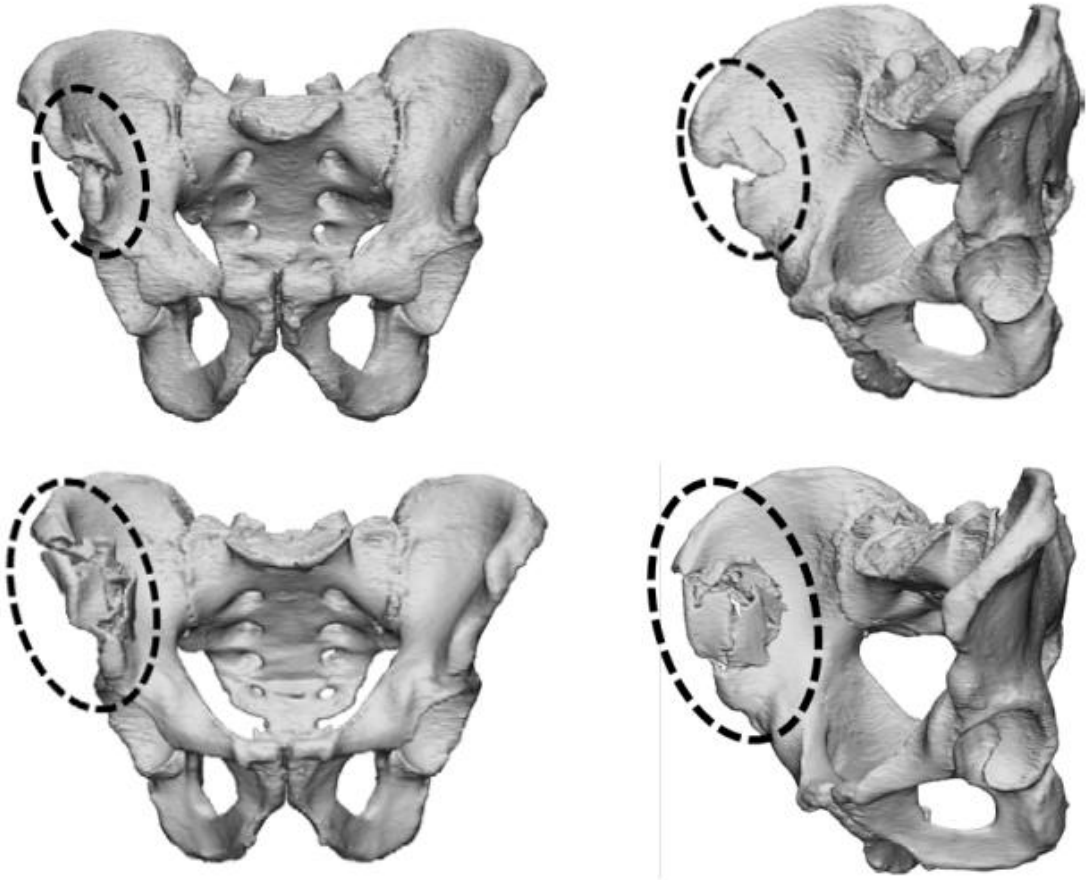
VIRGINIA TECH TRANSPORTATION INSTITUTE

THE OHIO STATE UNIVERSITY

Motivation

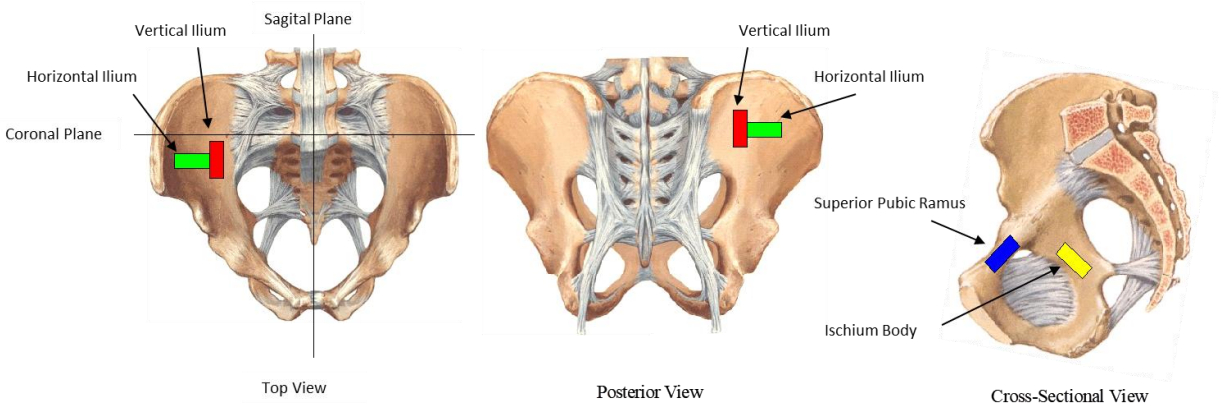
- Motor vehicle collisions are currently a common cause of pelvis fracture (Pereira et al., 2017; Ghosh et al., 2019)
- Increased autonomy in vehicles is expected to increase prevalence of:
  - Intersection crashes (Östling et al., 2019)
  - Reclined occupants, more aggressive belt systems
- These scenarios lead to increased lateral and frontal loading to the pelvis
- Need accurate material properties for HBMs to accurately predict injury for new loading scenarios and restraints

