JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

# Lightweight Armor-Induced Thoracic Behind Armor Blunt Trauma: Understanding Regional Injury Risk and Armor Design Implications


August 5, 2026
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MHSRS
Military Health System Research Symposium

# Lightweight Armor-Induced Thoracic Behind Armor Blunt Trauma: Understanding Regional Injury Risk and Armor Design Implications

August 5, 2026

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[2]*Armed Forces Medical Examiner System, Defense Health Agency, Dover Air Force Base, DE 19902*
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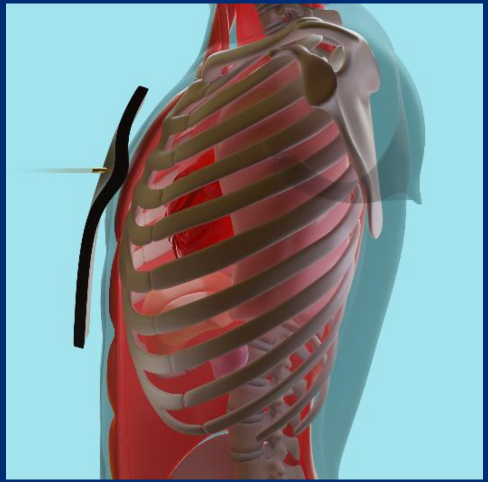
# Disclosure Slide

I, Alexander Iwaskiw, have no commercial relationships to disclose or conflicts of interest to report

