Abridged Version for Release

Characterization of Subcutaneous Pelvic Adipose Tissue for Enhancement of Human Surrogate Models

Study Overview and Preliminary Data

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Center for Injury Biomechanics

Wake Forest School of Medicine

CIB

Virginia Tech
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Project Team

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Fang Chi Hsu


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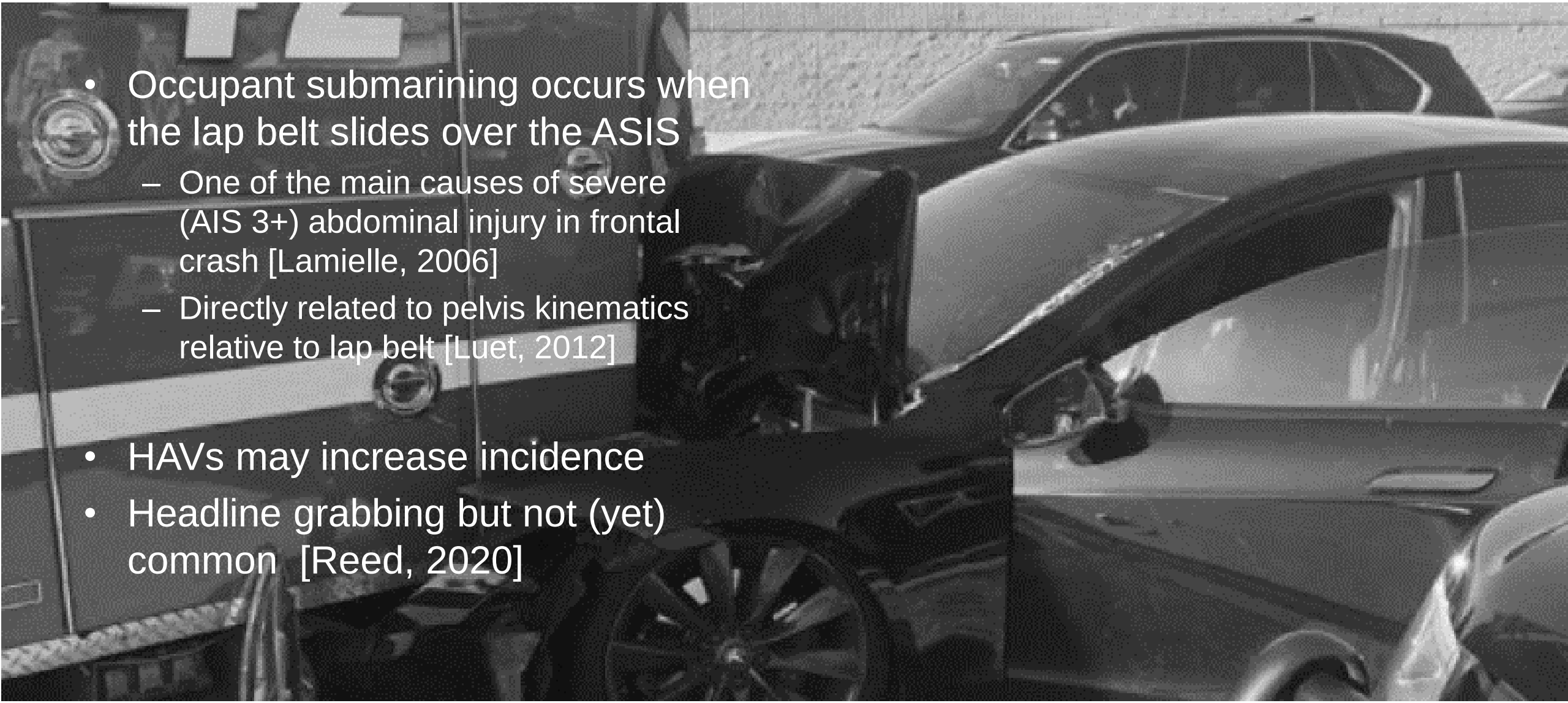
Background & Study Motivation



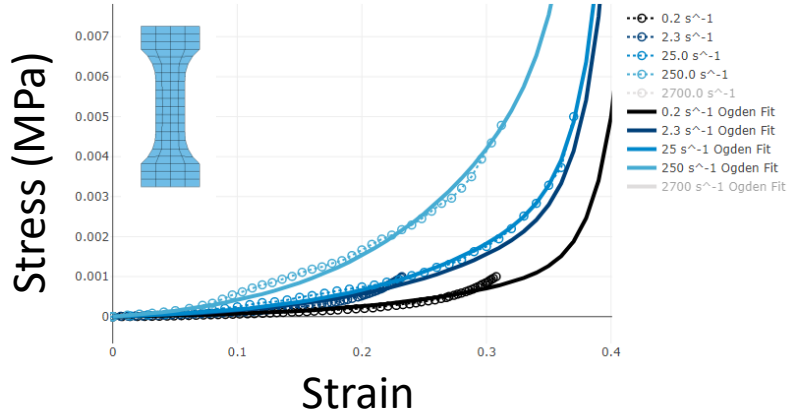
- Occupant submarining occurs when the lap belt slides over the ASIS
  - One of the main causes of severe (AIS 3+) abdominal injury in frontal crash [Lamielle, 2006]
  - Directly related to pelvis kinematics relative to lap belt [Luet, 2012]

- HAVs may increase incidence
- Headline grabbing but not (yet) common [Reed, 2020]

Technical Progress in the Literature: Human Surrogate Models

Materials

(e.g. Comley et al. 2012; Joodaki et al. 2018)

