Development and Validation of a Human Pelvis Finite Element Model for Lateral Impacts

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Introduction

- ❖ The human pelvis is vulnerable to side panel intrusion during automotive collisions and military blasts (VBIEDs).
- ❖ Finite element (FE) models are a useful tool in evaluation of injurious biomechanics: quick turn around time, low cost, tissue level behavior.
- ❖ Injury predictive metrics related to lateral pelvis loading have been recently challenged (Petit et al. 2018).

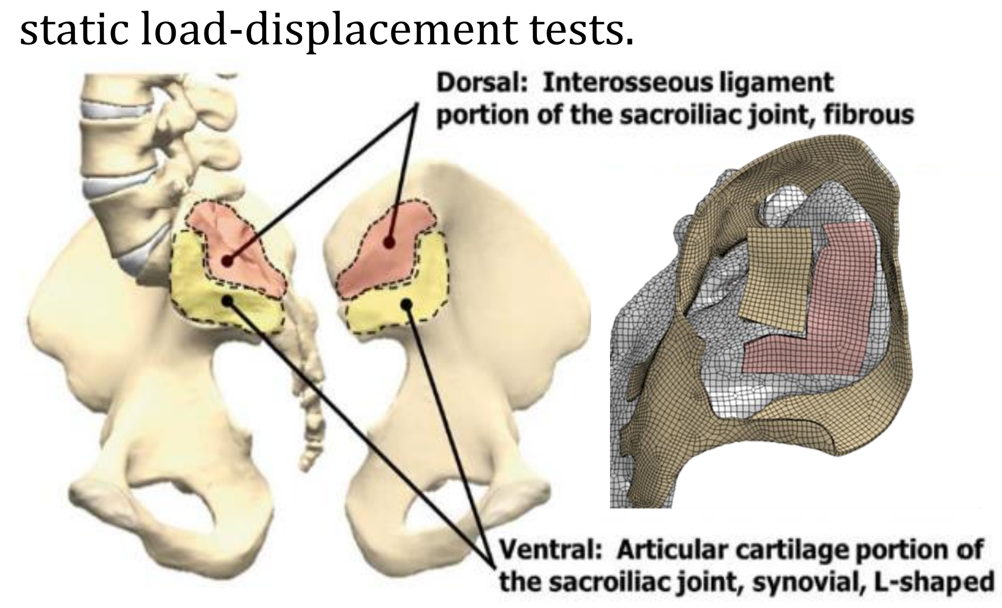
Objectives

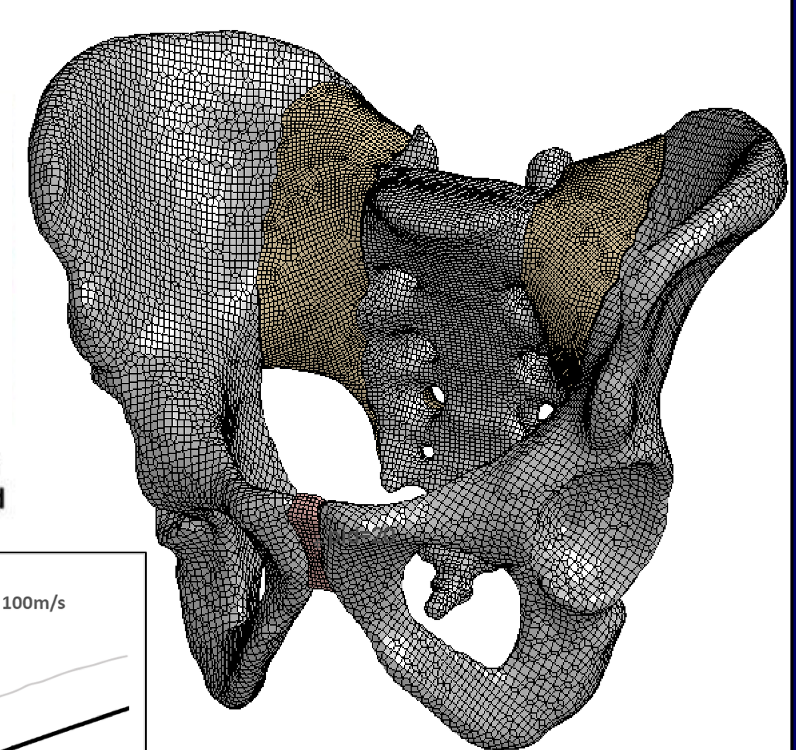
1. Develop and validate an injury predictive finite element model of the human pelvis for lateral impact, with special developmental focus on pelvic joints.
2. Perform and injury threshold analysis to determine fracture tolerances and define a consistent injury metric.

