Numerical and Empirical Investigations of Automotive Related Aortic Injury

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Epidemiology

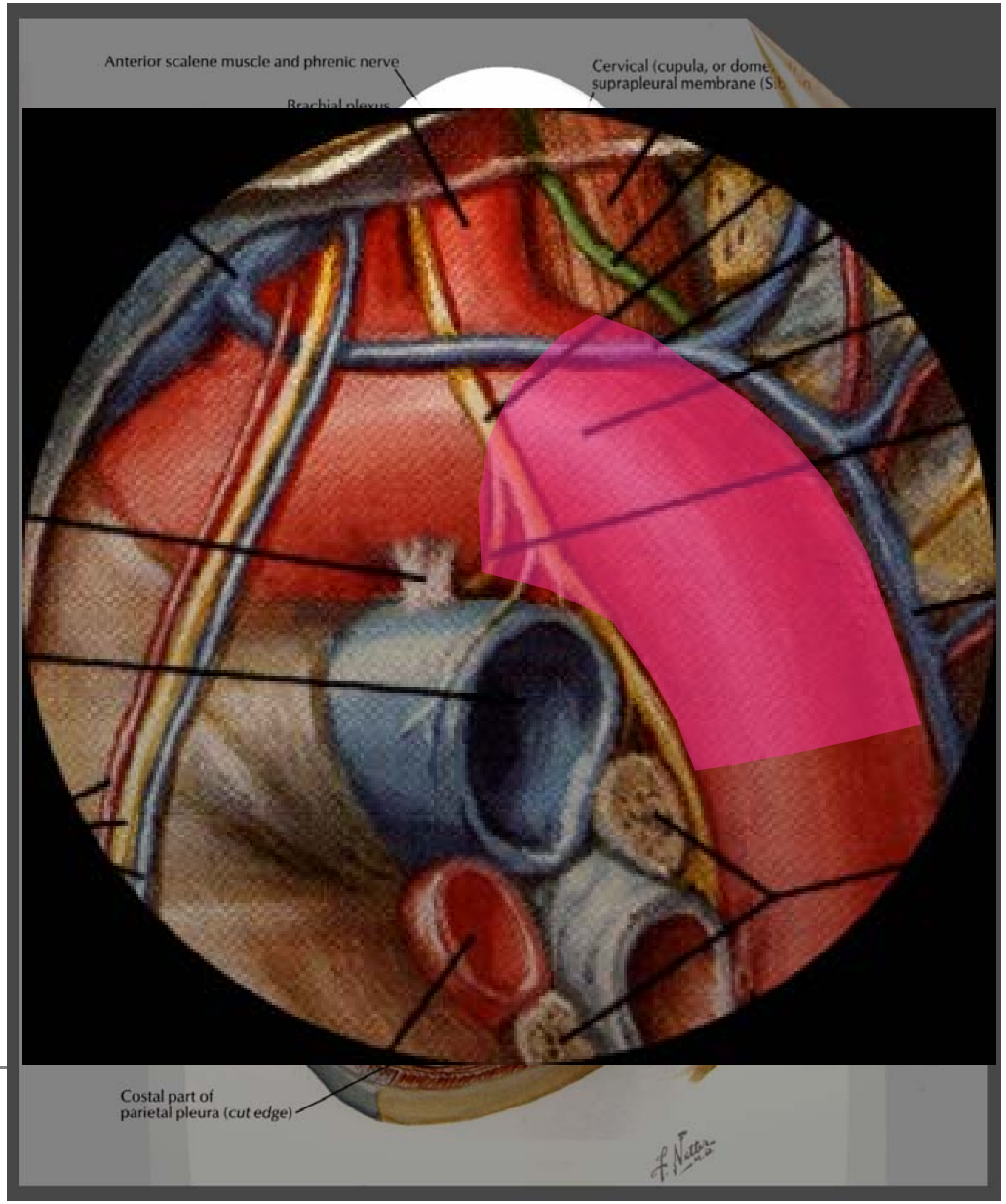
- **TRA is the second most common cause of death in motor-vehicle crashes**
  (Sauaia et al. 1995)
- **There are up to 8000 US fatalities annually**
- **TRA tends to be underestimated because most victims die at the scene**
- **TRA is associated with higher-speed accidents**

Epidemiology

- **The incidence of TRA is low overall, but it is largely represented among fatalities**
- **Transverse rupture** (Zehnder 1960)
- **94 % TRA confined to peri-isthmic region** (Katyal et al. 1997)
- **Retrospective and experimental studies yielded limited information**

Anatomical Structures

- Aorta
- Pulmonary artery
- Superior vasculature
- Pericardium
- Central tendon
- Diaphragm
- Parietal pleura
- Hilum
- Lig. arteriosum
- Recurrent laryngeal n.



Etiology

Cause	Isolated rupture	With heart injury	Total
Automobile	114	42	156
Airplane	12	31	43
Pedestrian	9	7	16
Fall	12	12	24
Motorcycle	3	1	4
Auto/train	0	2	2
Heavy object	4	0	4
Dirt	1	0	1
Direct blow	5	0	5
Unknown	11	9	20
Total	171	104	275

Parmley (1958)

Pathogenesis

Site	Isolated rupture	With heart injury	Total
Ascending	17	47	64
Arch	16	6	22
Isthmus	95	29	124
Thoracic	27	8	35
Abdominal	11	2	13
Multiple	5	12	17
Total	171	104	275

Parmley (1958)

Postulated Mechanisms

- Rindfleisch (1893): Stretch deformation
- Oppenheim (1918): Overpressure
- Letterer (1924): Falls, downward traction
- Hass (1944): Differing acceleration rates
- Cammack (1959): Torsion or shearing
- Zehnder (1960): Hilum fulcrum

Postulated Mechanisms

- Moffat (1966): Recurrent laryngeal n.
- Roberts (1966): No pressure, no acceleration
- Voigt (1969): Shoveling, traction of the head
- Viano (1983): Hypertension, atherosclerosis
- Melvin (1998): Anterior sternum displacement
- Skrum (1999): Disease and age factors

Key Questions

- How does TRA occur?
- At what levels does TRA occur?
- Why is the isthmus most vulnerable?
- What is the role of the lig. arteriosum?
- Why are tears predominantly transverse?
- Why is the pulmonary artery not injured?
- What is the influence of intraluminal pressure?
- What is the effect of whole-body acceleration?

Project Aims

1. **Simulate real-world accidents involving TRA**
   - **Vehicle FE simulations**
   - **Interaction of vehicle interior with whole-body FE human model (WSHM)**
2. **Conduct cadaver experiments**
   - **Enhance understanding of injury mechanisms**
   - **Provide additional local validation data for the aorta**