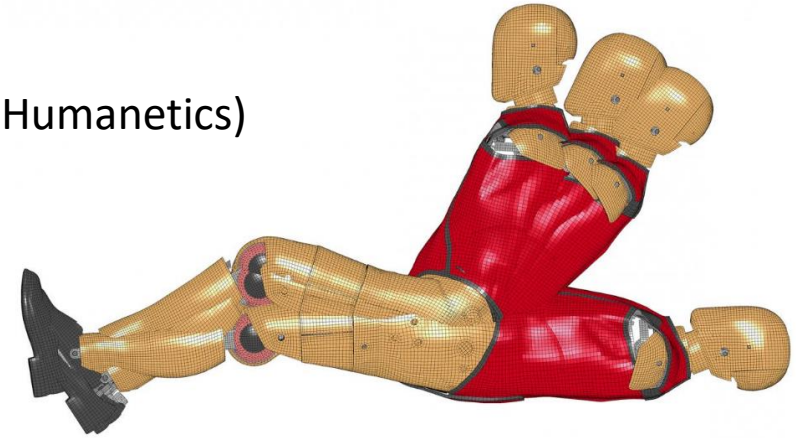


PMHS

(e.g. Kang et al. 2020; Richardson et al. 2020)

ATDs

(e.g. Thor AV, Humanetics)

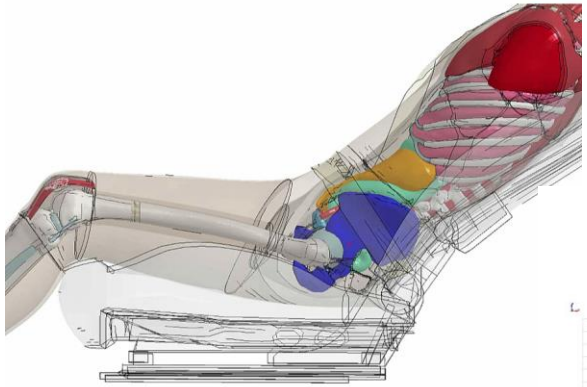


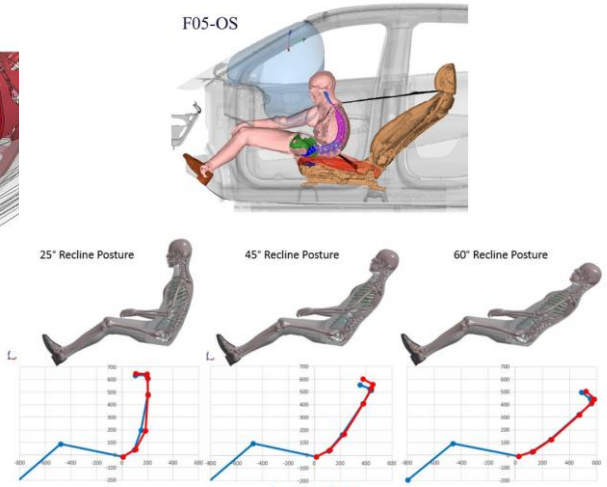
https://humanetics.humaneticsgroup.com/perspectives/autonomous-vehicle-occupant-safety

Human Models

(e.g. GHBMC, Thums)

Recent Activity modeling these scenarios (e.g. Rawska, 2020, Boyle 2019)





Technical Progress in the Literature: Human Surrogate Models

Materials
(e.g. Comely 2012, Joodaki 2018)

ATDs
(e.g. Thora AV, Humanetics)

Gap: Characterize morphology and structure of subcutaneous adipose tissue (SAT) through image analysis in a real world targeted population

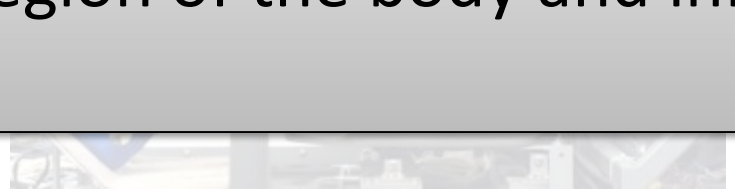
Strain

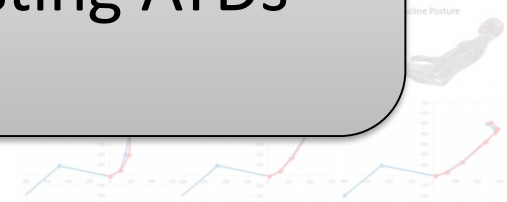
PMHS
(e.g. Kang et al. 2020, Richardson et al. 2020)

Human Models
(e.g. GHBMC, Thums)

Recent Activity modeling these scenarios
(e.g. Rawska, 2020, Boyle 2019)

Benefit: Data to improve human body model biofidelity in a key region of the body and inform design modifications to existing ATDs





Project Goals

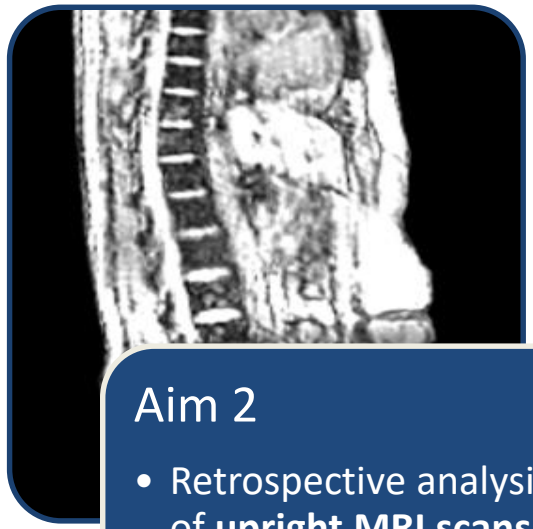
- **Research Objective:** A combination retrospective and prospective imaging study to characterize subcutaneous adipose tissue (SAT, e.g. belly fat) cross-sectional area, depth and structure in the vicinity of the pelvis, with a focus on posture, body mass index (BMI) and sex.