**Some slides contain graphic and sensitive photos of dissections from human cadaver experiments**

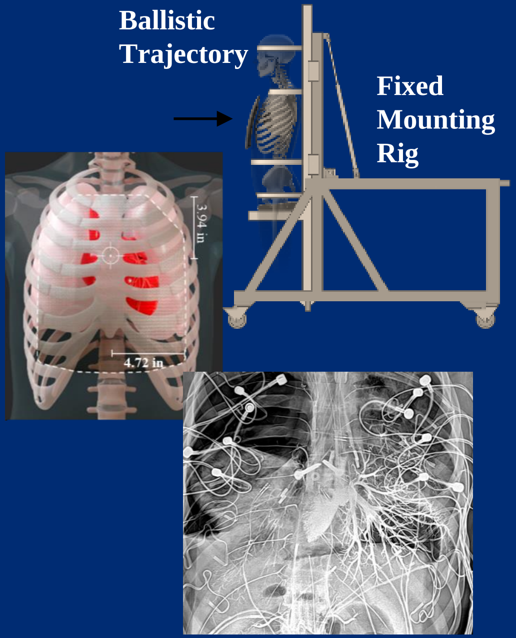
# Agenda

## BABT Introduction

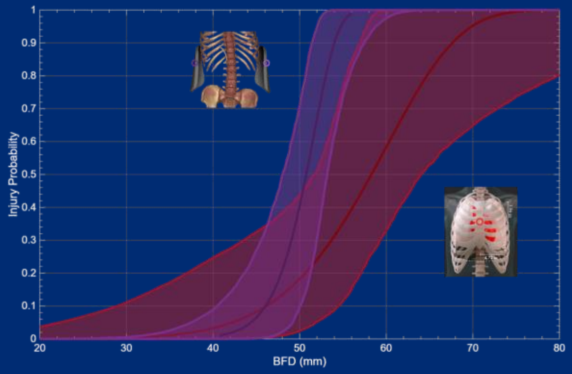


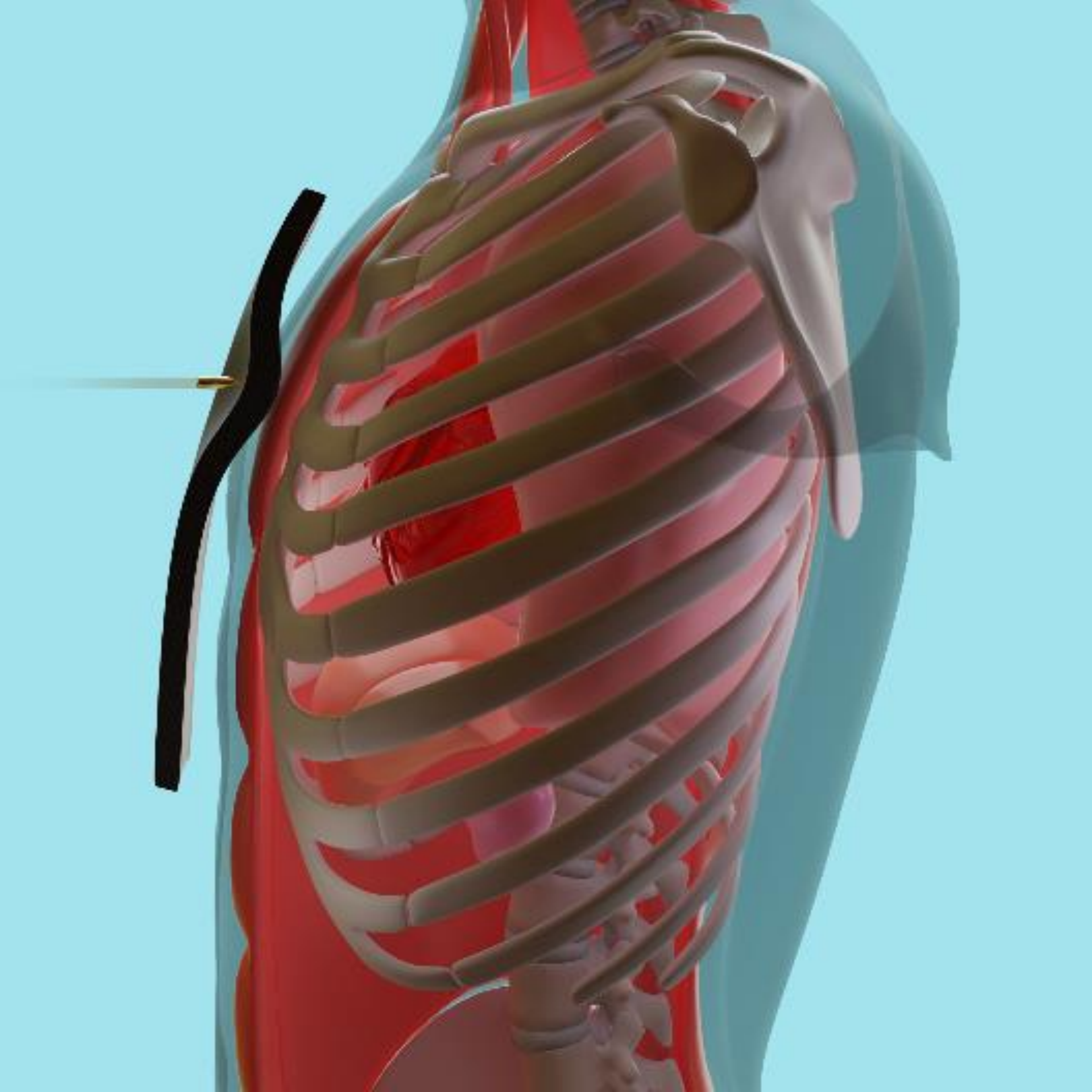
## Program Motivation

## Program Methods & Outcomes




## Program Achievements





Behind Armor Blunt Trauma (BABT) is caused by the backface of ballistic armor striking the wearer as a result of a non-penetrating ballistic event.