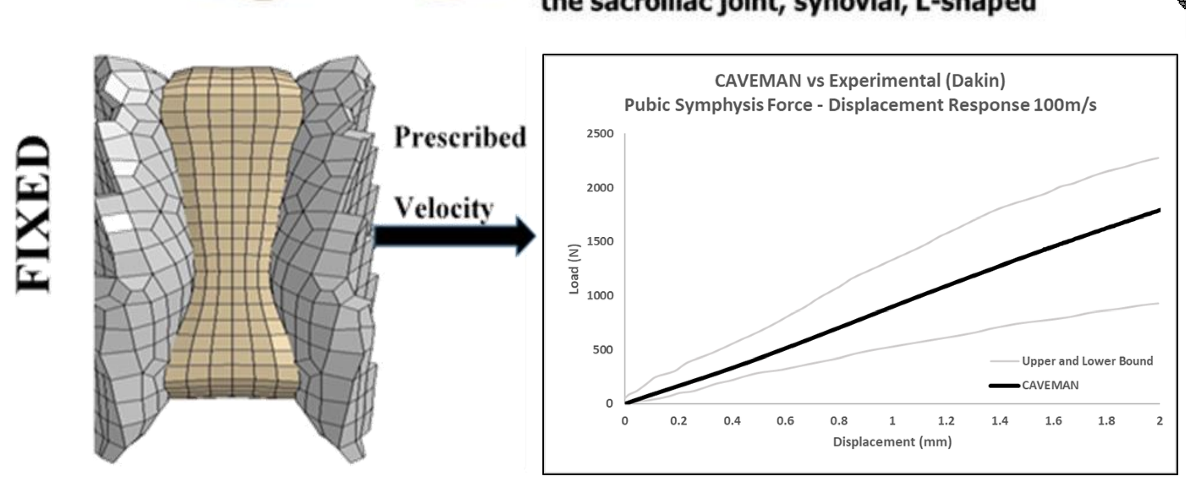
Methodology

CAVEMAN Pelvis Model Development

- ❖ Computational Anthropomorphic Virtual Experiment Man (CAVEMAN), a high-fidelity explicit finite element human body model developed by Corvid Technologies.
- ❖ The defleshed pelvis model consists of cortical and trabecular bone as well as the connective tissues comprising the pubic and sacroiliac joints, material properties have been taken from available literature and refined through optimization
- ❖ Pubic symphysis was individually validated against experimental tests performed on isolated pubic joints in dynamic and quasi-static loading.
- ❖ Sacroiliac joint ligaments (anterior, posterior, and interosseous) were virtually reconstructed to match coverage areas reported in literature and properties tuned to static load-displacement tests.