Review of Aims

Proposed Future Work

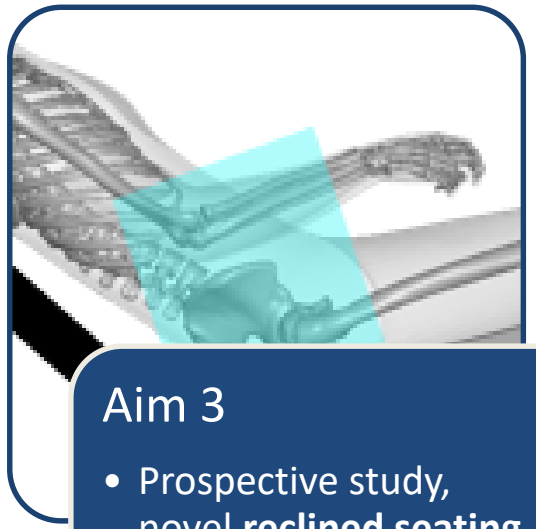
Aim 1

- Retrospective analysis of supine scans
- **Subcutaneous fat measures as function of BMI & sex**



Aim 2

- Retrospective analysis of **upright MRI scans**
- Subcut. fat measures as function of BMI & sex **including posture**



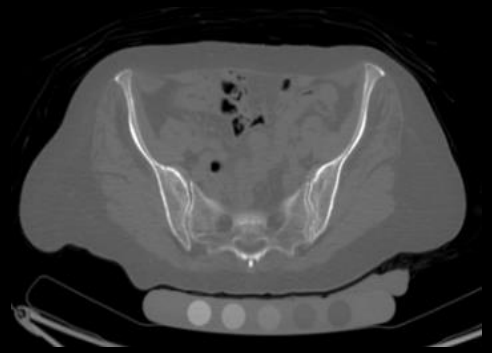
Aim 3

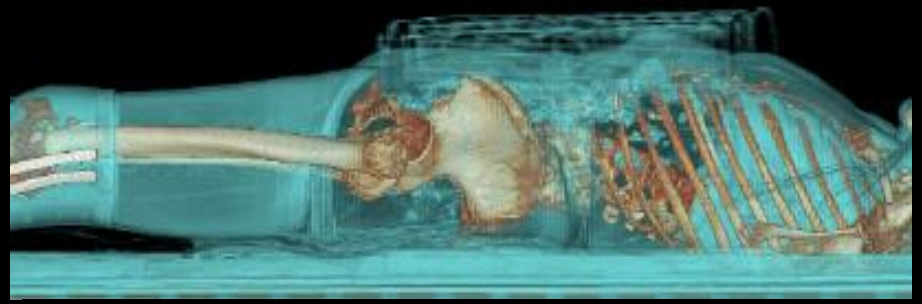
- Prospective study, novel **reclined seating MRI** data
- Subcut. fat measures as function of BMI & sex **with posture variation**

Aim 1 in progress, current phase Jan – Sept 2021

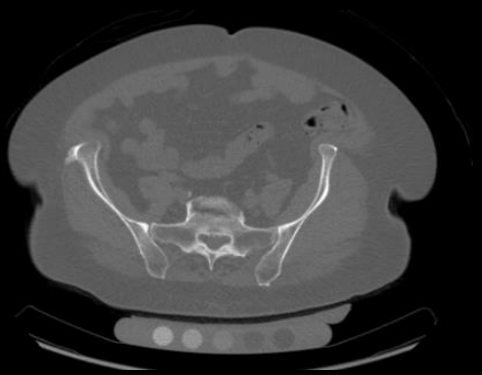
Aim 1

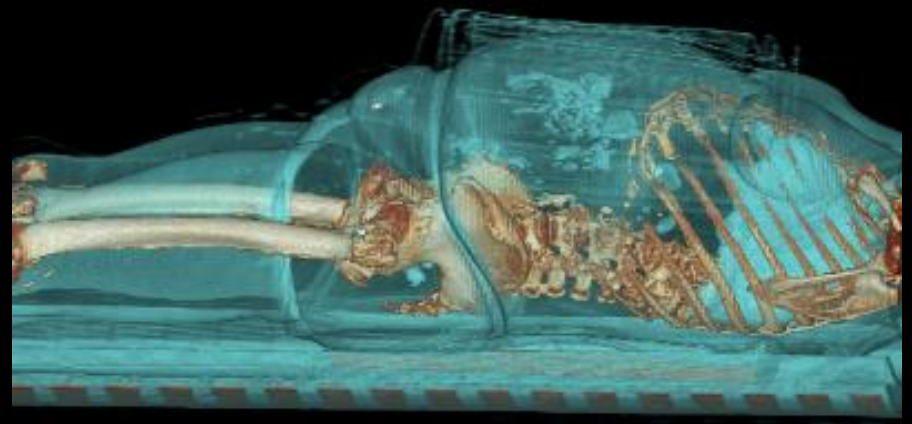
- Extract measures of morphology and characteristics of SAT from existing abdominopelvic CT and MRI scans.





Low BMI





High BMI

Age and Image Data Considerations for Aim 1

Age Considerations

- SAT changes with age, limit analysis to younger population (Ponti et al., 2020)
- Target age range is 25-45 years old
  - Based on population of Phase II data (largely from younger individuals) and covers a large portion of driving pop.