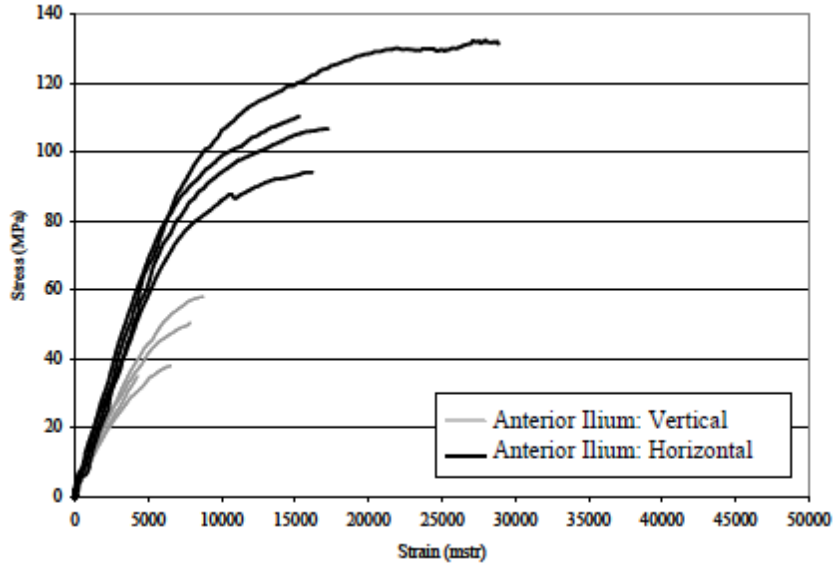


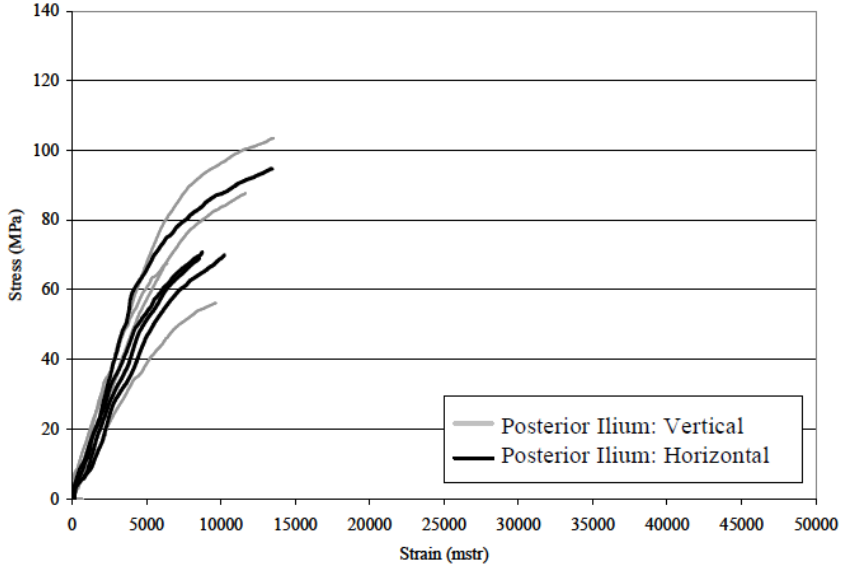
Richardson et al., 2020, IRCOBI Proceedings.

Previous Study: Kemper et al. (2008)

- Tension testing of dog-bone coupons from four locations
  - Subjects: 4 males, 41-75 years
- Material response varied, likely depending on coupon orientation relative to osteons
  - Anterior ilium material properties significantly differed between coupon orientations
  - Posterior ilium did not differ between coupon orientations
  - Unknown osteon orientation





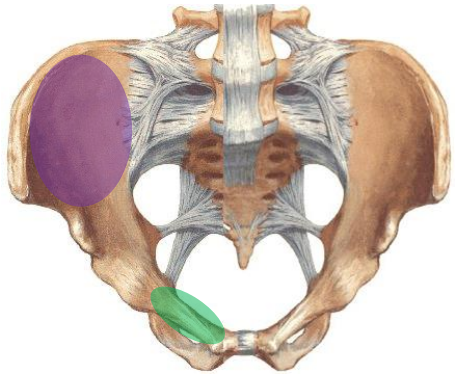


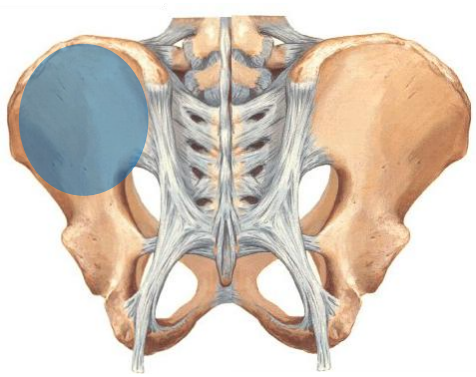
Objectives

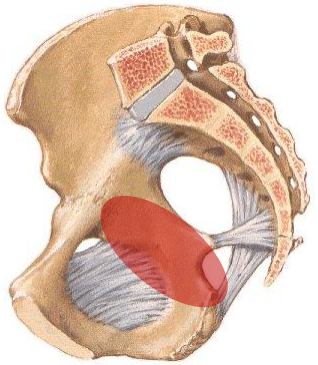
Investigate the relationship between pelvic cortical bone material properties and microstructure

1. Quantify the tensile and compressive material properties of pelvis cortical bone

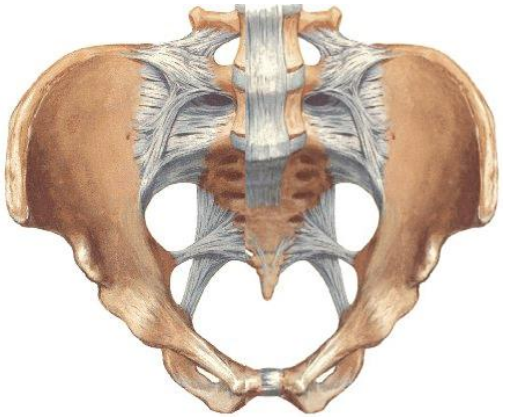
2. Characterize the microstructure of pelvis samples, including osteon orientation, using high-resolution microCT imaging