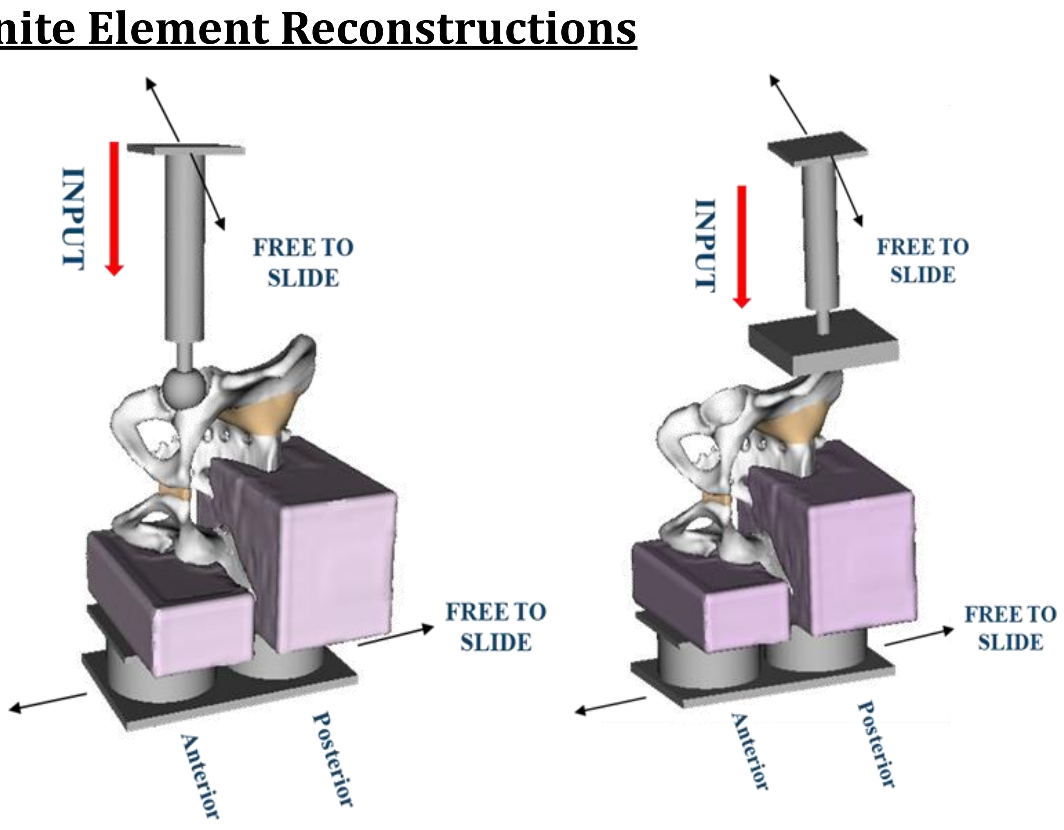






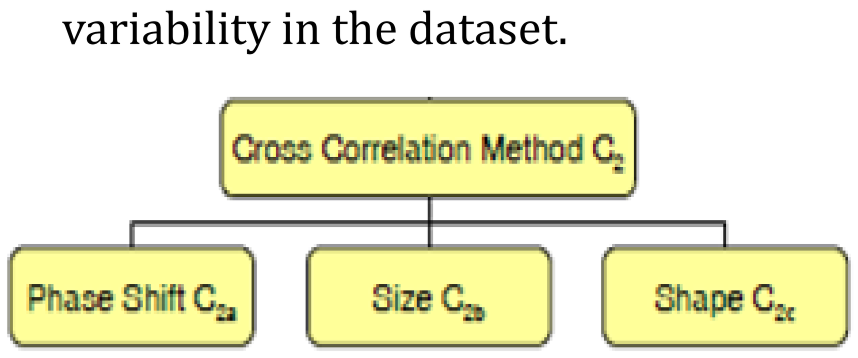
Experimental PMHS Tests and Finite Element Reconstructions

- ❖ Validation performed using the test series by Salzar et al. 2009 where defleshed human pelvises were impacted at either the acetabulum or iliac wing.
- ❖ Anterior and posterior forces were measured to assess the load distribution within the pelvis.
- ❖ Input velocity traces obtained from high speed motion tracking, boundary conditions defined to replicate test setup.



PMHS Conscious CORA Scoring

- ❖ CORA cross-correlation scoring was used and averaged, evaluating biofidelity of the FE model scored traces compared to PMHS-to-PMHS scored data traces, considering the variability in the dataset.