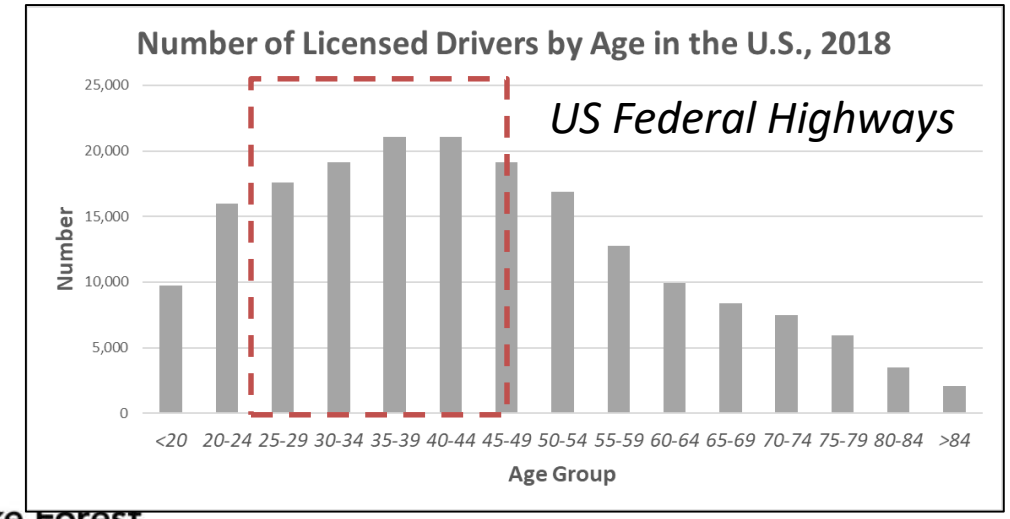
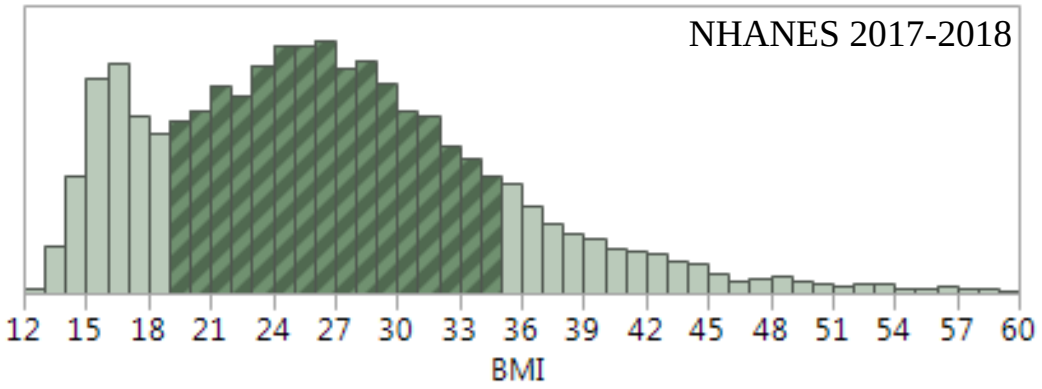


Image Type

- CT or MRI
- Strengths and weakness of both
  - MRI is highly dependent on pulse sequence
  - MRI data will be used in Aims 2 and 3
  - CT data is less variable, more common

Aim 1 Sample Size & Target Population

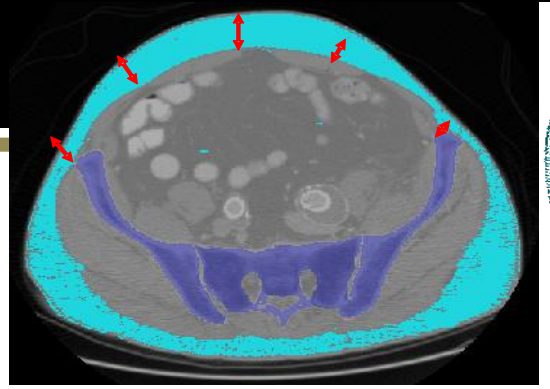
- Abdominopelvic medical images from ~84 human subjects are being analyzed
  - Goal: ~14 males, ~14 females in each BMI category
- Collect data from M & F subjects across normal, overweight, and obese BMI ranges

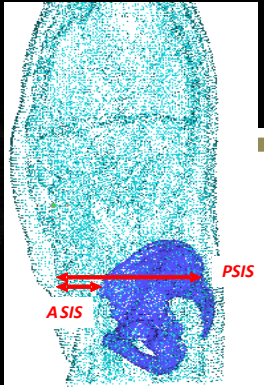


Study Targets

BMI Category	N (Male)	N (Female)
Normal (19-24.9)	14	14
Overweight (25-29.9)	14	14
Obese (30-35)	14	14