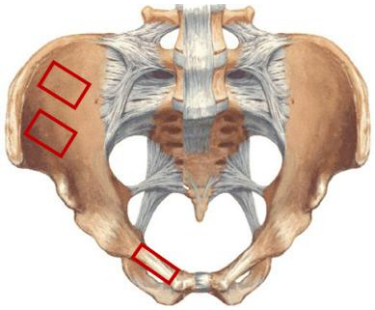


Project Workflow



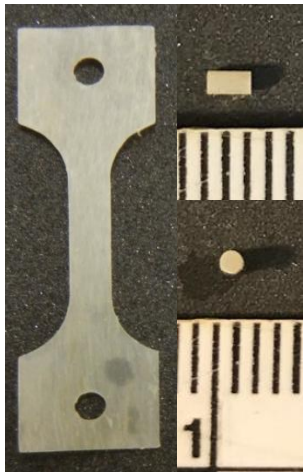
n = 6

Microstructural Imaging

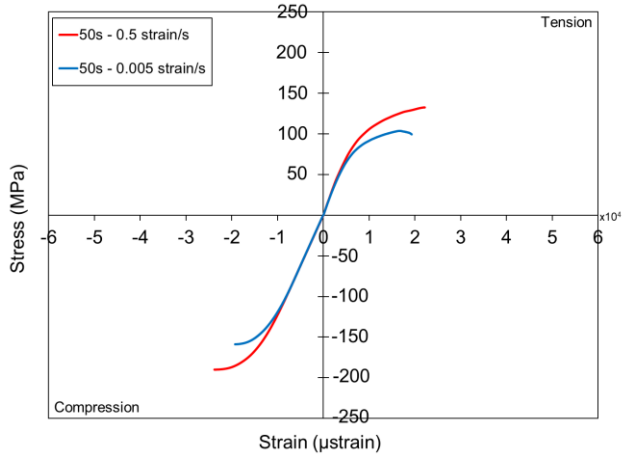


Sample Orientation & Microstructural Properties

Sample Fabrication Methodology



Material Testing



Material Properties

Confirmatory Imaging

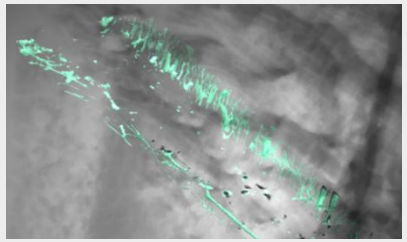
Tension Samples

Preliminary Material & Microstructural Property Analyses

Publication of Results

2025
RCCADS Workshop

Osteon
Orientation



2025
NHTSA Biomechanics Workshop

Compression
Material Properties

2026
RCCADS Workshop

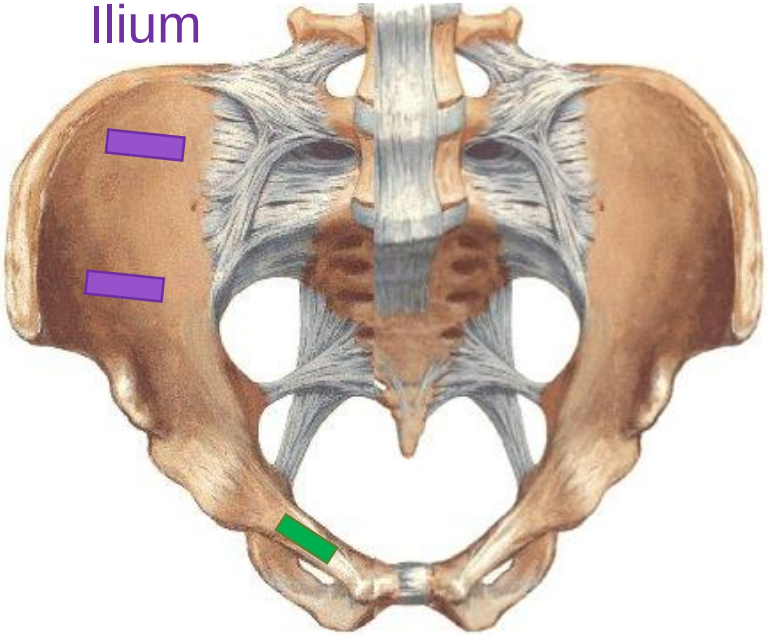
Tension Material Properties
Post-Test Imaging

2026
IRCOBI Conference

Study Overview
All Results

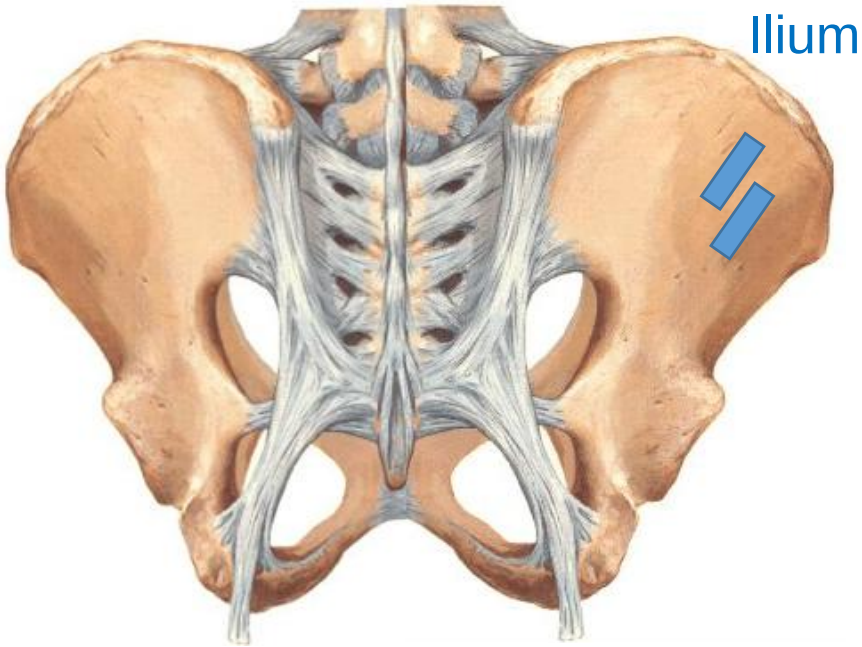
Pelvis Sectioning & Osteon Orientation

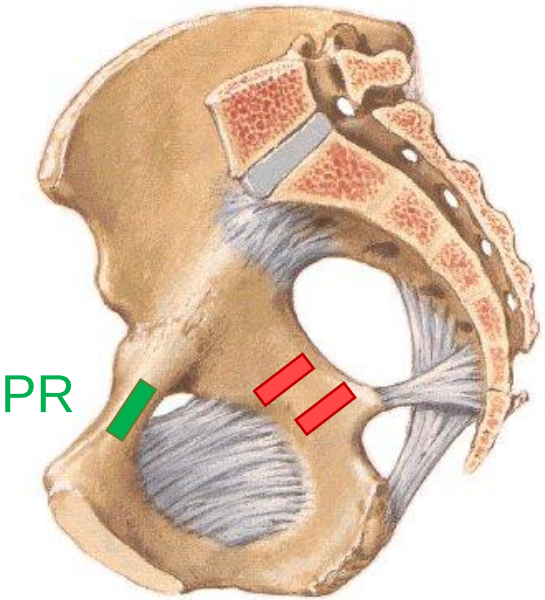
Anterior Ilium



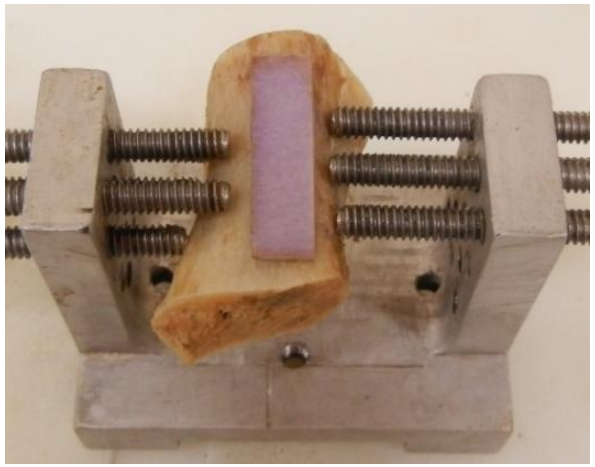
Superior Pubic Ramus (SPR)