# BABT Landscape

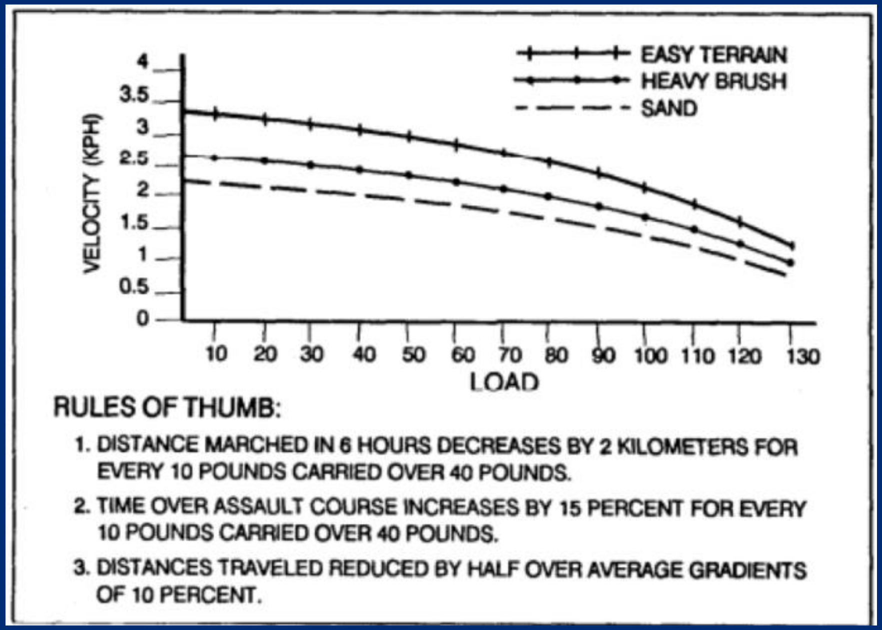
## Motivating Conditions

1. Desire to lighten the load

### Warfighter Survivability

- Higher PPE weight can increase fatigue [1] and decrease mission-critical equipment
- Over design can lead to increased costs for PPE systems
- Need to lighten load to increase warfighter operational effectiveness

**Soldier Speed as a Function of Load and Terrain[1]**




**Soldier Equipment Weights [2]**

| Notional Individual Soldier Equipment | Pounds |
|---|---|
| Army Combat Helmet | 6.5 |
| Body Armor | 33.2 |
| 2 armor plates (ESAPI) | 12.5 |
| IOTV | 15.7 |
| 2 side plates | 5 |
| Weapon + Ammo (210 rounds) | |
| M4 | 5.9 |
| M249 | 17 |
| Ammo | 7 |
| Light Thermal Sight | 1.9 |
| Night Vision Goggles (PVS14) | 1.4 |
| Rucksack | 8 |
| Power Sources (Batteries: 3-day mission) | 16 |
| Comms/Radio (Leader Only) | |
| PRC148 | 1.9 |
| PRC152 | 2.6 |
| Rations (3-day mission) | |
| First Strike Ration | 6 |
| MRE | 13.5 |
| Other (Uniforms, water, personal hygiene, first aid, etc.) | 19 |

[1] Under heavier loads and in more adverse terrain, soldiers move slower. (Source: Army Field Manual 21-18, Procedures and Techniques of Foot Marches, page 5-5)
[2] J. Q. Zheng and S. M. Walsh, "Materials, manufacturing, and enablers for future soldier protection," in Lightweight Ballistic Composites, 2nd ed., Woodhead Publishing, 2016.