Aim 1 Primary Measures

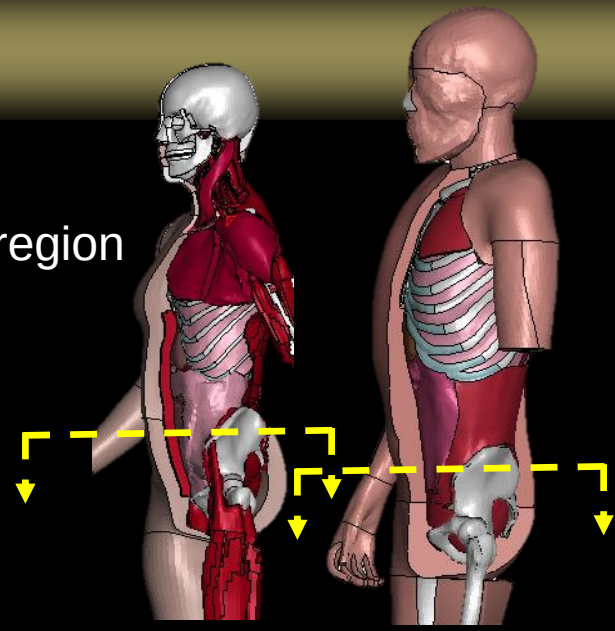




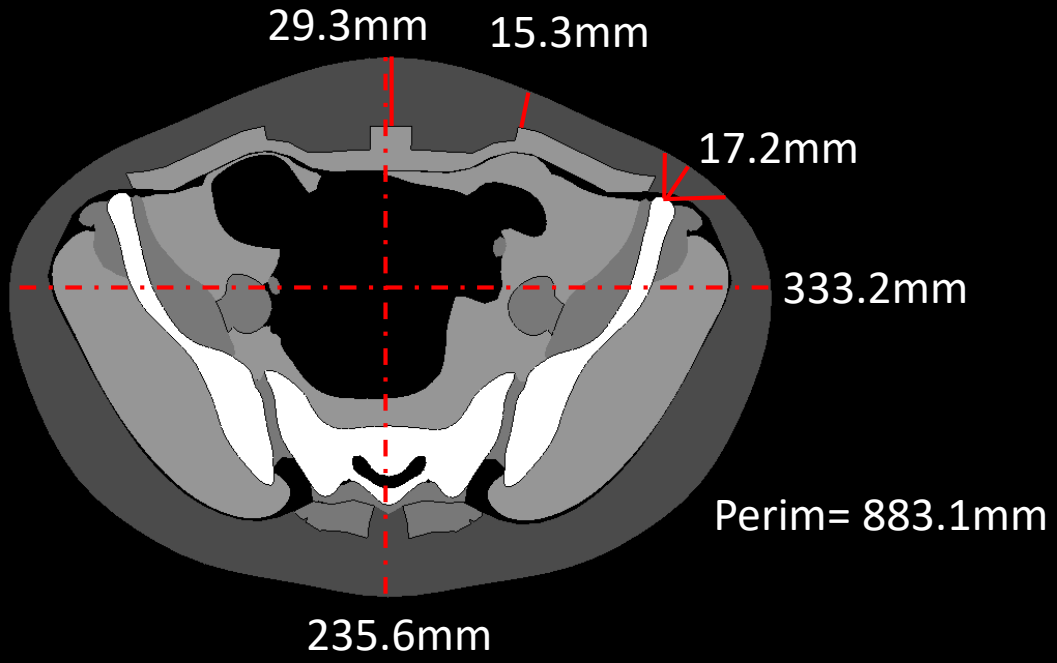
Output Measure	Abbrev.	Description
Subcutaneous adipose tissue cross-sectional area (cm^2)	CSA_{SAT}	Taken at an axial slice through left and right ASIS
Subcutaneous adipose tissue depth measures (mm)	$D_{SAT,1,2,N}$	Measured to bony pelvic prominences (e.g. ASIS), and regional depth measures taken at various locations across the surface of the adipose tissue anterior to the pelvis.
Fat quality	Q_{SAT}	Measured by Hounsfield Unit attenuation on CT
Abdominal seat belt sign location distance to ASIS	SBL	If visible on CT fat rendering, measure axial distance between slice containing ASIS and slice containing seatbelt sign. There are at least 50 CIREN occupants in the CIB image repository with abdominal seat belt sign, including occupants with normal, overweight, and obese BMI.

SAT Data is Built into Human Models

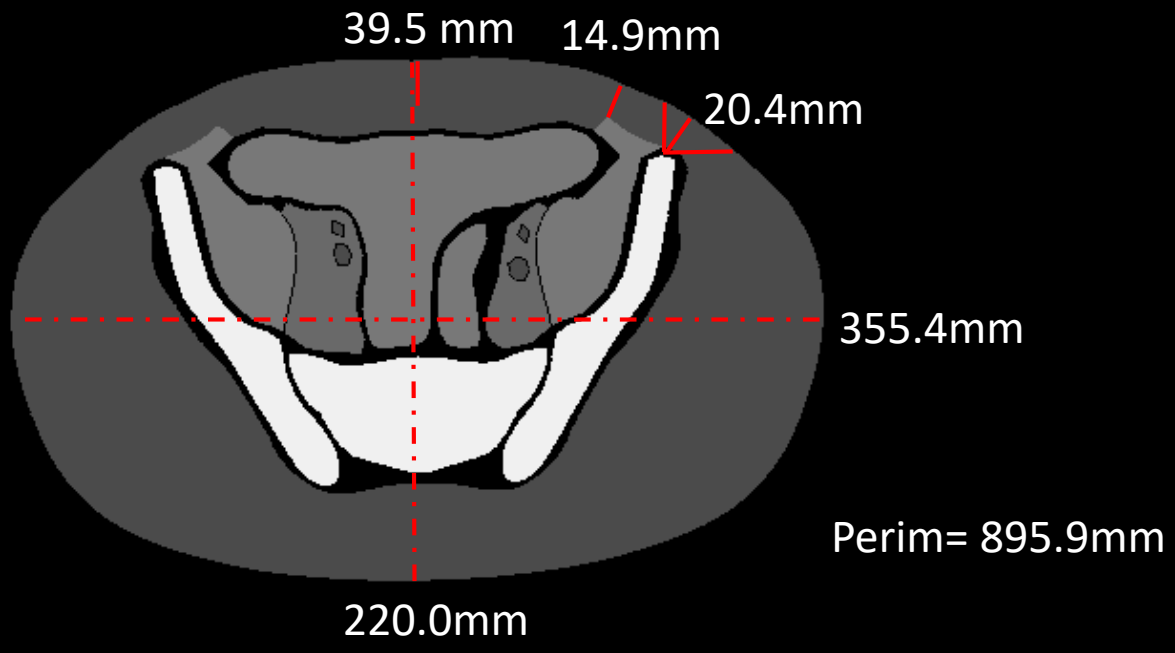
- **SAT data is built into models but how accurate is it?**
- Morphological population data in this region can inform models (& ATDs?) in a critical region
- Data from models in standing posture below (only supine scans so far…)
- Future use of study data…to verify current, or morphed obese models, or changes by posture. **The medical image data can potentially be used as targets.**