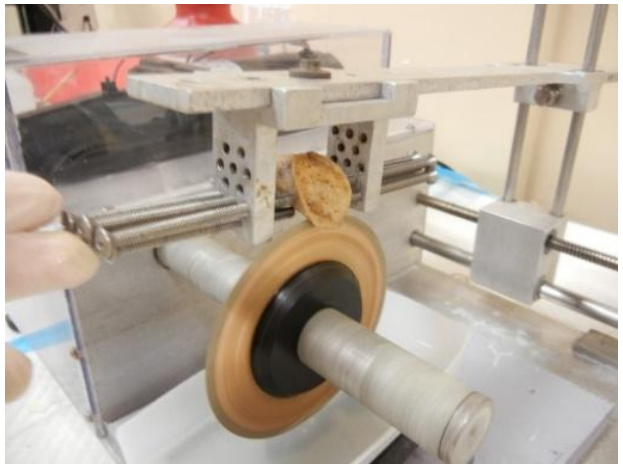
Posterior Ilium

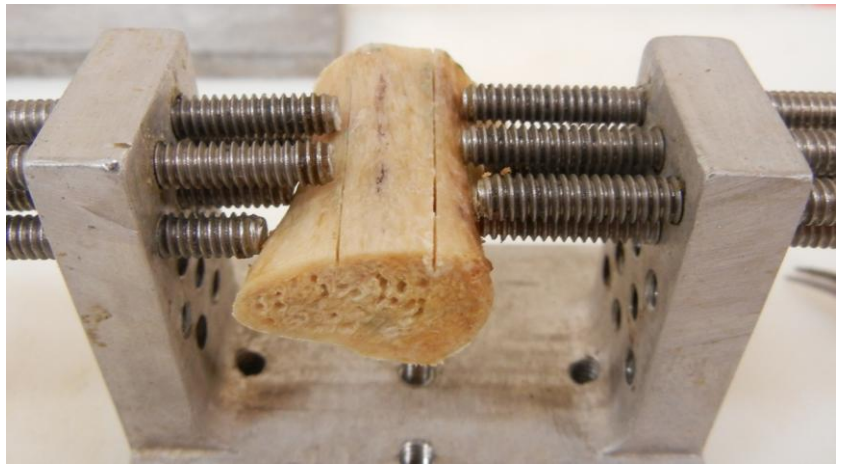


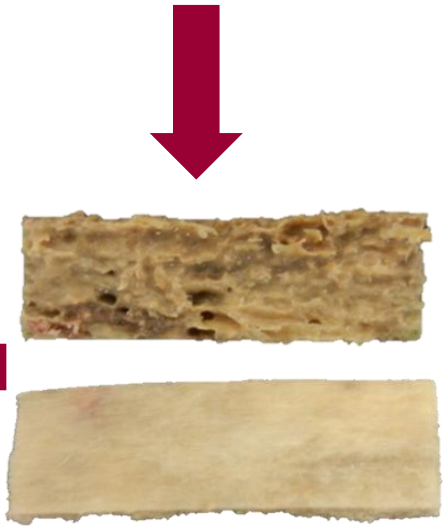


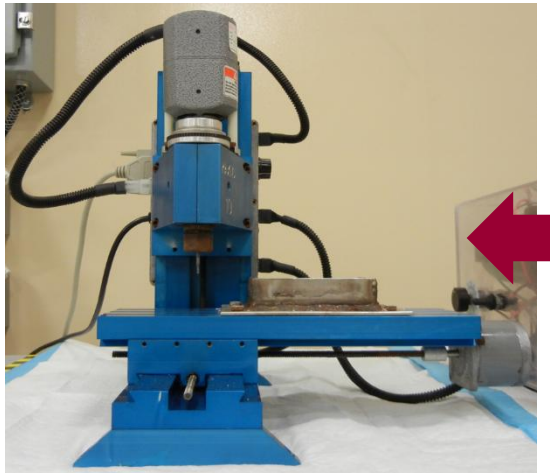
Coupon Fabrication

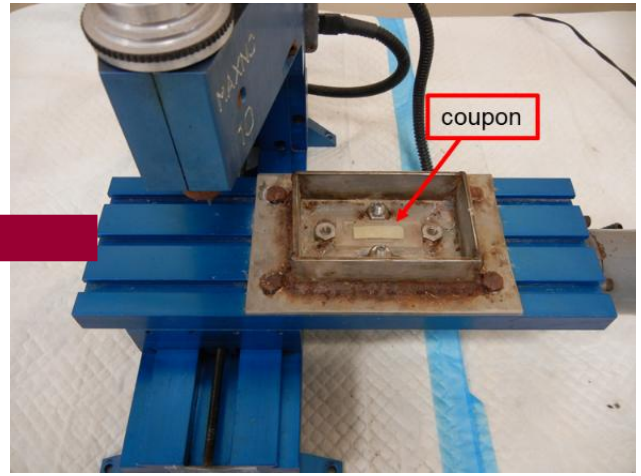










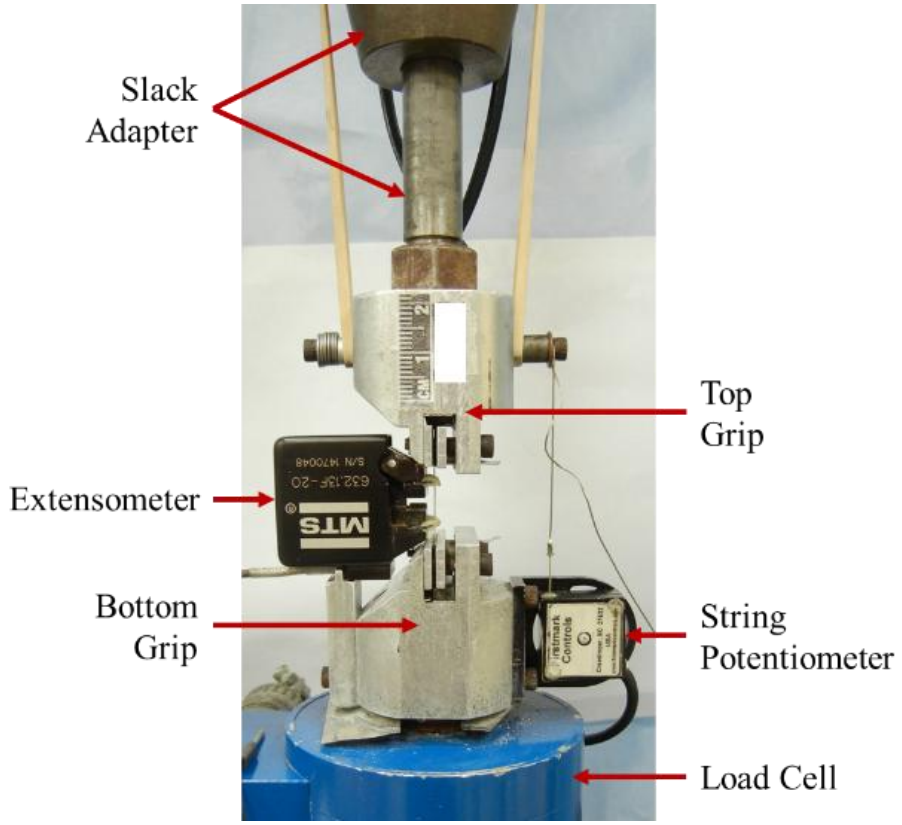


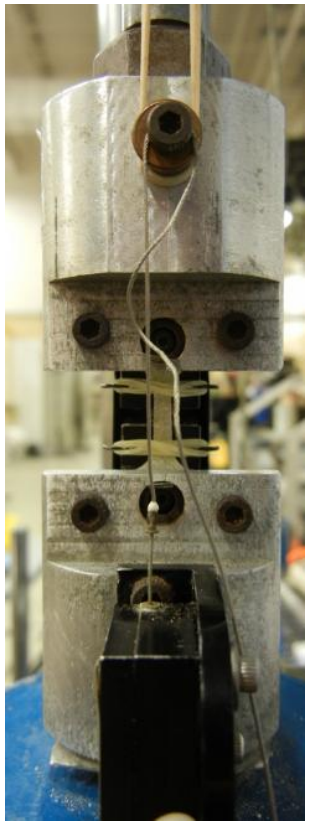
Final Coupon

Tension Testing

- Target rate: 0.5 strain/s

- Parameters of interest:
  - Modulus
  - Yield Stress/Strain
  - Ultimate Stress/Strain
  - Strain Energy Density (SED)