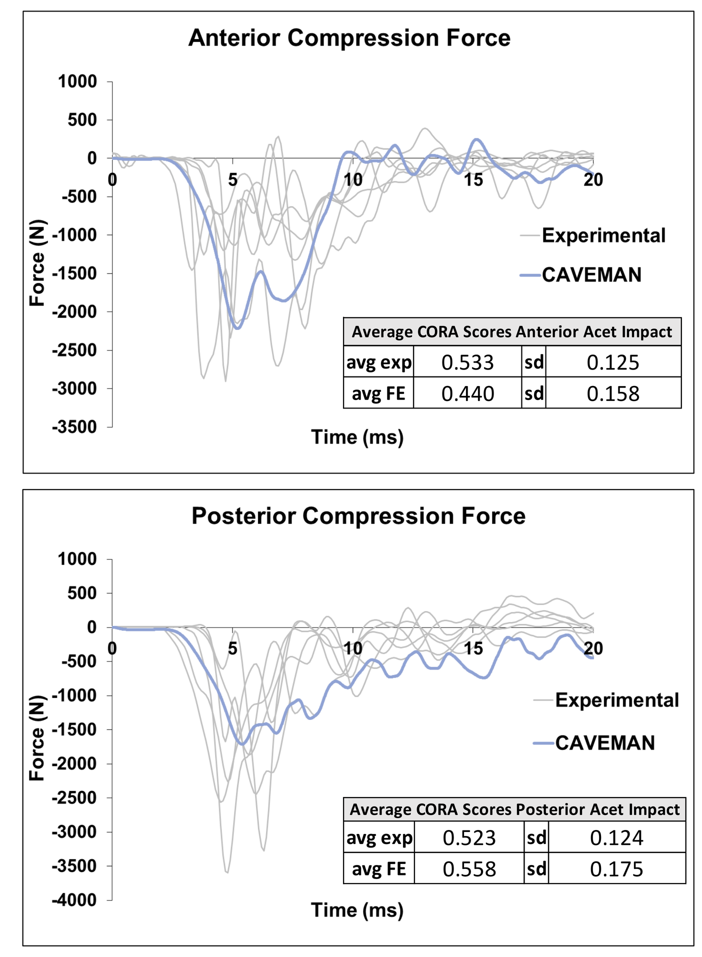


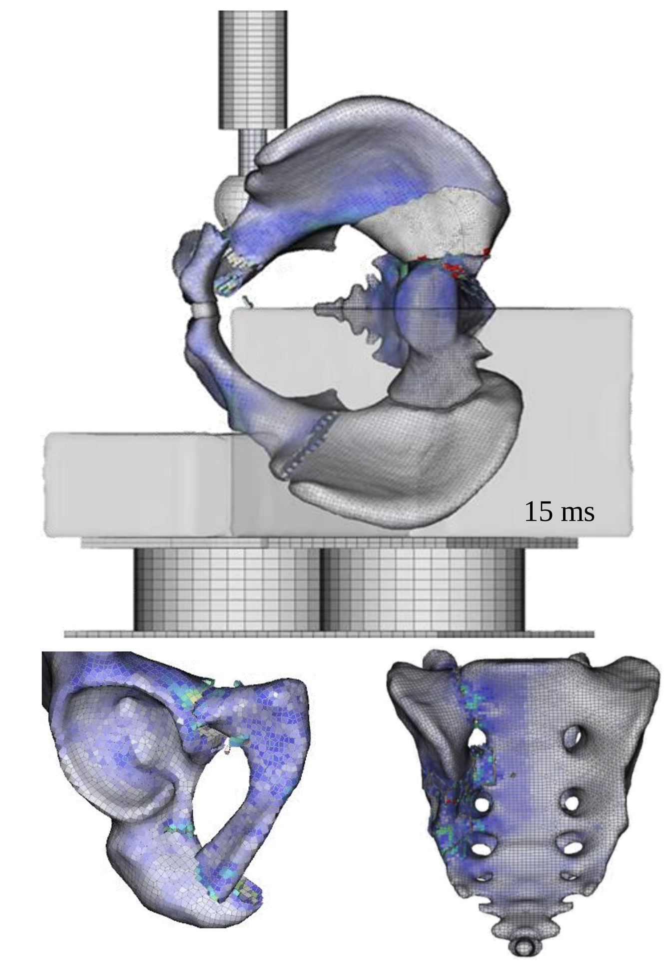
Injury Threshold Assessment

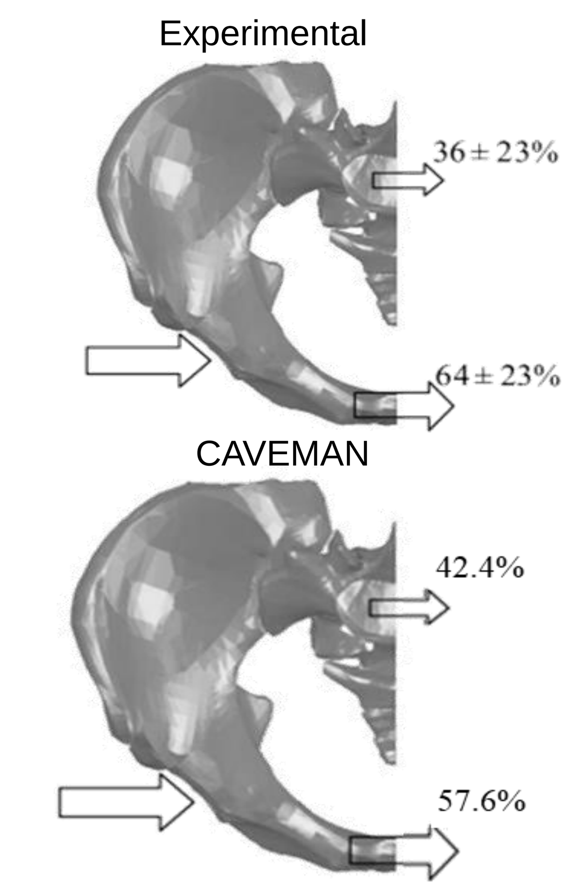
- ❖ Impactor mass and initial velocity was varied for each impact condition.
- ❖ Injury thresholds were calculated based on impactor kinetic energy and momentum, to determine pelvis vulnerability.
- ❖ Statistical analysis was performed to generate injury risk