Aim 1
Simulate real-world accidents involving TRA

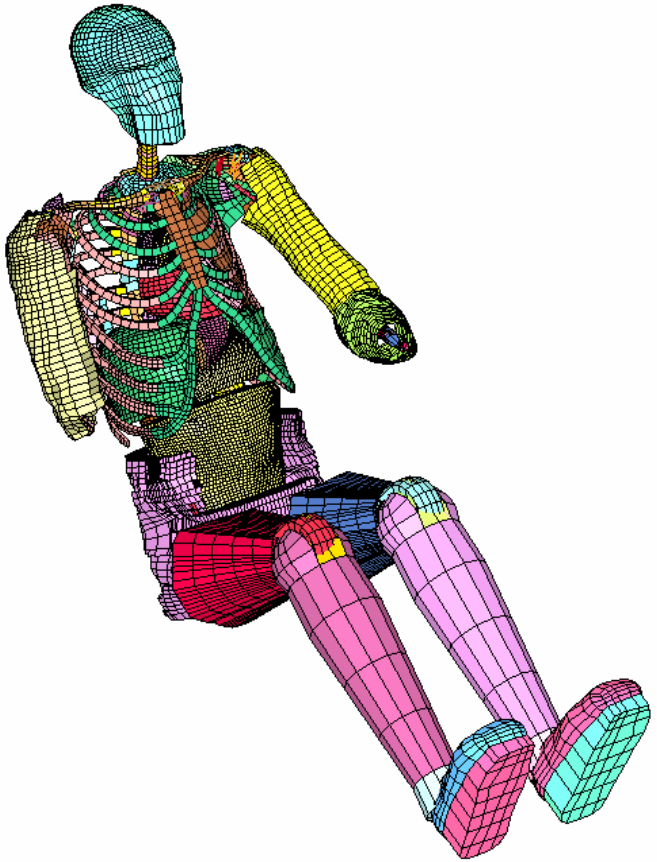
Rationale

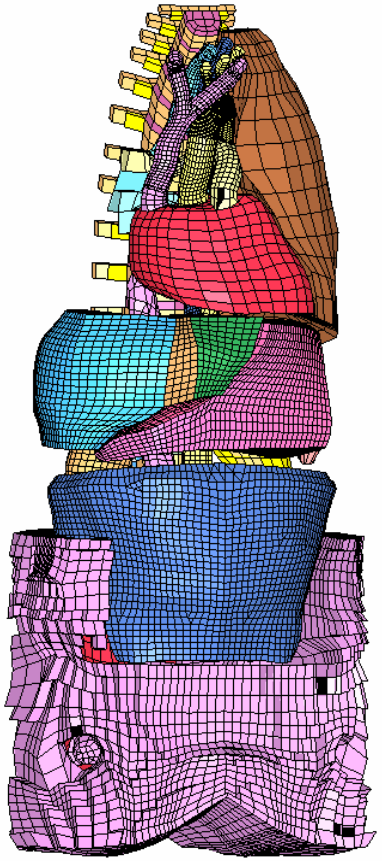
- **70% TRA from motor vehicle crashes (MVC)** (Burkhart et al. 2001)
- **45% frontal, 22.5% side impact MVC** (McGwin et al. 2003)
- **Rate of TRA in near-side impact was found to be twice that in frontal MVC** (Steps 2003)
- **MVC is a major cause of TRA**
- **FE simulations of real-world MVC will provide insight for designing future experiments aimed at elucidating the mechanisms of TRA**

Methods

- **Real-world aortic injury cases obtained from UMDNJ**
- **Phase 1**
  - **Car-to-car simulation**
  - **Kinematics of selected structures recorded and saved for phase 2 simulation**
- **Phase 2**
  - **Application of previously recorded kinematics of structures**
  - **Occupant interaction with selected vehicle interior structures**

Whole-body Human FE Model

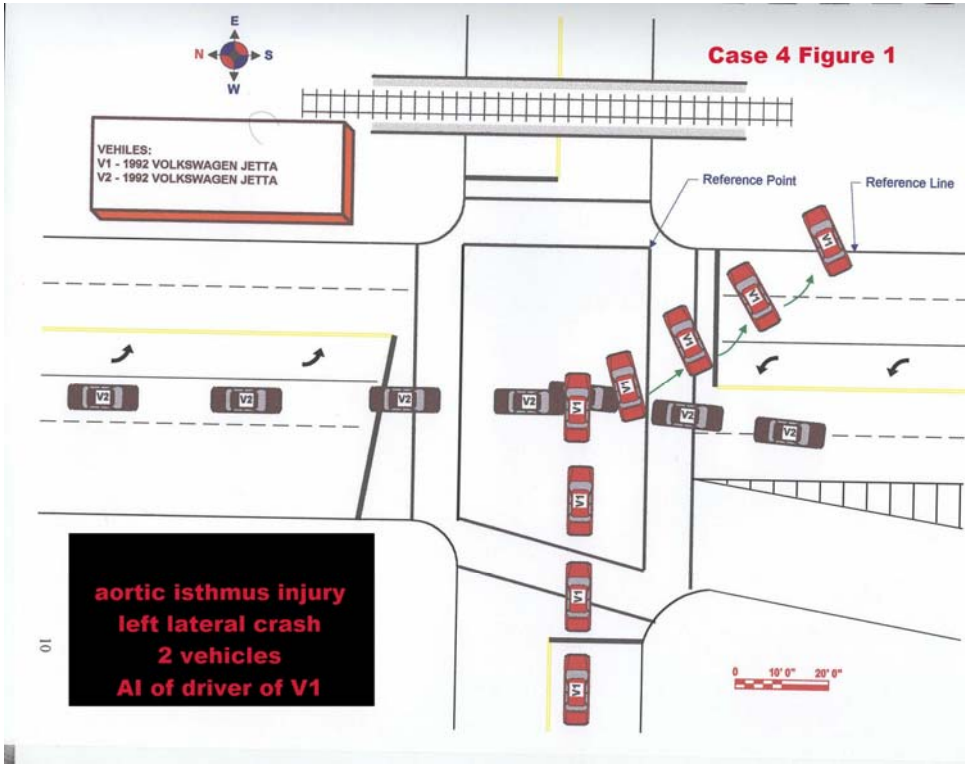




Side Impact

V1: 1992 VW Jetta (Red)
V2: 1992 VW Jetta (Black)
Delta-v: 62 kph
PDoF: 310 degree

V1 Occupant
Male, 29 , 183 cm, 100 kg
2-pt shoulder, no lap, no airbag
Aortic isthmus injury (survivor)