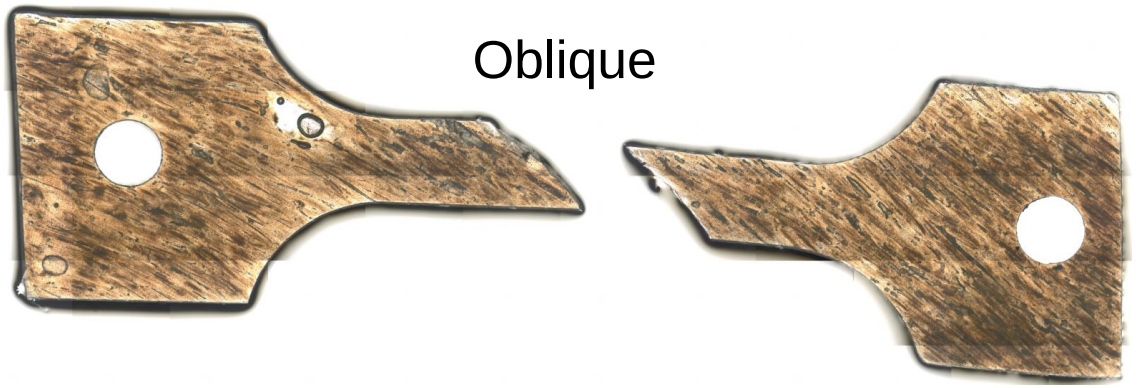


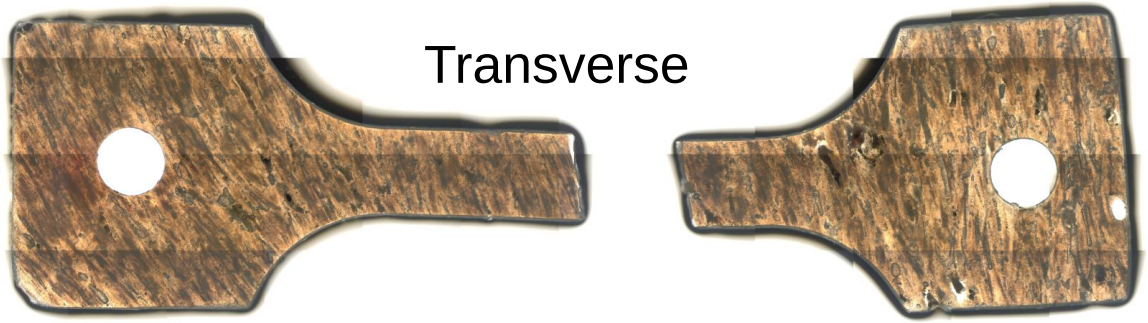


Post-Test Imaging

- Bright field microscopy
  - Dried samples immersed in xylene
  - Imaged without mounting at 4 times objective magnification

- Binned based on qualitative osteon orientation near fracture
  - Longitudinal (Aligned)
  - Oblique
  - Transverse
  - Unknown





Test Matrix

Pelvis #	Sex	Age	Ant. Ilium	Post. Ilium	Ischium	SPR
1	F	80	1	1	2	1
2	F	90	1	0	1	1
3	F	58	1	1	1	1
4	F	59	1	0	1	1
5	F	59	1	1	0	1
6	F	68	1	1	1	0