functions (IRFs) and determine whether anterior or posterior force was a better injury predictor.

Computational Analysis

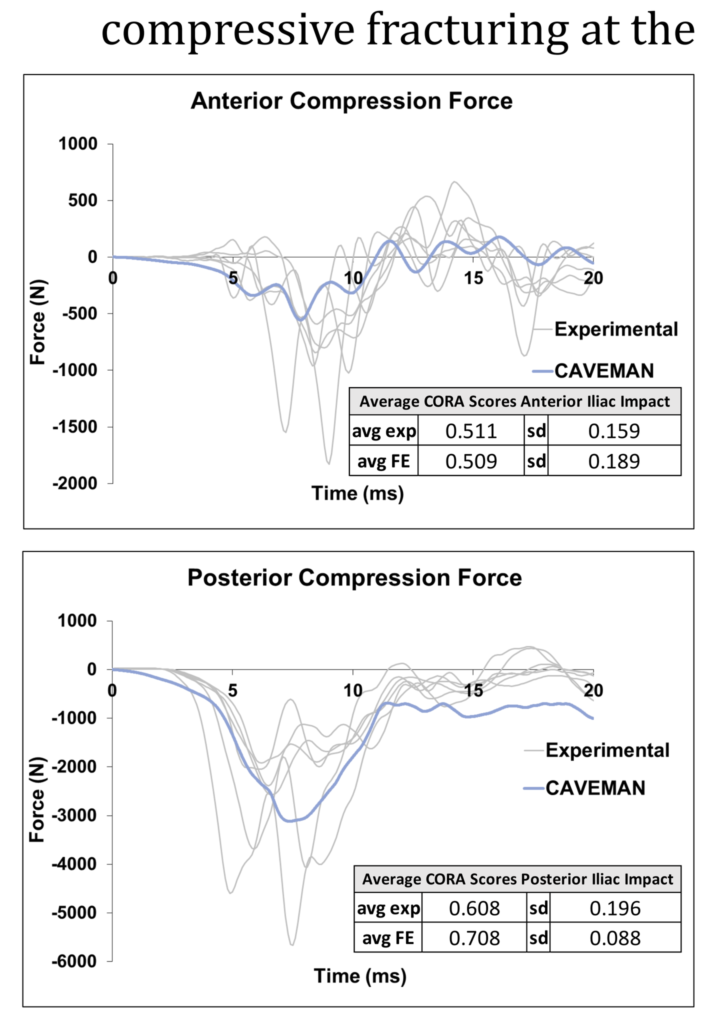
- ❖ In the acetabulum impact, force response and peak force distribution was within 1 standard deviation of the experimental averages. Predicted injuries include pubic ramis, ischium, and closed book sacral fracture which all compare favorably to PMHS.