GHBMC v.1.2 5th Female - Pedestrian



Thums v. 4.02 50th Male - Pedestrian

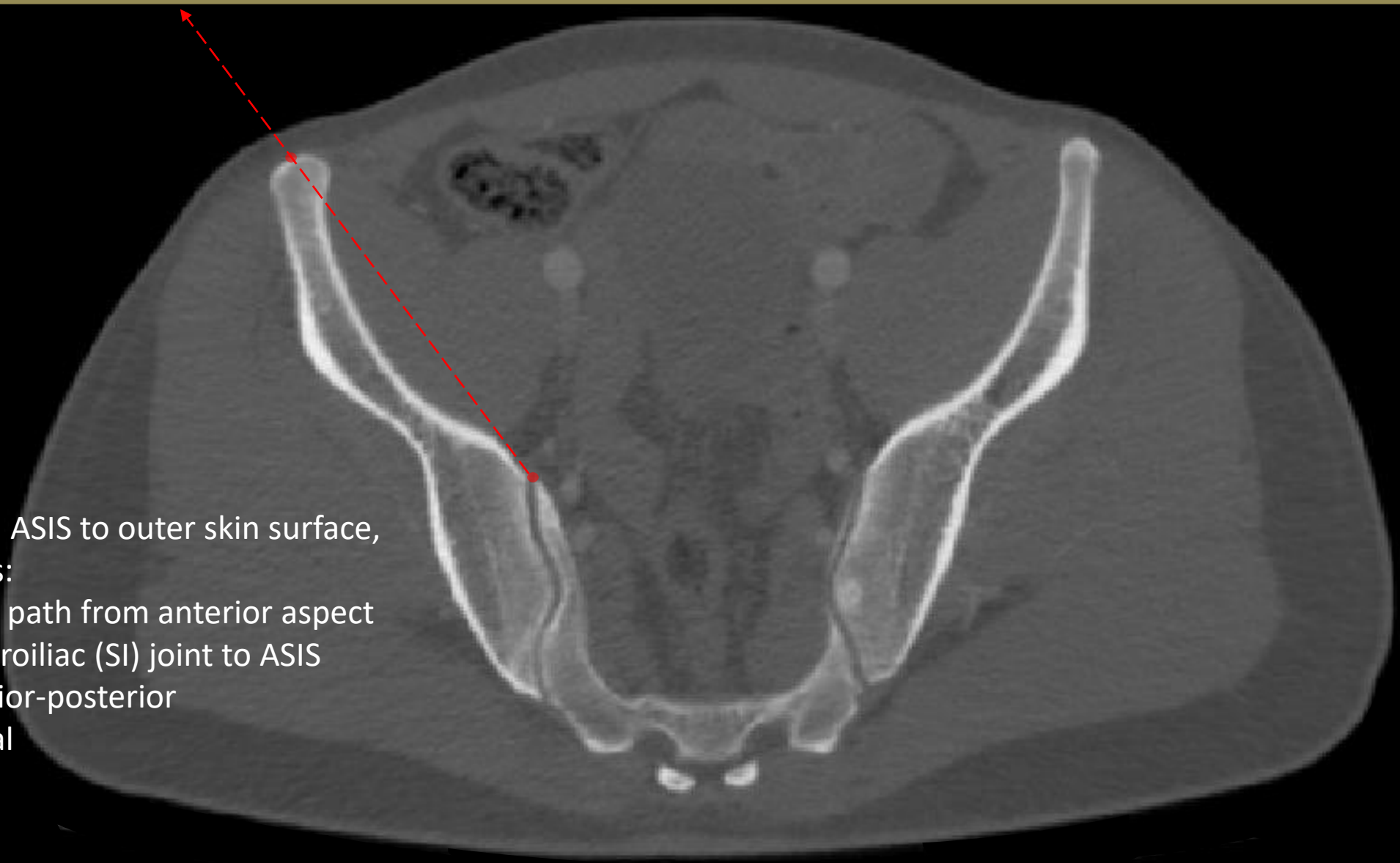


DATA COLLECTION METHODS

Scan Selection: Eligibility Criteria

- Dataset: CIREN (n ~870) + ~1000 retrospective scans from prior biomechanics studies @WFU
- Age 25 yr – 45 yr
- BMI 19 - 35
- No pelvic or lumbar vertebral fracture
  - Verified in injury coding and visual scan inspection
- Left and right ASIS visible in scan
- At least one flank in field-of-view (FOV) at axial level of ASIS

Exemplar Measurement: ASIS depths



Distance from ASIS to outer skin surface, in 3 directions:

- Along path from anterior aspect of sacroiliac (SI) joint to ASIS
- Anterior-posterior
- Lateral

Summary of Linear and Angular Measures

Depth, linear, angular measures taken by subject:

- R&L ASIS, linea alba, rectus abdominis depths
- Lumbar lordosis angle
- Perimeter
- A-P distance
- L-R distance