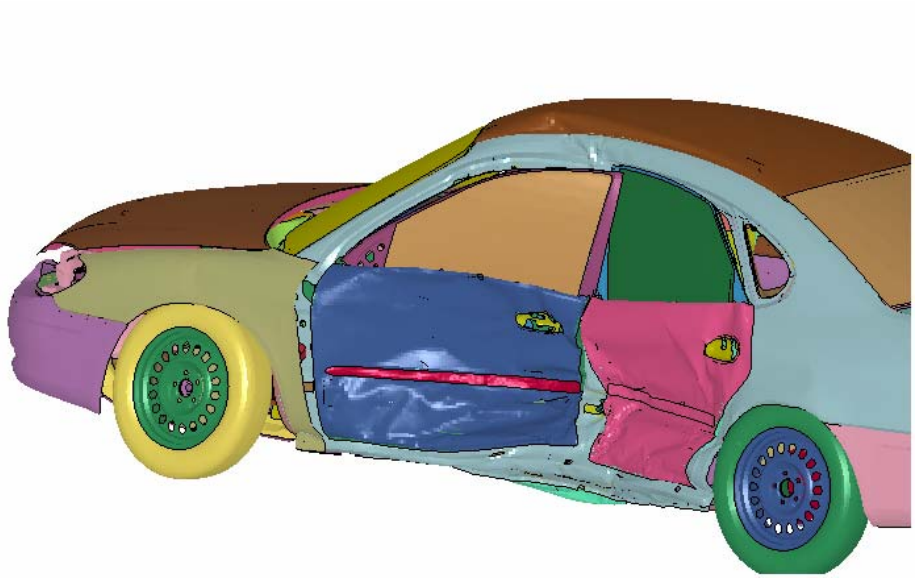


Side Impact

Phase 1

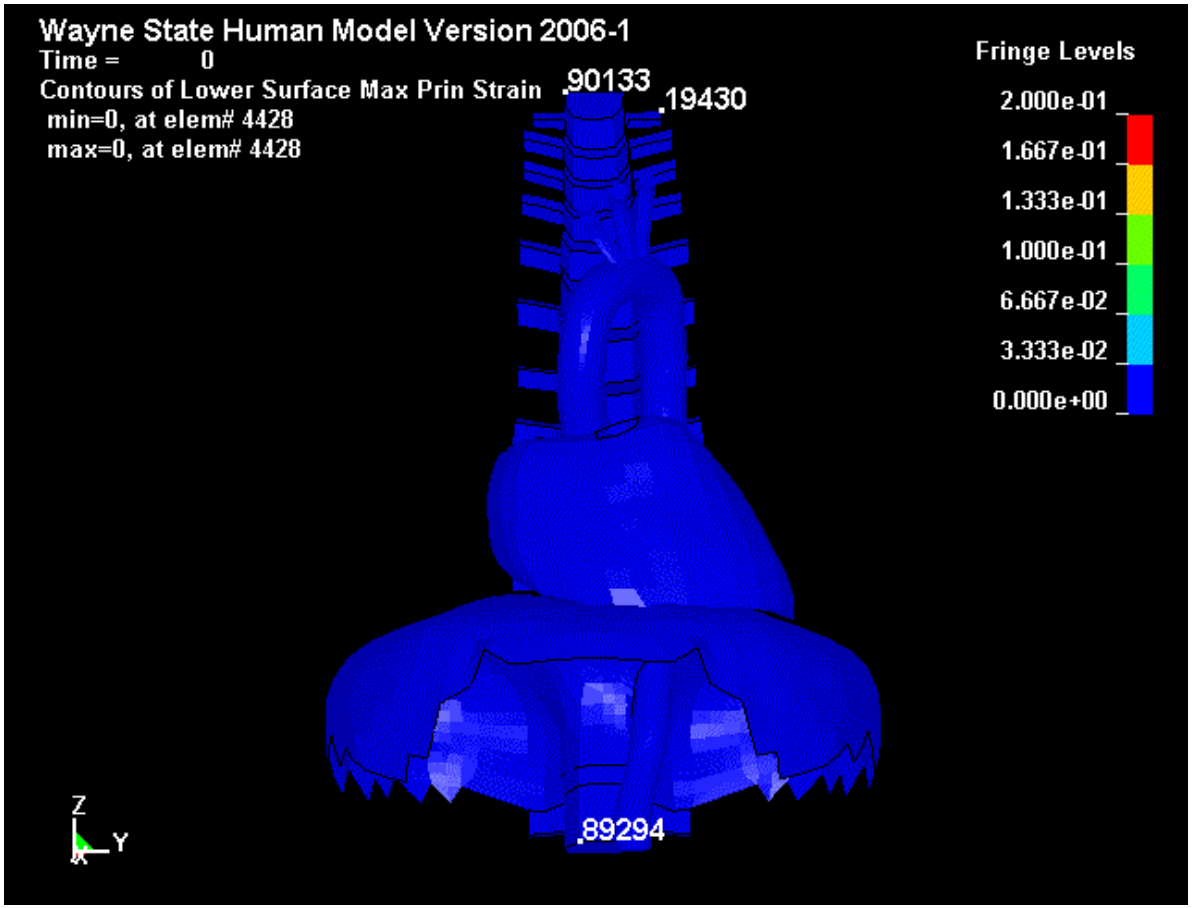
Phase 2

Side Impact



	C1	C2	C3	C4	C5	C6
Actual (mm)	0	120	640	620	500	120
FE simulation (mm)	-	111	570	542	-	-

Side Impact


Wayne State Human Model Version 2006-1
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max=0, at elem# 4428
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.19430
.89294
Fringe Levels
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1.333e-01
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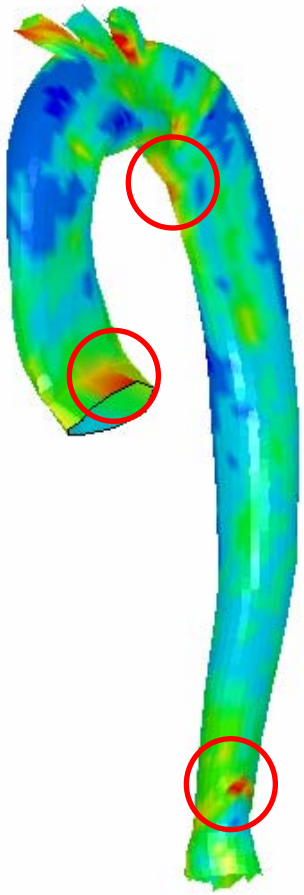
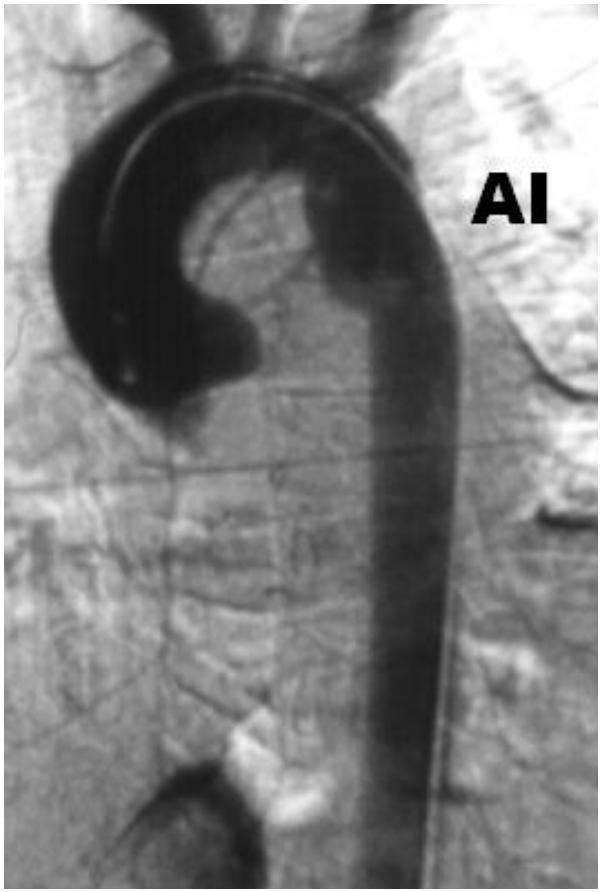
6.667e-02
3.333e-02
0.000e+00
Z
Y