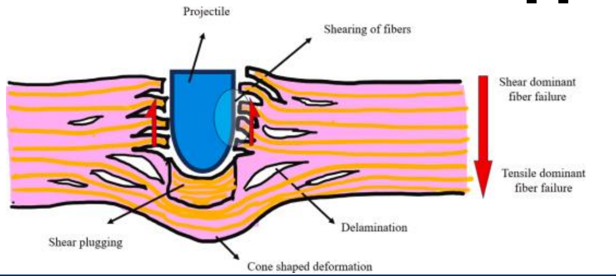
# BABT Landscape

## Motivating Conditions

1. Desire to lighten the load
2. Modern materials leading to high energy threats defeated

**Dyneema Armor Panels [3]**

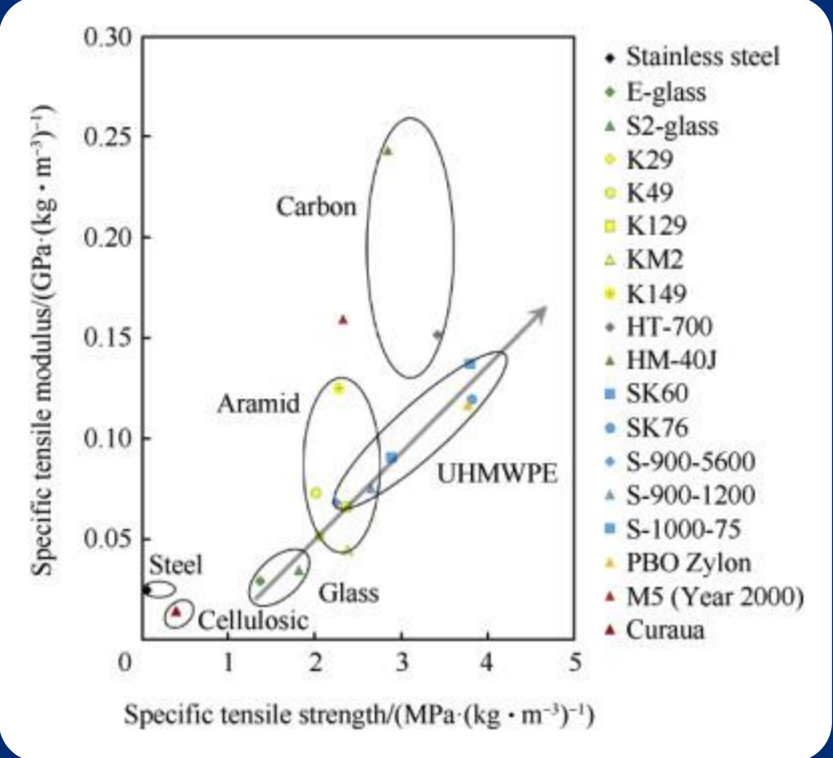
**UHMWPE Defeat Mechanism [4]**




### UHMWPE Development

- UHMWPE fibers (Spectra®, Dyneema®) emerged as a ballistic material in the 1980s
- Exceptional specific strength and specific stiffness
- Allow for higher level of protection at thinner form factors and lower weights

**High Performance Ballistic Material [5]**

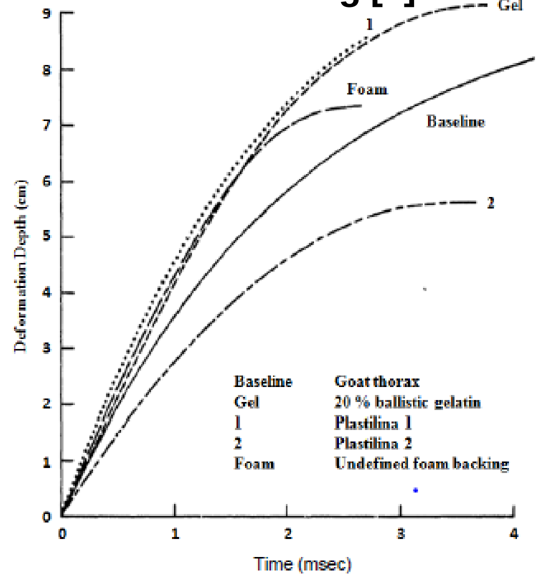


# BABT Landscape

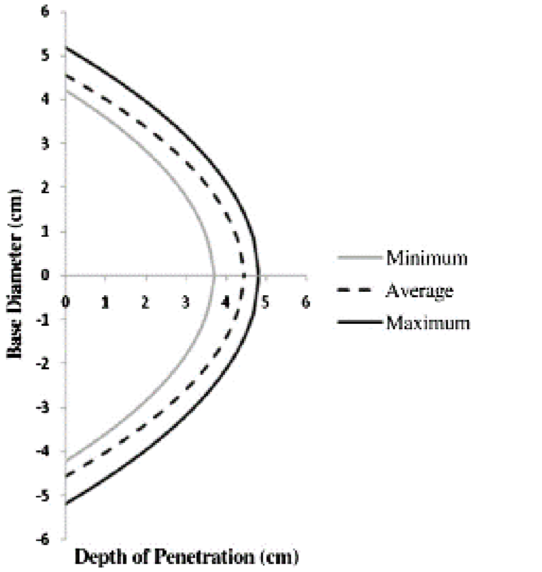
## Motivating Conditions

1. Desire to lighten the load
2. Modern materials leading to high energy threats defeated
3. Unknown type and risk of BABT injuries with modern armor

**Deformation response of BABT with backing [7]**




**BABT shape with backing [7]**




### BABT Injury Studies

- Foundational BABT studies were developed using animal models, soft armor, and limited threat conditions [6].
- Injuries due to UHMWPE are not known
- Legacy clay-based BABT criteria may not represent modern armor performance.