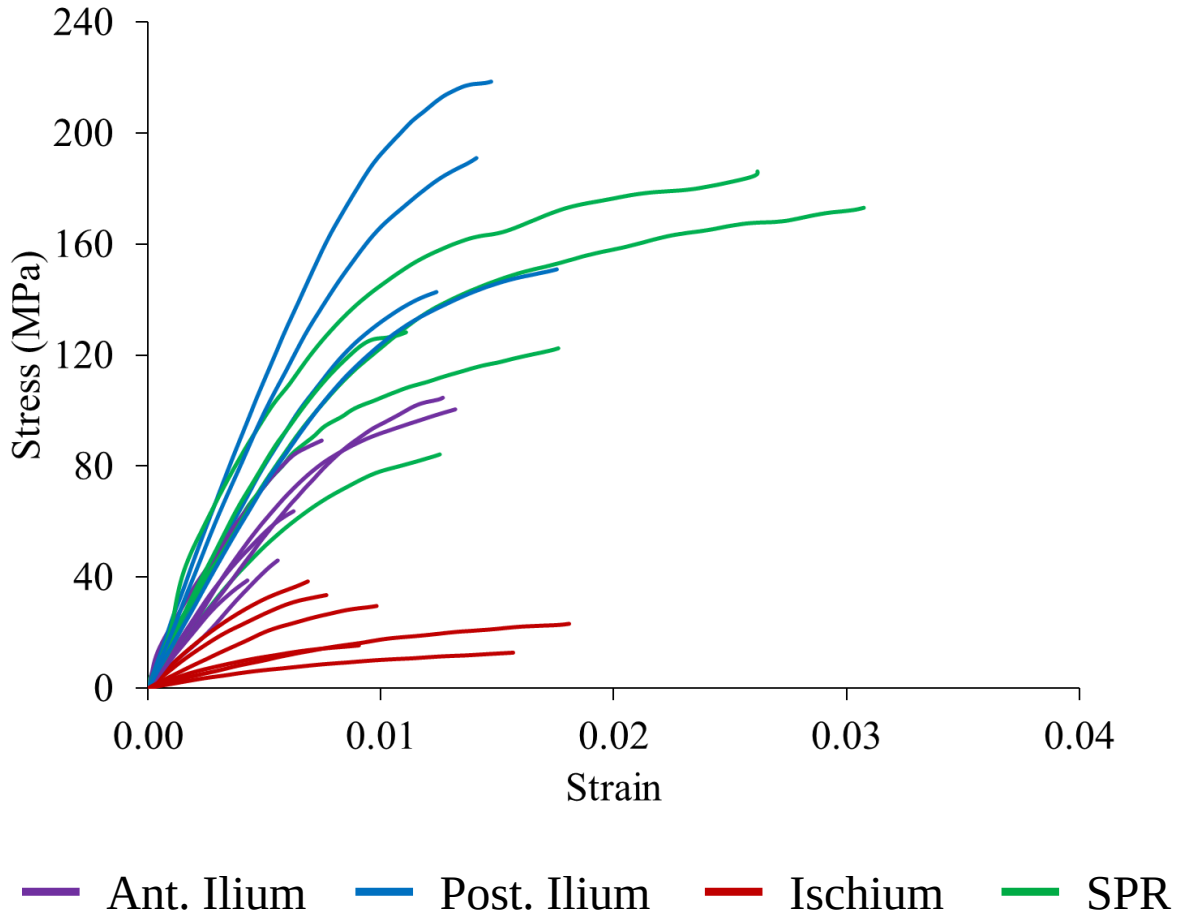
Total successful tests: 31

Tension Material Properties

ANOVA
Regional Differences

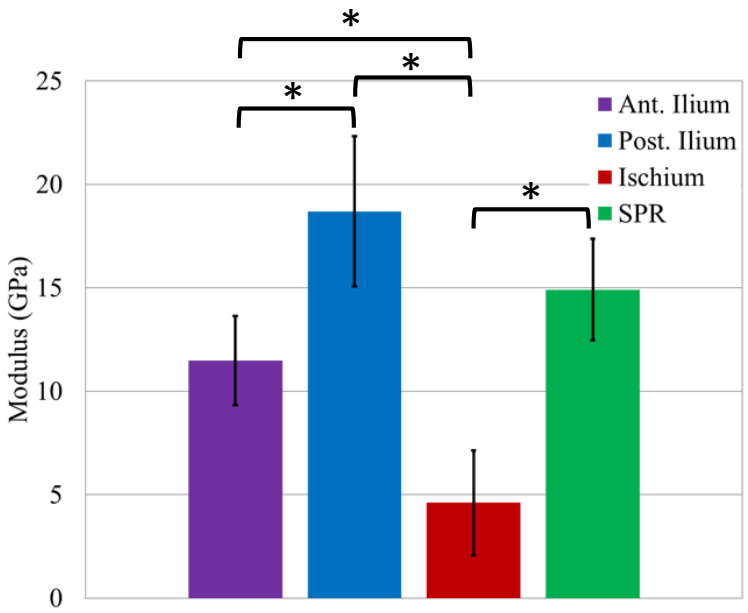
Material Property	p-value
Modulus	**<0.0001**
Yield Stress	**<0.0001**
Yield Strain	0.0541
Ultimate Stress	**<0.0001**
Ultimate Strain	**0.0129**
SED	**0.0035**