Side Impact





Aim 2
Conduct cadaver experiments

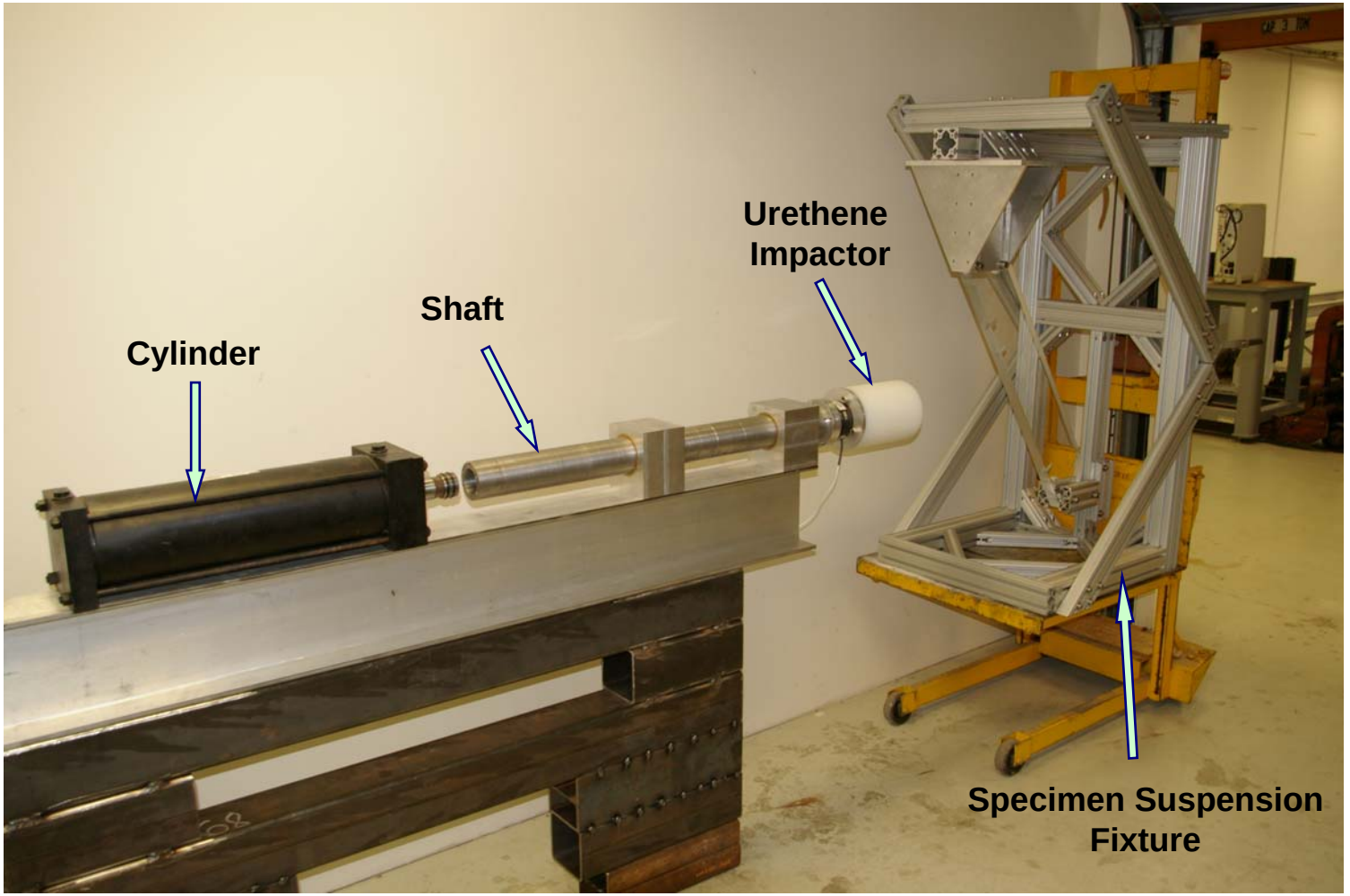
Rationale

- Finite element modeling of the aorta becoming increasingly important for TRA
- Local validation data necessary before model predicted stress and strains reliably interpreted
- No such local validation data available
- *Objective*: To conduct cadaver experiment to obtain local aorta deformation data

Methods

- Unembalmed human cadaver subjects
- Specially designed fixture
- Linear impactor (32 kg)
- 152-mm diameter urethene impacting face
- High-speed biplane x-ray system facility at Henry Ford Hospital (HFH)

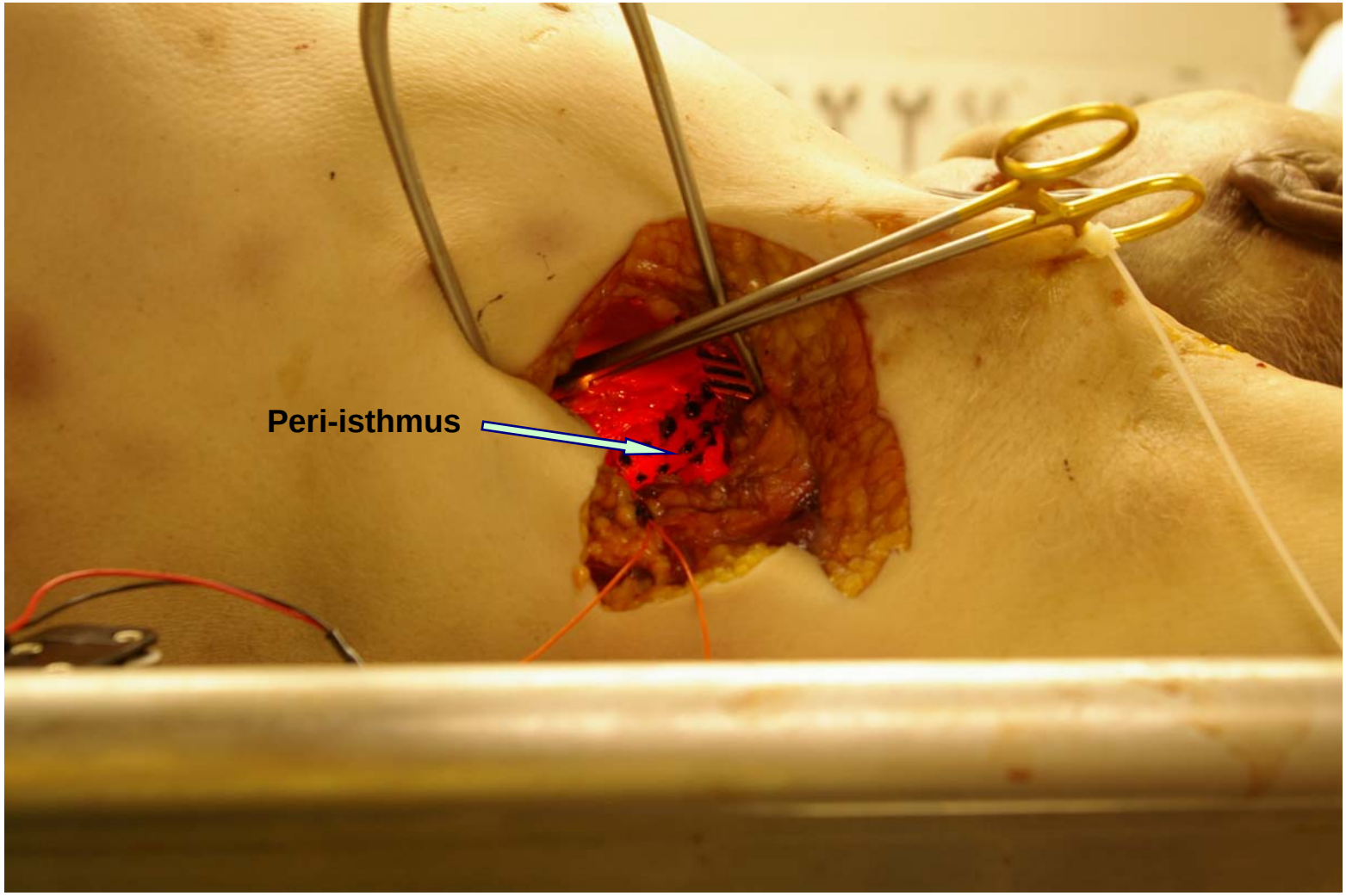
Experimental Fixture



Specimen Preparation

- Axillary thoracotomoy
  - Left arm and shoulder displaced superiorly
  - 75-mm incision between left 3rd and 4th ribs
  - 3rd and 4th ribs were spread
  - Left lung retracted
  - Exposed peri-isthmus region
  - Fifteen 2-mm diameter lead spheres glued to peri-isthmus region (cyanoacrylate gel)