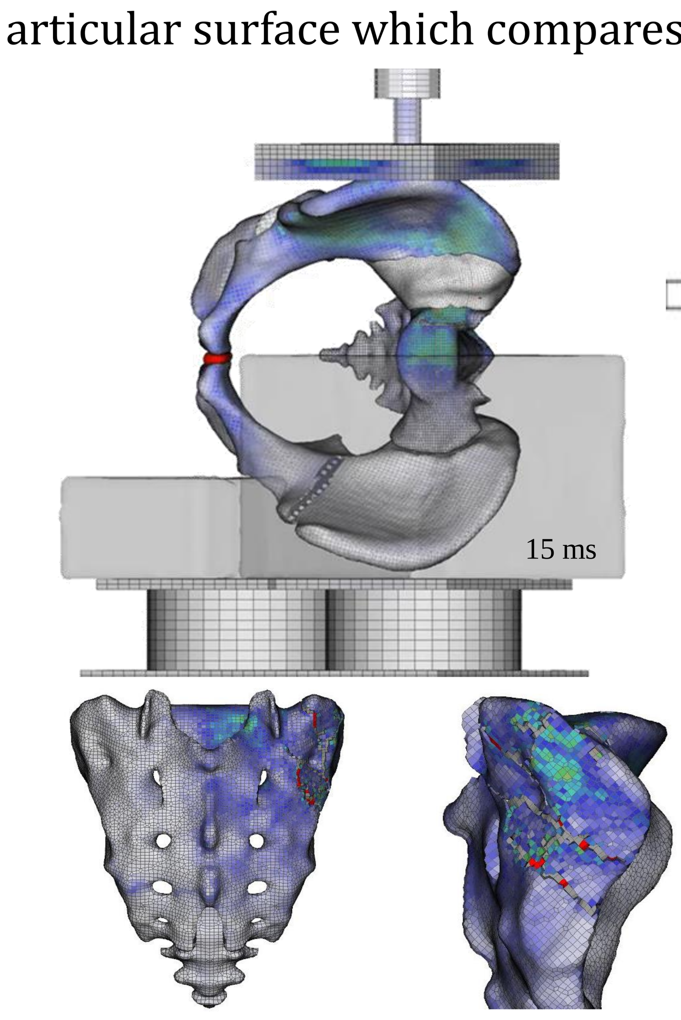


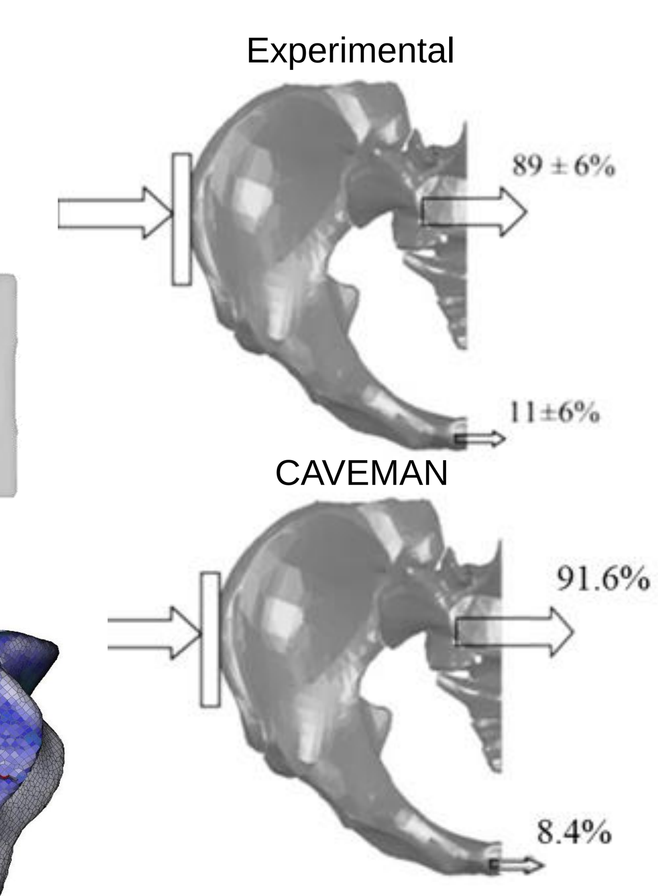




- ❖ In the iliac wing impact, force response and peak force distribution was within 1 standard deviation of the experimental averages. Predicted injuries include compressive fracturing at the articular surface which compares favorably to PMHS.