Stress-Strain Curves
All Pelves

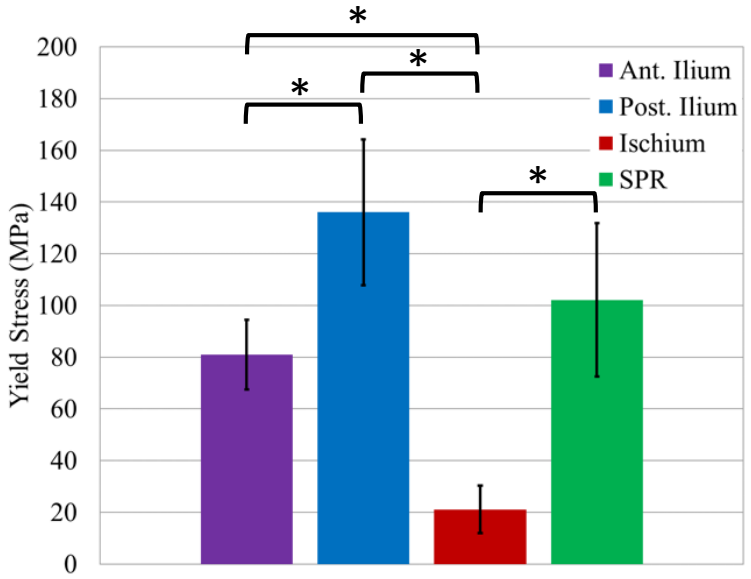


Regional Differences

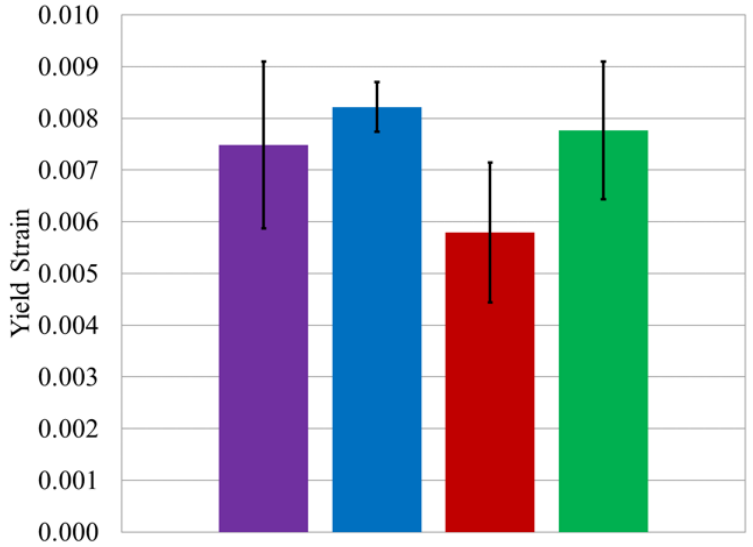
Modulus



Yield Stress



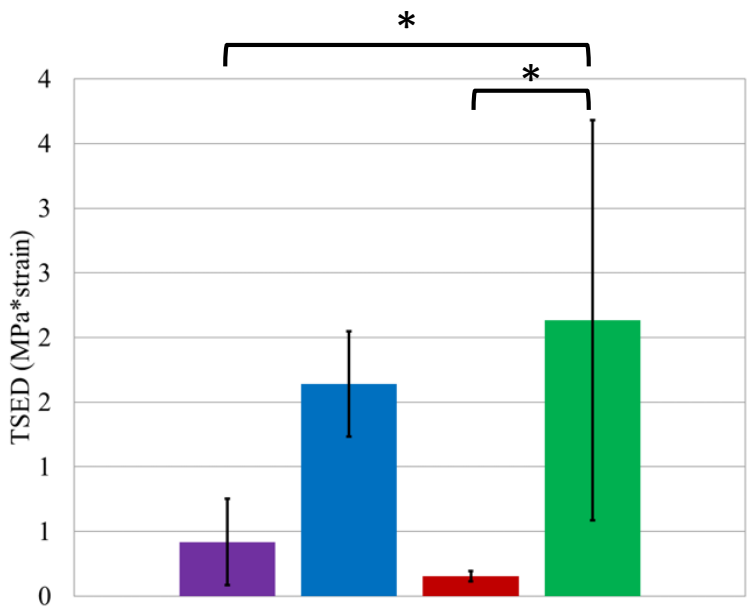
Yield Strain



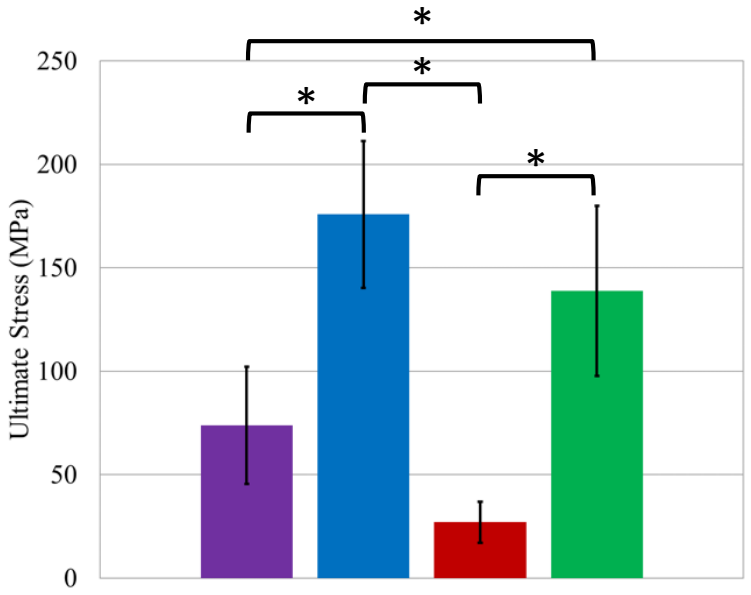
Ant. Ilium Post. Ilium Ischium SPR

Regional Differences

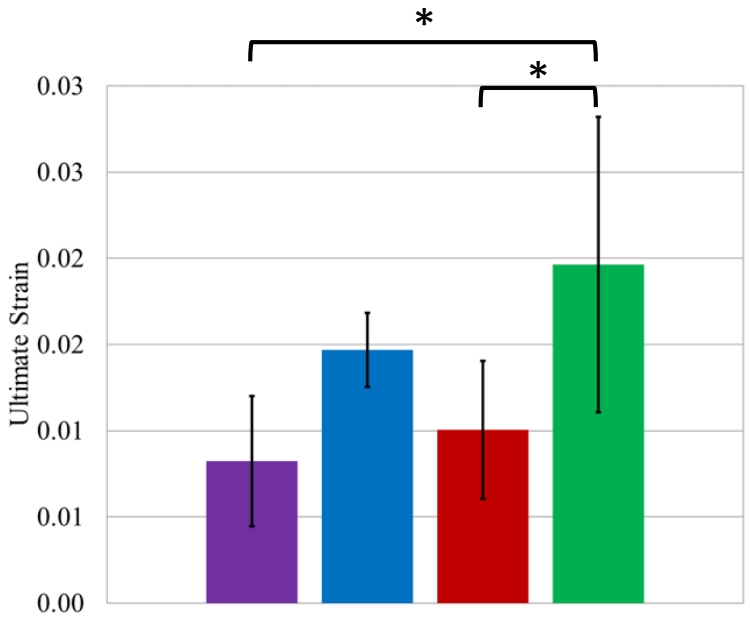
SED



Ultimate Stress



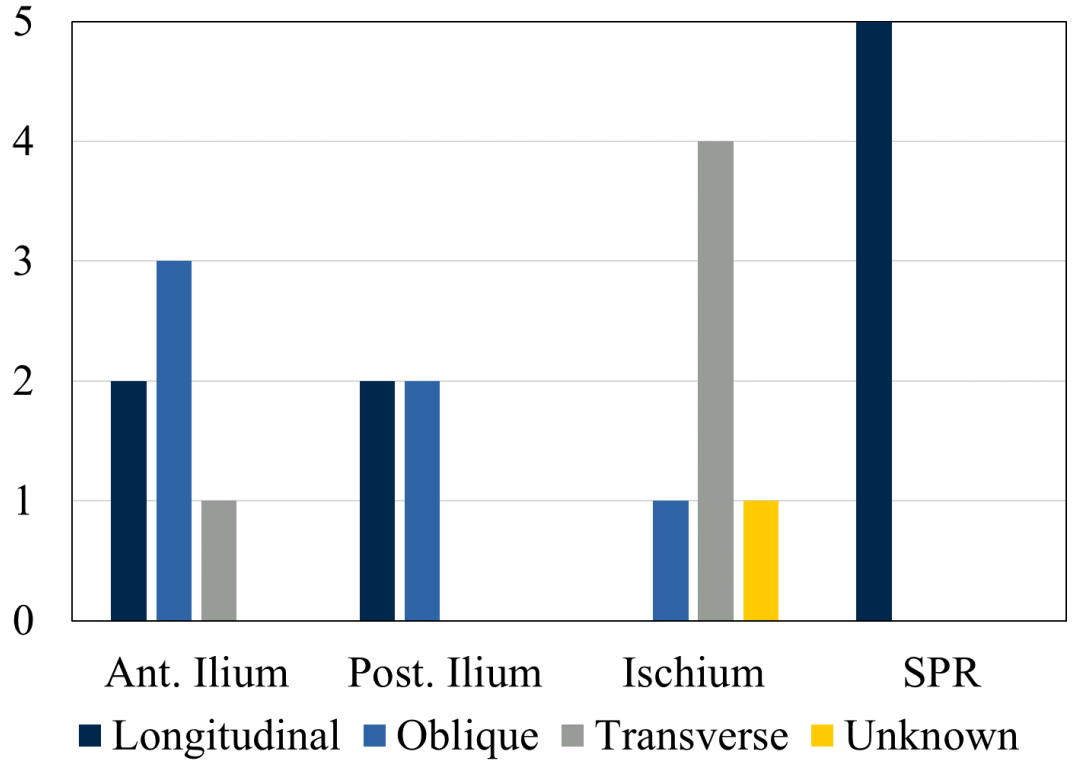
Ultimate Strain



Ant. Ilium Post. Ilium Ischium SPR

Post-Test Osteon Orientation

- SPR coupons were all aligned
- Ischium coupons were least aligned
- Ilium coupons were mixed in orientation
- Variation in osteon orientations were observed within coupons
  - Orientation was determined at point of failure