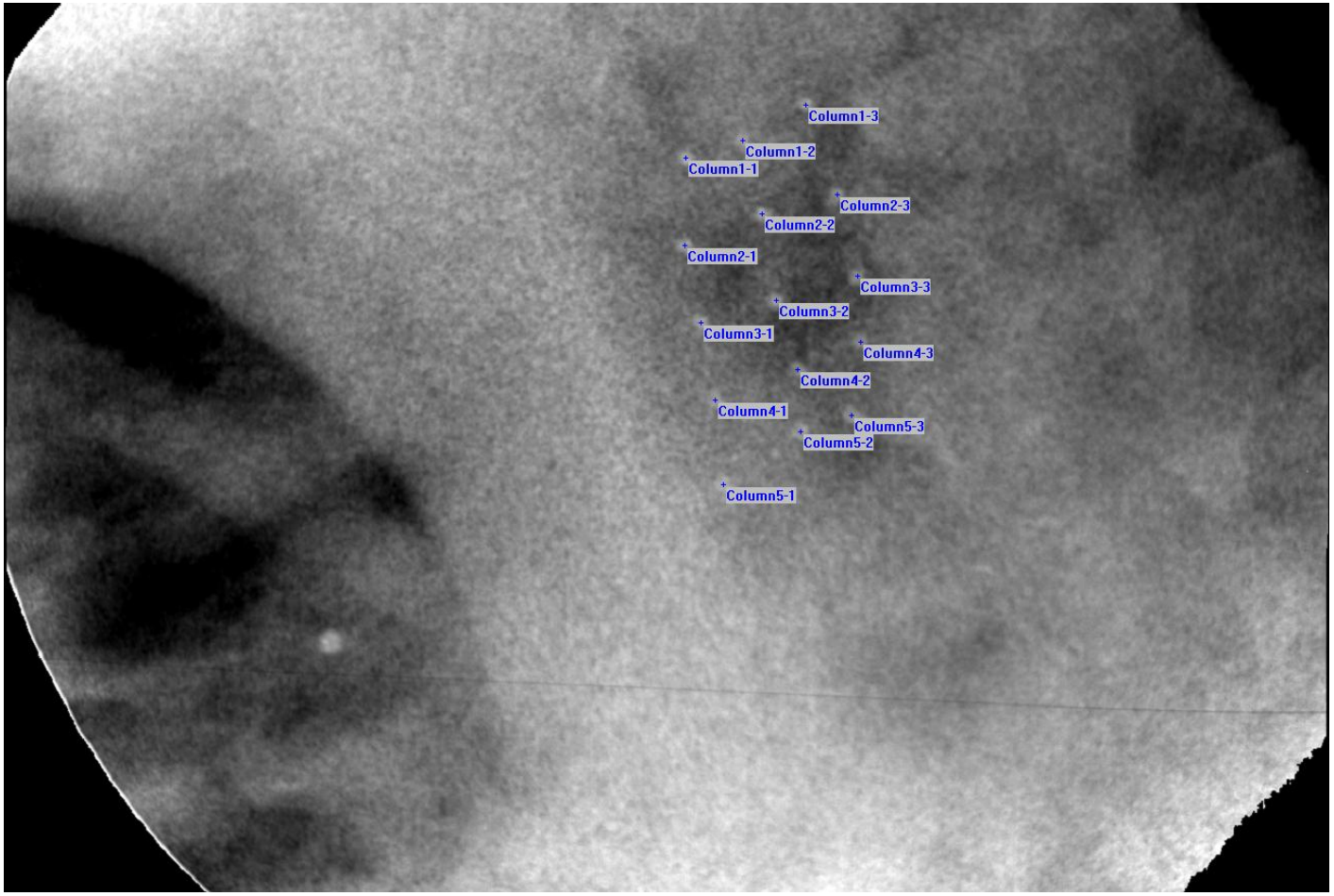
Specimen Preparation



Vascular Re-pressurization

- Left ventricle occluded using 300 ml gel
- Foley catheter above celiac trunk
- Pressure transducer through lumen until tip reached peri-isthmus region
- Perfusion fluid pass through foley lumen
- Abdominal incision sutured
- Lower extremities amputated

X-ray Image of Targets



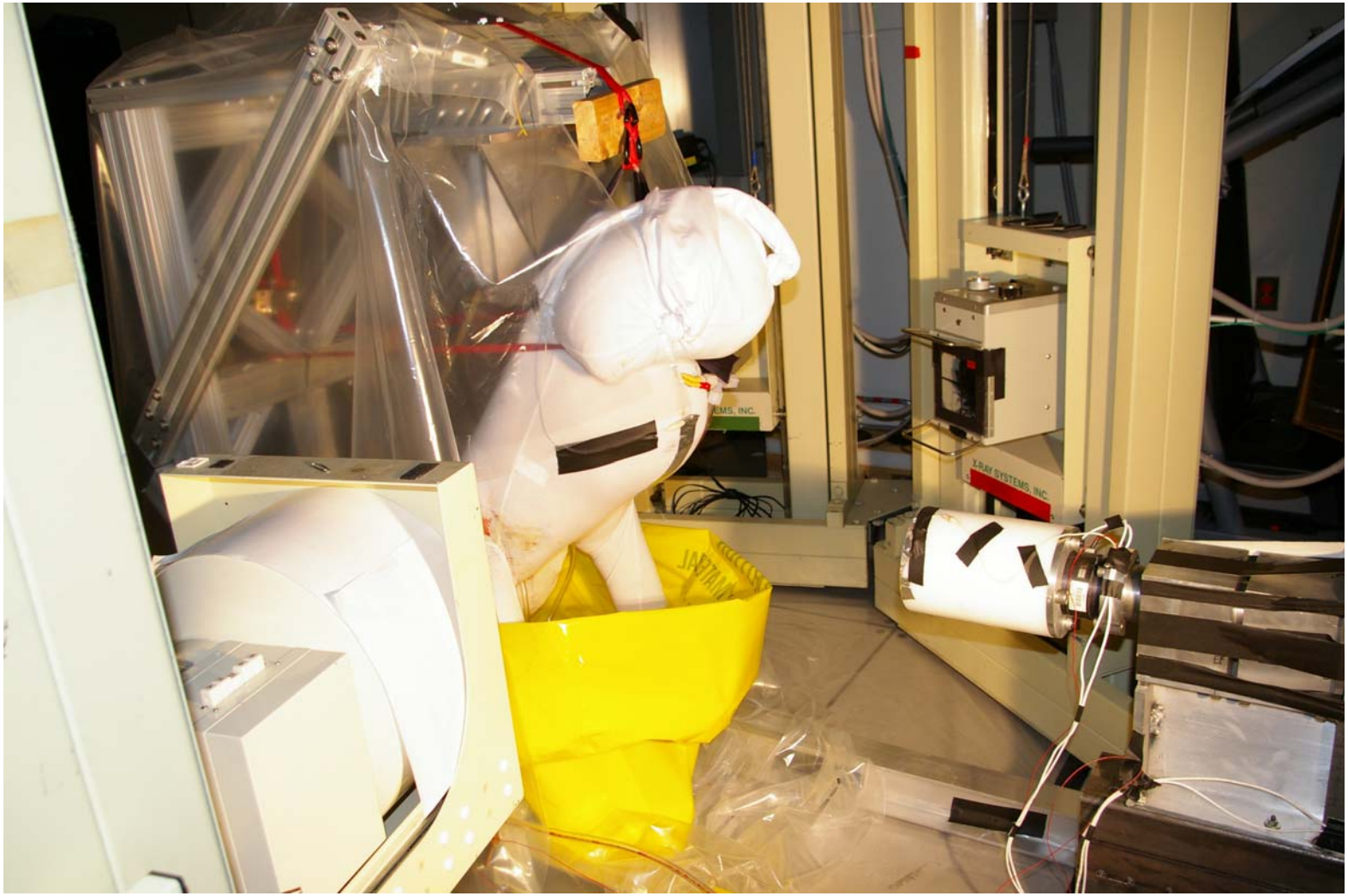
Test Setup

- Impactor nominal speed - 6.7 m/s
- Two tests
  - One frontal
  - One lateral
- Frontal
  - Impact centered over xiphoid of the sternum
- Lateral
  - Impact centered over mid-humerus
- Cadaver inverted upside down
  - Attempt to reposition heart to initial position