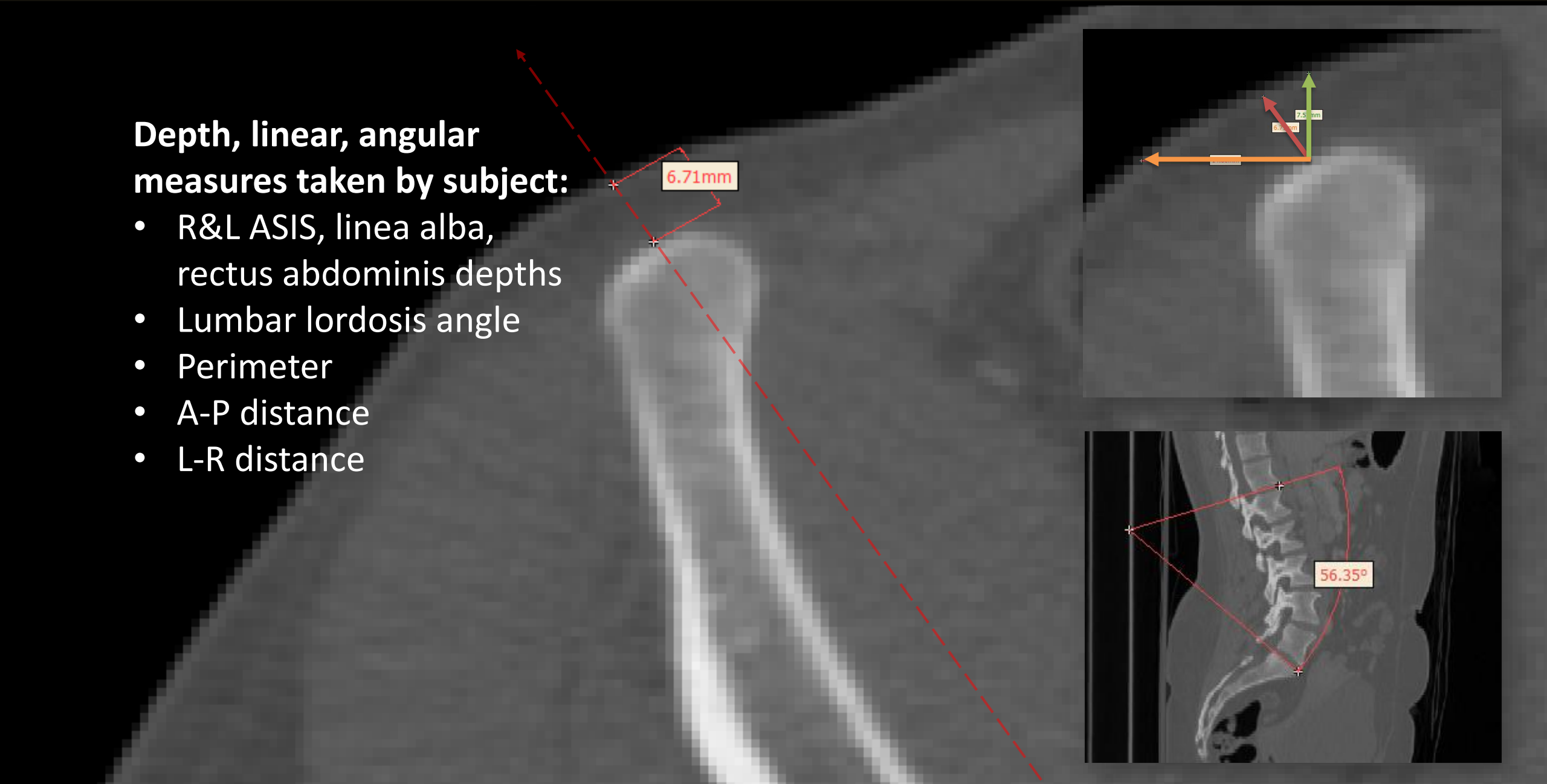
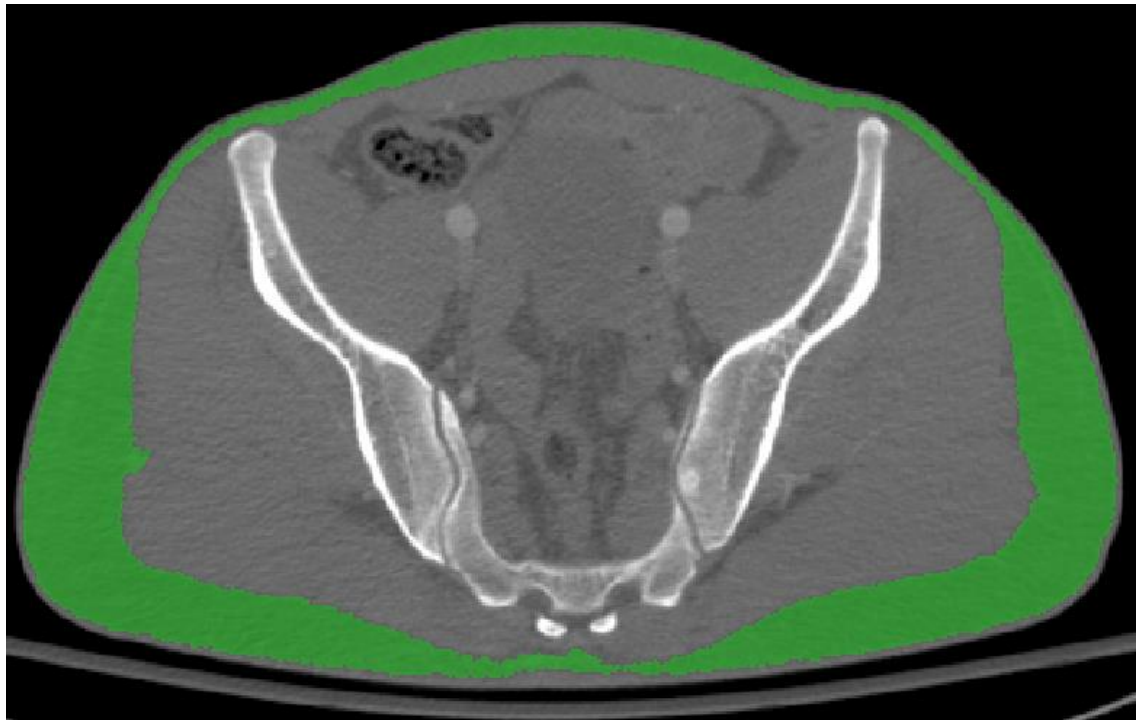