[6] Prather R, Swann C, Hawkins C; Backface Signatures of Soft Body Armors and the Associated Trauma Effects. ARCSL-TR-77055. Aberdeen Proving Ground, MD, Edgewood Arsenal, 1977.
[7] Hanlon, Erin, and Patrick Gillich. "Origin of the 44-mm behind-armor blunt trauma[7] Hanlon, Erin, and Patrick Gillich. "Origin of the 44-mm behind-armor blunt trauma standard." Military medicine 177.3 (2012): 333-339.

# BABT Landscape

Motivating Conditions

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3. Unknown type and risk of BABT injuries with modern armor

High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# BABT Landscape

Motivating Conditions

1. Desire to lighten the load
2. Modern materials leading to high energy threats defeated
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Research Gap

High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# USSOCOM JHU/APL Research Team

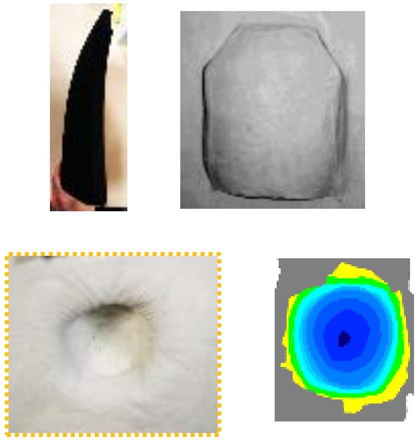
- USSOCOM PM - Protection & Integration
  - Team of engineers and SMEs
  - Collaborate with SOCOM customers to provide guidance to industry/researchers
  - Aim to deliver an educational product to customer requirements representatives to better understand risk acceptance related to BABT

- JHU/APL
  - Team of engineers and SMEs
  - Facilities and capabilities for engineering support, data analysis, and program integration

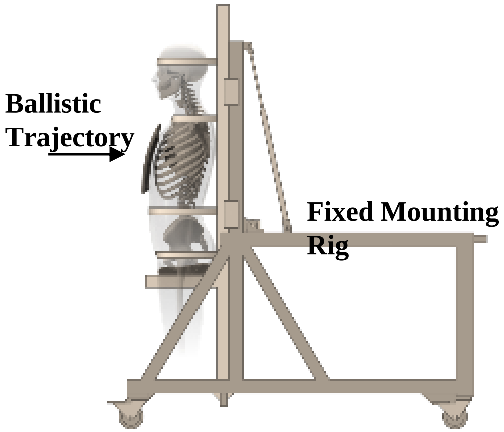
- JTS and AFMES
  - Forensic pathologists and trauma surgeons
  - Facilitate medical forensics and categorization of operational outcome

# Evaluating a Future Injury Threat

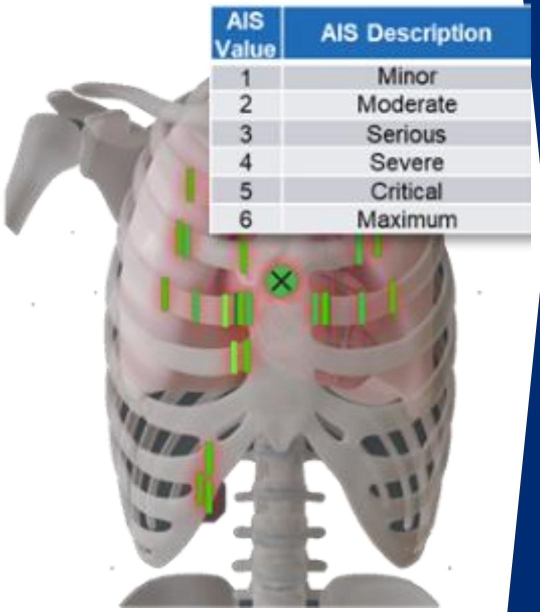
Matched clay standard testing to establish relevant backface loading