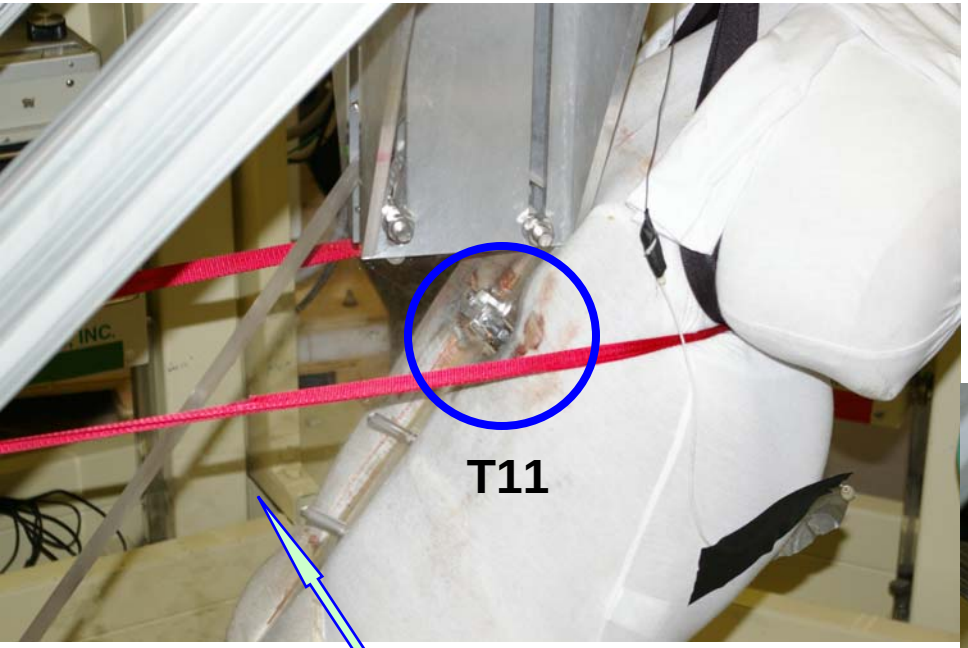
Frontal Impact

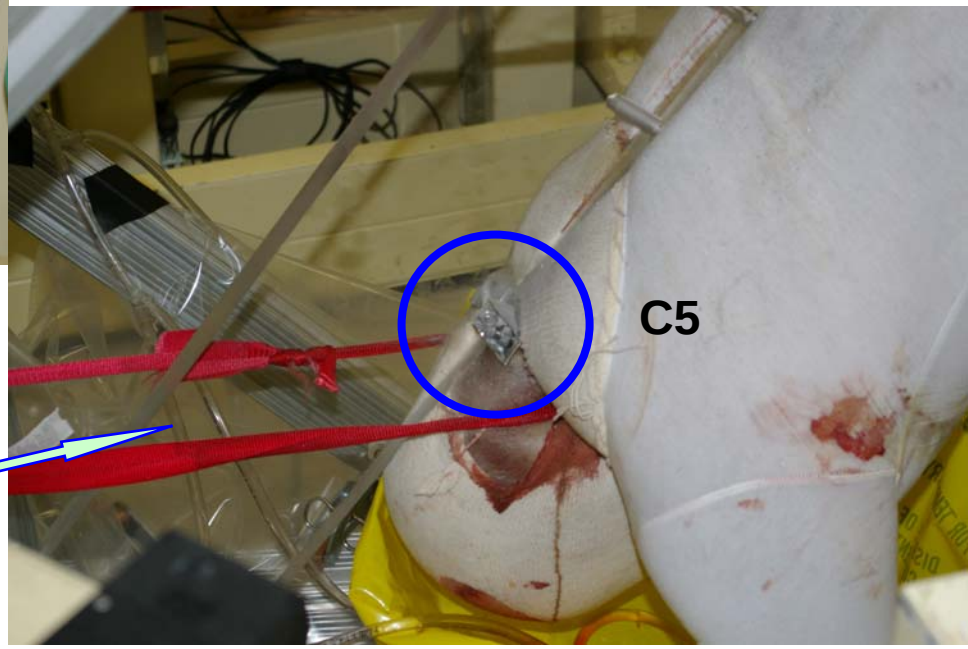
- U-bots around C5 and T11 bolted to 50-mm wide acrylic beam (part of fixture)
  - Constrain spine but allow free movement of ribs
- Acrylic beam made 45 degrees with vertical
- Arms were allowed to dangle out of x-ray field
- Subject
  - Male
  - Age 29 years
  - Weight 74 kg
  - Height 184 cm