Image Analysis Protocol

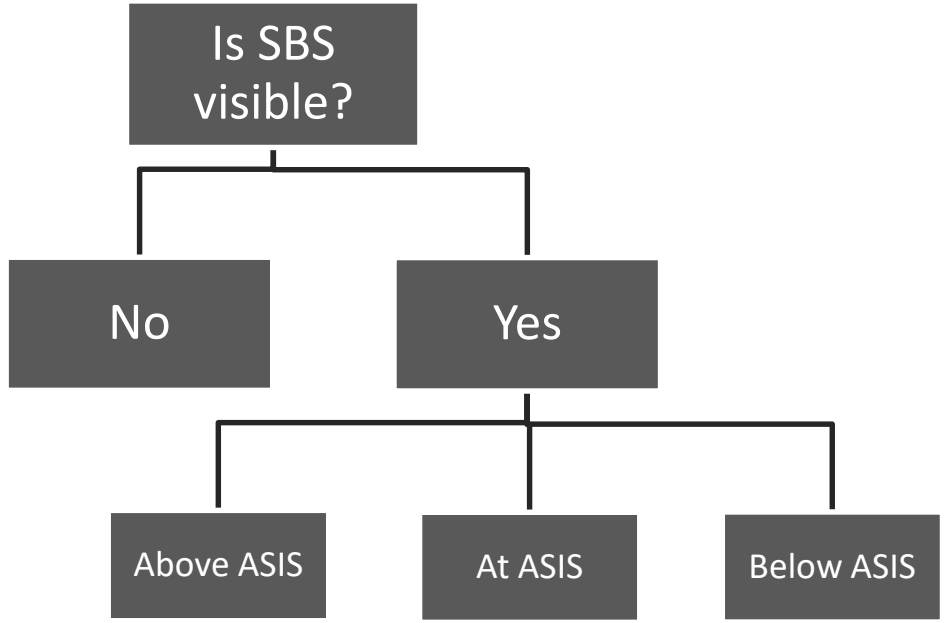
- Semi-automatic threshold (-150HU to -40HU)
- Manual user edit
  - Remove voxels at skin, viscera, table
  - Fill holes in subcutaneous fat
- Document mask volume,
  number of pixels,
  average HU value
- Calculate area

$$\mathrm{A} = \frac{mask\ volume}{slice\ thickness}$$



Seatbelt Sign: Protocol

- Visualize 3d fat rendering
- Determine if SBS is visible
- Measure distance from plane containing ASIS to middle of SBS in z-direction at midline
  - Analyze in bins, relative to ASIS location:
    - Above ASIS
    - at ASIS
    - Below ASIS



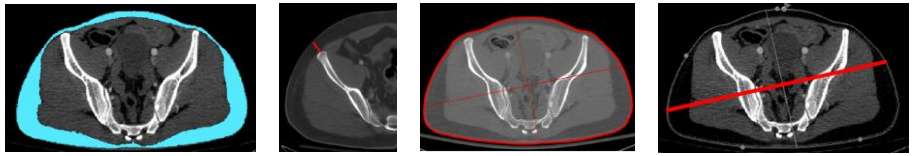
Preliminary Statistical Analysis (N = 50)

- Linear regression models to evaluate the associations between outcome measures (e.g., SAT and L-R diameter) and independent variables (e.g., BMI, sex and age).

Independent Variables:

Vs.

Outcome Measures:



- Sex by BMI Interaction was also tested.

PRELIMINARY RESULTS AND STATUS

Scan Selection Metadata: Current Snapshot

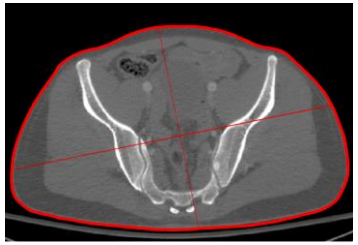
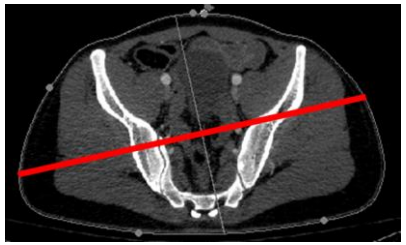
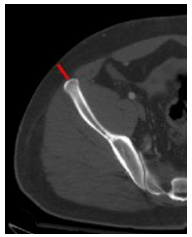
- 58 eligible subjects identified (68%)
- 50 subjects analyzed (58%)
  - **Results are subject to change!**
- 19 positive seatbelt sign (SBS)
- Goal: 85 subjects
  - Goal: ~14 males, ~14 females in each BMI category

BMI Category	N (Male)	N (Female)
Normal (19-24.99)	14	11
Overweight (25-29.99)	14	7
Obese (30-35)	8	4

BMI Category	Age (Std. Dev.) (Male)	Age (Std. Dev.) (Female)
Normal	32.4 (5.7)	32.6 (5.7)
Overweight	32.9 (5.9)	27.6 (2.9)
Obese	35.8 (6.6)	32.0 (4.3)

DISCUSSION AND CONCLUDING REMARKS

Table of Preliminary Summary Statistics

Independent Variables	SAT Area	Perimeter	Lmax (L-R diameter)	ASIS Depth (Along S-I)
R^2	> 0.6	> 0.7	> 0.6	> 0.6
BMI	+	+	+	+
Sex	+	+	+	-
Age	-	+	-	+
Left-to-Right	N/A	N/A	N/A	-

Preliminary Analysis

Significance level is alpha = 0.05, Left-to-Right only evaluated on ASIS Depth

Preliminary Statistics Summary

- Several preliminary models were assessed
  - Preliminary (n = 50, 58% of data)
- BMI appears to be highly associated with the outcome measures
- Sex appears to be associated with the outcome measures
  - Most measures, female values were greater than male at same BMI
- Age significance appears to vary by measure
  - Narrow age range of subjects
- Interactions generally were not significant, e.g. BMI impacts outcomes measures same for male and female

Long Term Study Goals

1. Provide morphological data on subcutaneous adipose tissue in the vicinity of the pelvis from a large sample of supine images.
2. Provide matched pair analysis of supine and upright imaging data to assess if differences in SAT morphology are noted between these endpoints.
3. Provide new data of SAT and structure in the vicinity of the pelvis in reclined postures.

Near Term

- Predictive models for fat depth and cross-sectional area based on seated posture
- **New insights from a large quantity of supine scans that are readily available, including sex and age differences**
- May inform and/or update human body modes and potentially ATDs

Thank you!

- Questions & Comments?

RCCADS | Research Consortium for Crashworthiness in Automated Driving Systems

TRC

NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

HONDA

Autoliv

HYUNDAI

TOYOTA

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