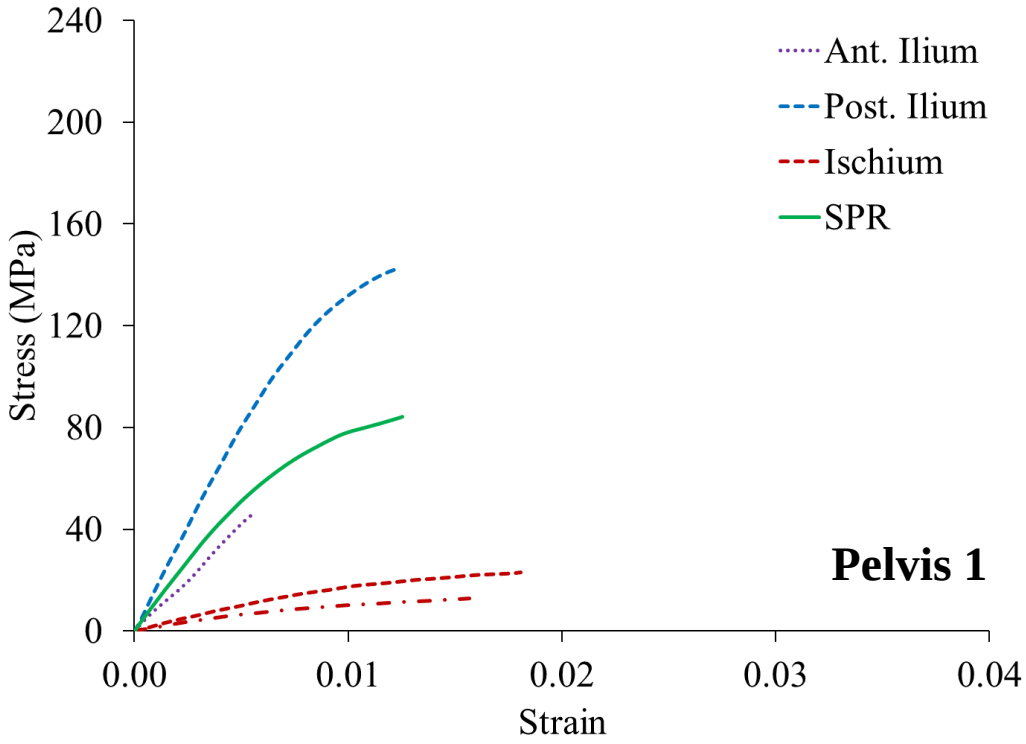
Effect of Orientation on Material Properties

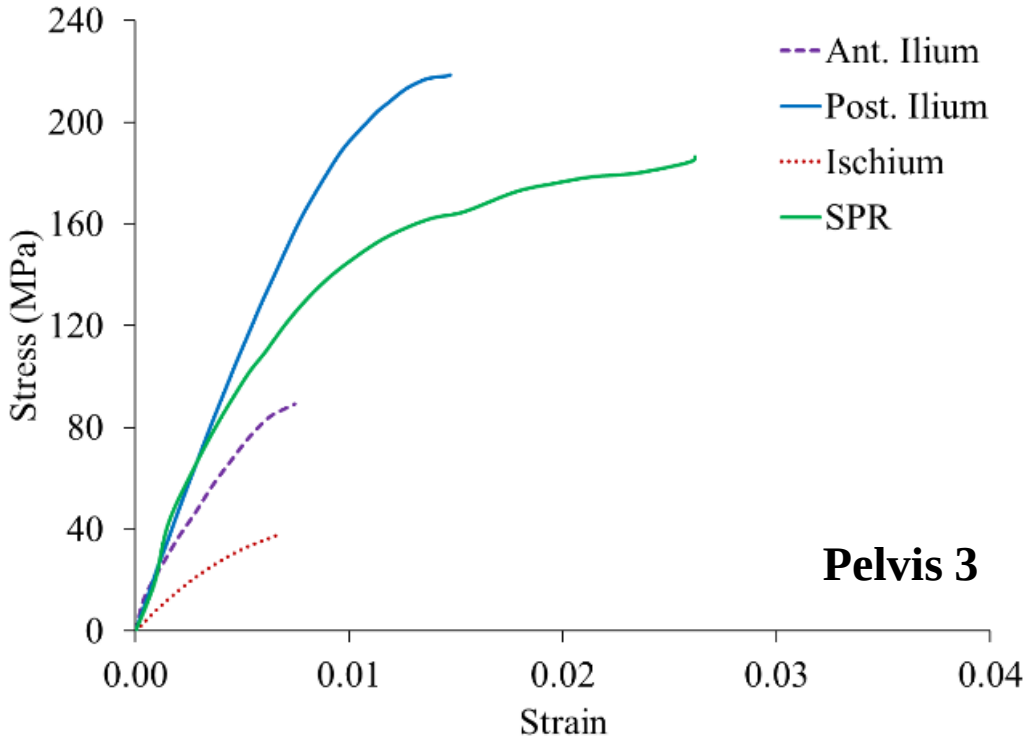
- ANOVA evaluating orientation
  - Each material property evaluated separately
  - Tukey HSD to evaluate differences between orientations
- Results
  - Longitudinal (aligned) material properties were significantly greater than transverse
  - Fewer differences between oblique and other alignments

Material Property	ANOVA	Longitudinal > Oblique	Oblique > Transverse	Longitudinal > Transverse
Modulus	**0.0020**	0.1954	0.0746	**0.0014**
Yield Stress	**0.0023**	0.2323	0.0659	**0.0016**
Yield Strain	**0.0058**	0.7823	**0.0313**	**0.0047**
Ultimate Stress	**0.0008**	**0.0446**	0.1518	**0.0007**
Ultimate Strain	**0.0025**	0.1491	0.6346	**0.0275**
SED	**0.0109**	0.0720	0.6486	**0.0132**

Ischium material properties are likely underestimated due to osteon alignment

Effect of Orientation on Material Properties





Longitudinal Oblique Transverse Unknown

Material properties are likely influenced by osteon orientation, regional differences, and subject variability

Limitations

- Coupon misalignment with osteon direction, particularly for the ischium
  - Variation observed in post-test imaging
  - Pre-test imaging was simplified/limited
  - More detailed mapping of pelvis osteons is needed
- Other microstructural properties could be influencing observed material properties
- Limited sample
  - 6 pelves
  - All older females
  - A larger sample size encompassing more population variability is necessary

Summary

- Material property differences were observed between pelvic regions
  - Posterior ilium and SPR had greater material properties than the anterior ilium and ischium
  - Ischium had the least yield stress and ultimate stress
  - Ischium coupons were least aligned with the osteon direction

- Differences in material properties are likely influenced by
  - Osteon orientation
  - Other microstructural properties
  - Inter-subject & intra-subject variability

Acknowledgements

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