Frontal Impact



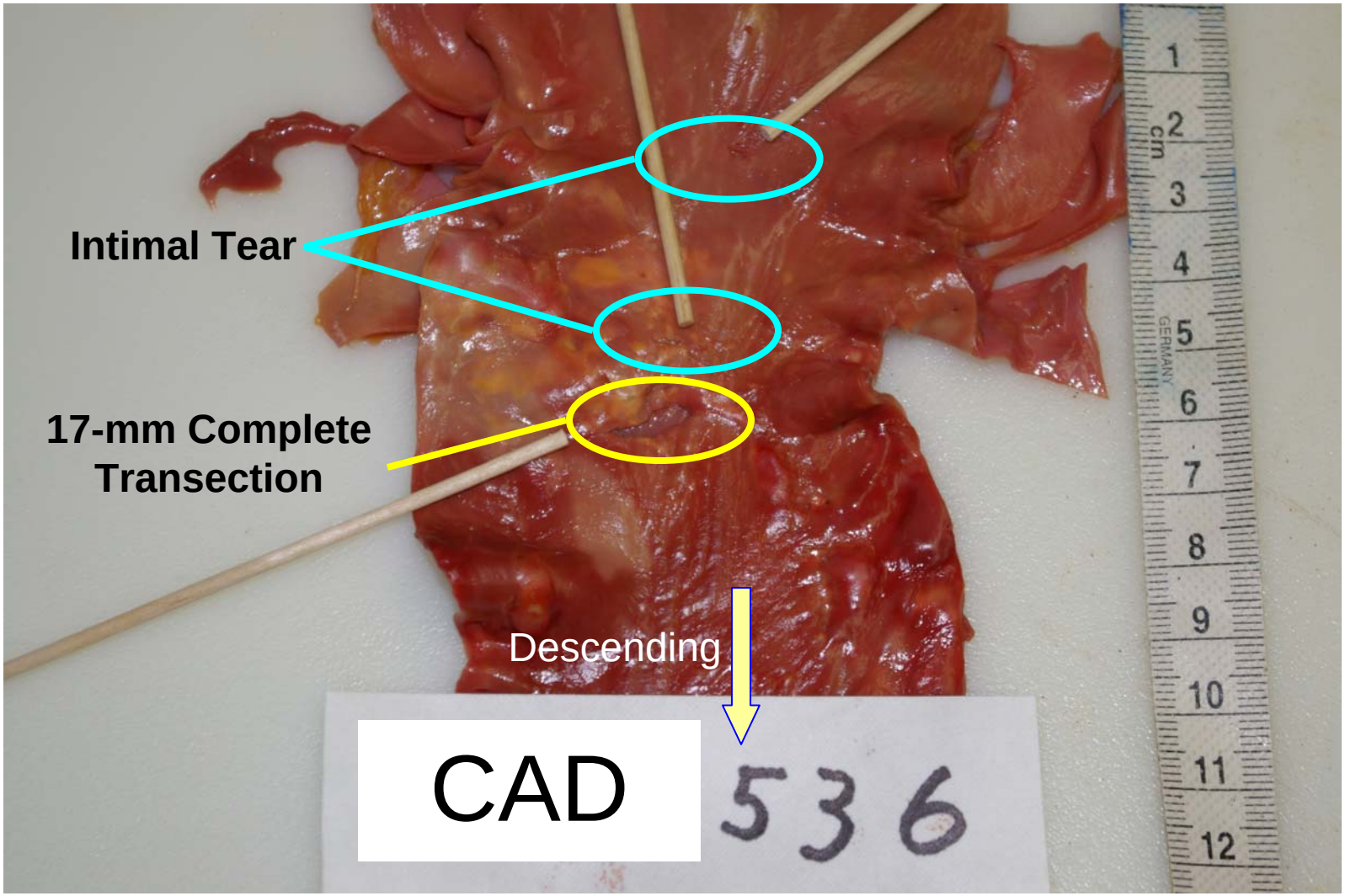
Frontal Impact – Spinal Constrains





Acrylic Beam

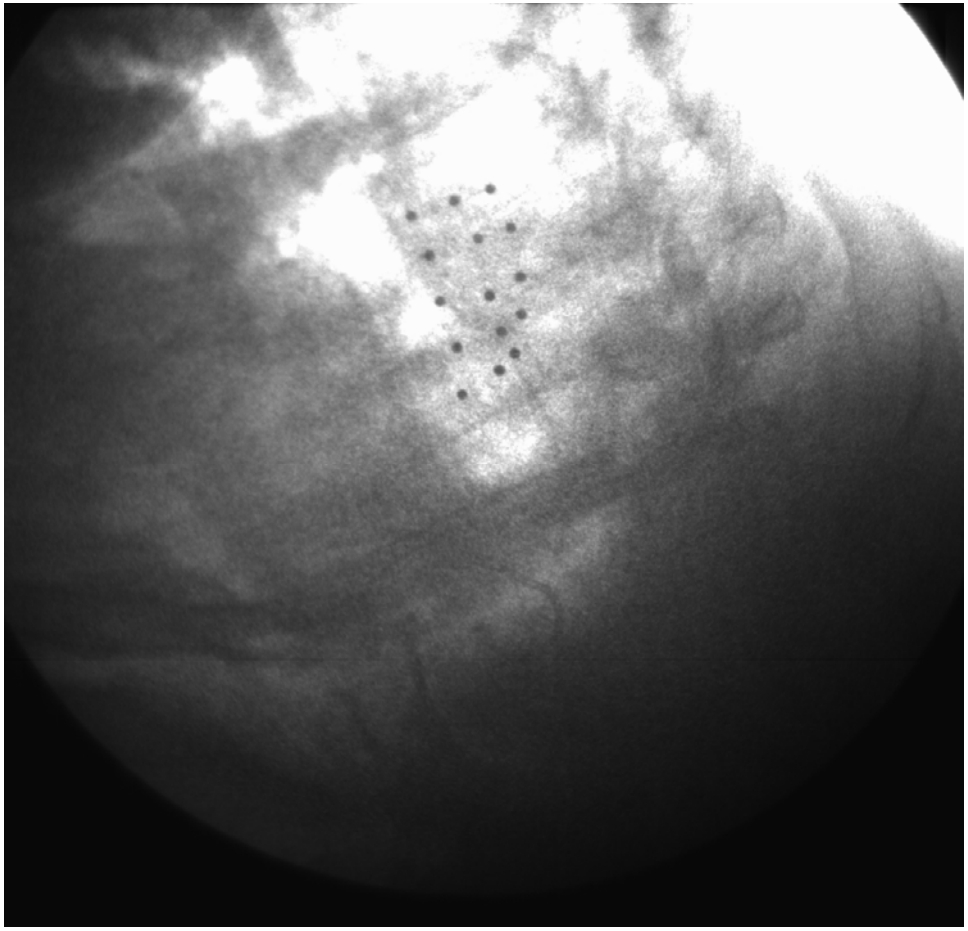
Frontal Impact - Results



Frontal Impact - Results

Peak aorta pressure 172 kPa

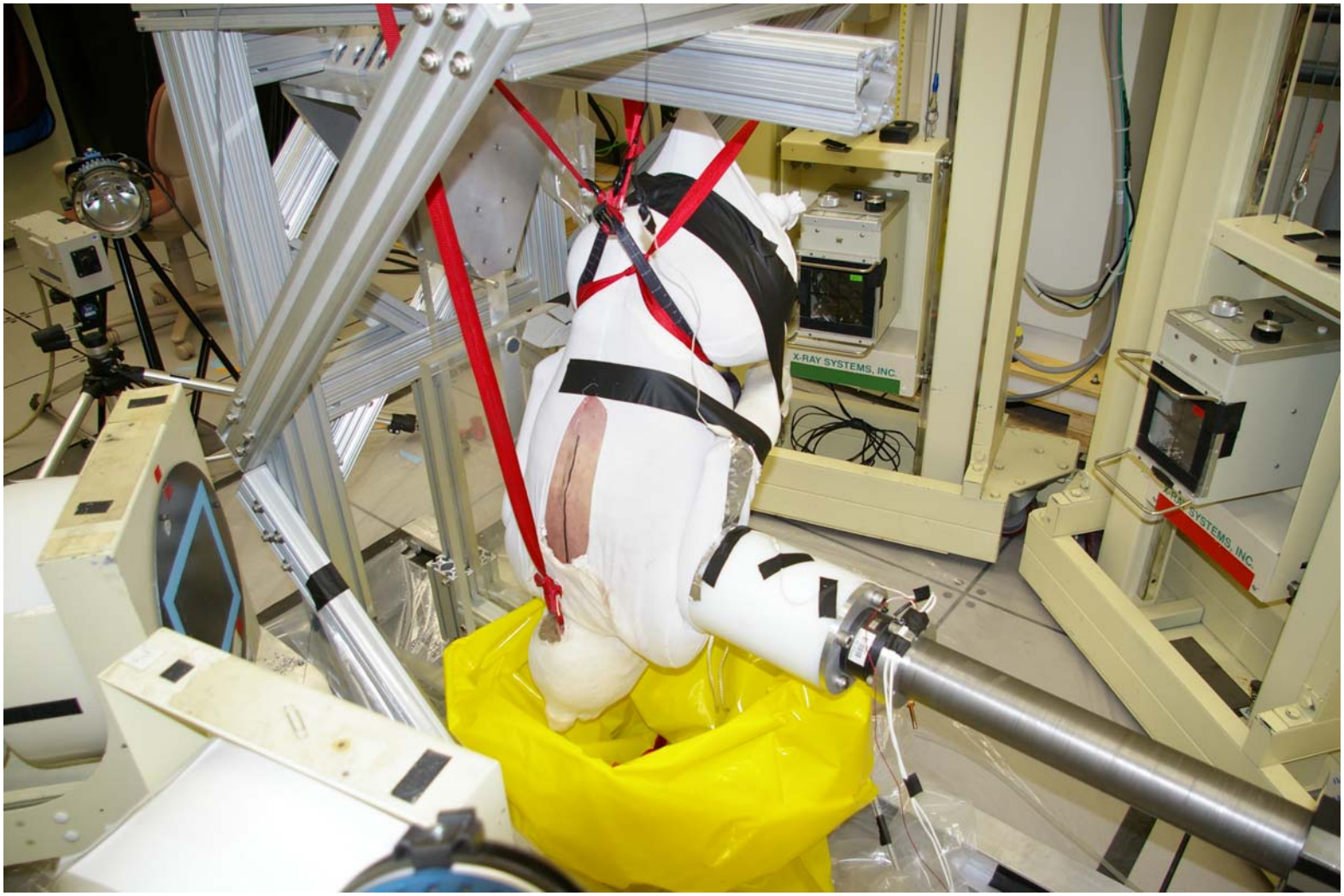
Frontal Impact - Result



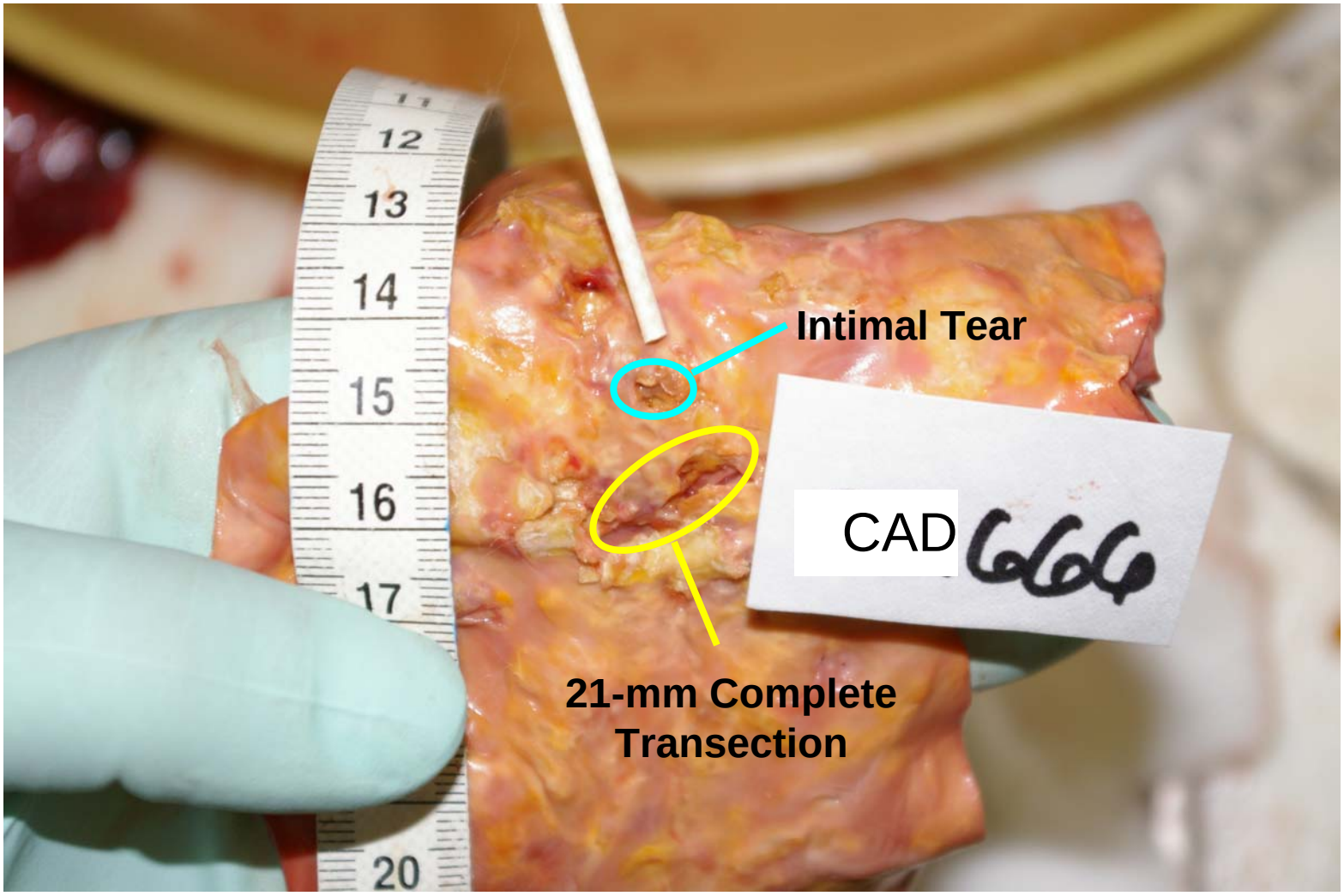
Lateral Impact

- No U-bolts, no spinal constrains
- Subject's right side against flat acrylic surface
- Both arms were involved in impact
- Subject
  - Female
  - Age: 85 years
  - Weight: 55 kg
  - Height: 163 cm

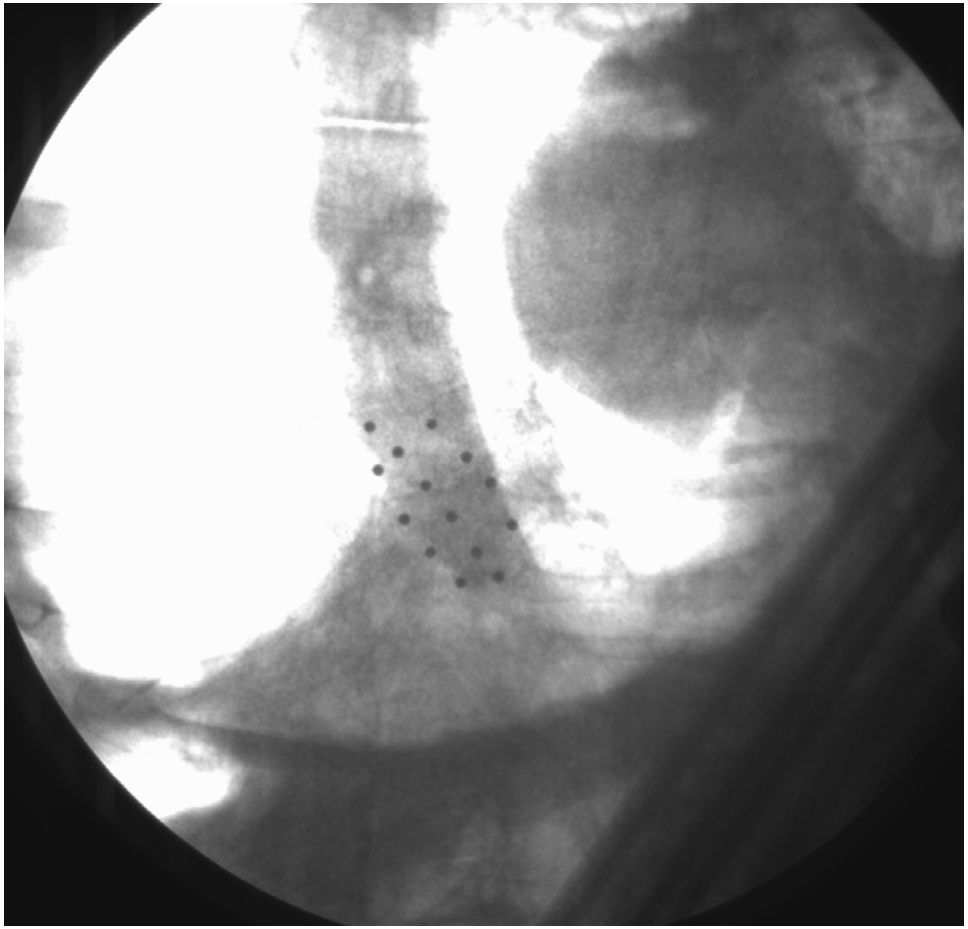
Lateral Impact



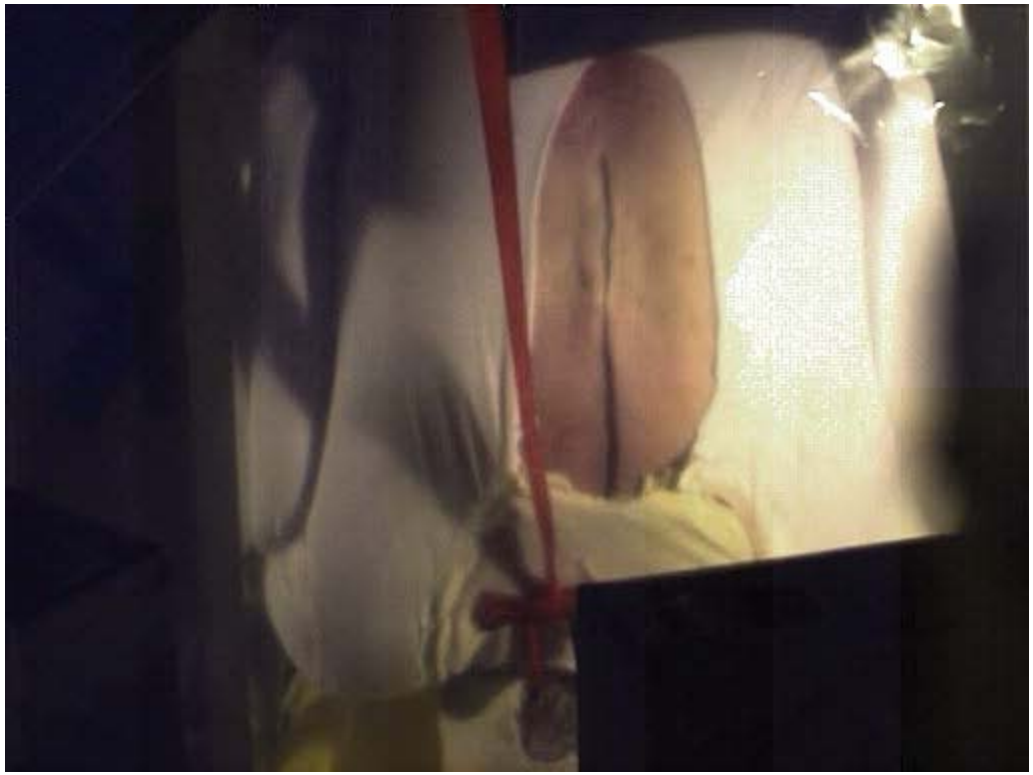
Lateral Impact - Results



Lateral Impact



Lateral Impact (Posterior View)



Peak aorta pressure 103 kPa

Lateral Impact (Latero-medial From Right)

Summary and Future Work

- Accidents reconstructions will help design future experiments
- High-speed biplane x-ray data will enable local aortic deformation
- Local aortic deformation will be used to locally validate aorta FE model of Wayne State Human Model

Future Work

- Total of 20 cases obtained from UMDNJ
  - Lateral or oblique simulations of car vs. car or car vs. SUV will be simulated first
  - Frontal car vs. car or car vs. SUV crashes will be simulated next
  - Frontal or lateral crashes with a fixed object will be simulated
- Two additional cadaver tests
  - High-power pretensioner test to abdomen
  - Lateral test without involvement of arms

Acknowledgment

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Thank you for your kind attention

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