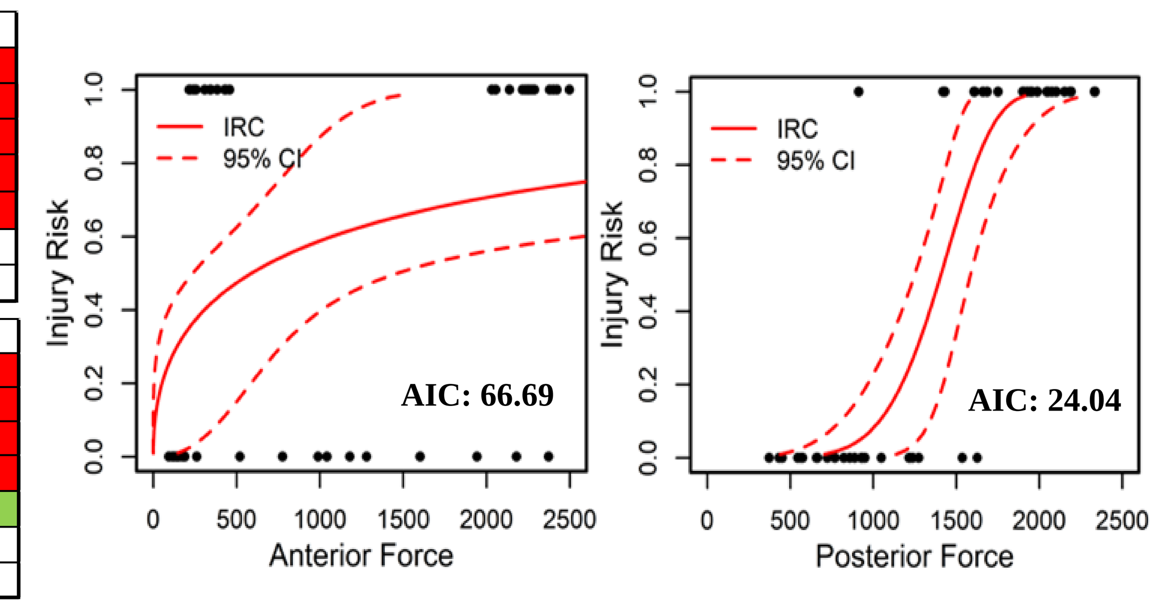




- ❖ Injury threshold matrices were created and it was noted that the anterior pelvis was more prone to injury than the posterior pelvis. Based on injury risk functions developed from these analyses, posterior force was determined to be the more consistent injury predictor across both impact conditions.

		Pelvic Ring Fracture (Acetabulum Impact)				
Mass (kg)	5	No	Yes	Yes	Yes	Yes
	4	No	No	Yes	Yes	Yes
	3	No	No	Yes	Yes	Yes
	2	No	No	Yes	Yes	Yes
	1	No	No	No	No	Yes
		1	2	3	4	5
		Velocity (m/s)				

		Pelvic Ring Fracture (Iliac Wing Impact)				
Mass (kg)	5	No	Yes	Yes	Yes	Yes
	4	No	No	Yes	Yes	Yes
	3	No	No	Yes	Yes	Yes
	2	No	No	No	No	Yes
	1	No	No	No	No	No
		3	4	5	6	7
		Velocity (m/s)				



Conclusions and Future Work

1. The CAVEMAN pelvis model's predictions of injury and force response compares favorably to the PMHS dataset.
2. The anterior pelvis was more susceptible to injury than the posterior pelvis. Protection designs related to lateral pelvis impact should focus on mitigating acetabular loading.
3. Force traveling through the posterior the pelvis was a better injury predictor than anterior pelvic force. This is applicable in future IRF generation and ATD development.

- ❖ Integration of this pelvis model into the whole body CAVEMAN model for evaluations related to other loading modes (UBB).

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[2] Salzar, R. S., D. Genovese, C. R. Bass, J. R. Bolton, H. Guillemot, A. M. Damon, and J. R. Crandall. "Load Path Distribution within the Pelvic Structure under Lateral Loading." International Journal of Crashworthiness 14, no. 1 (February 28, 2009): 99–110.

[3] Petit, Philippe, Xavier Trosseille, Matthieu Lebarbé, Pascal Baudrit et al. "Update of the WorldSID 50th Male Pelvic Injury Criterion and Risk Curve," 2018. SAE Technical Paper 2018-01-0539, 2018, doi:10.4271/2018-01-0539

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