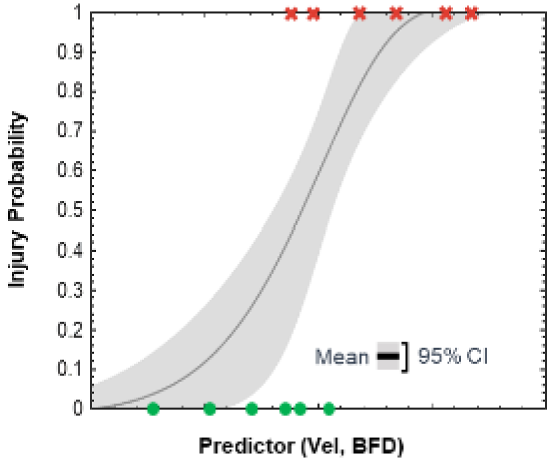
Simulate BABT events on instrumented postmortem human surrogates (PMHS)




Establish Projected Operational Injury Outcome (POIO)




Generate injury risk curve with survival analysis



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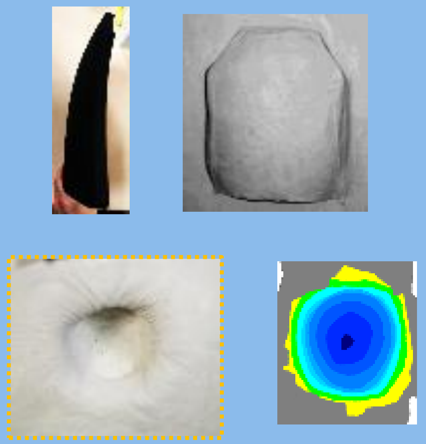

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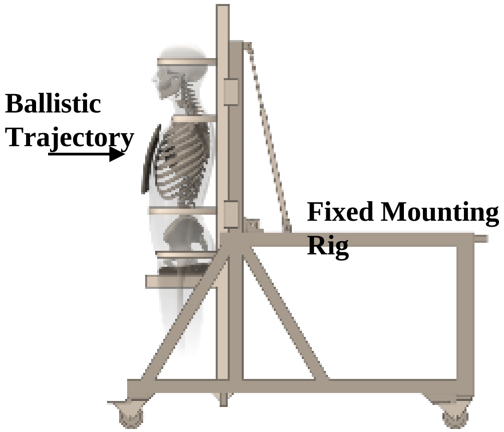


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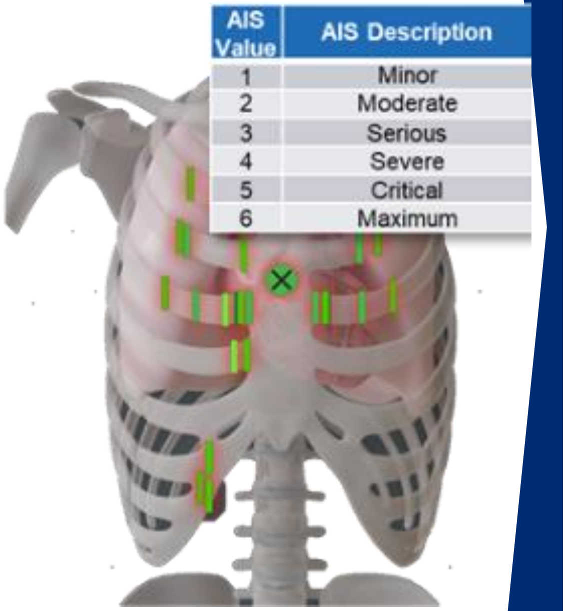


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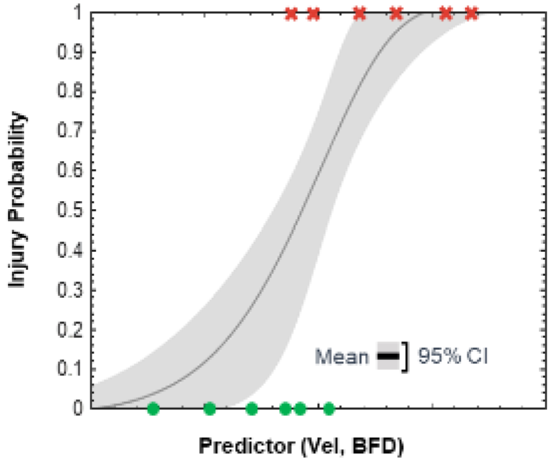


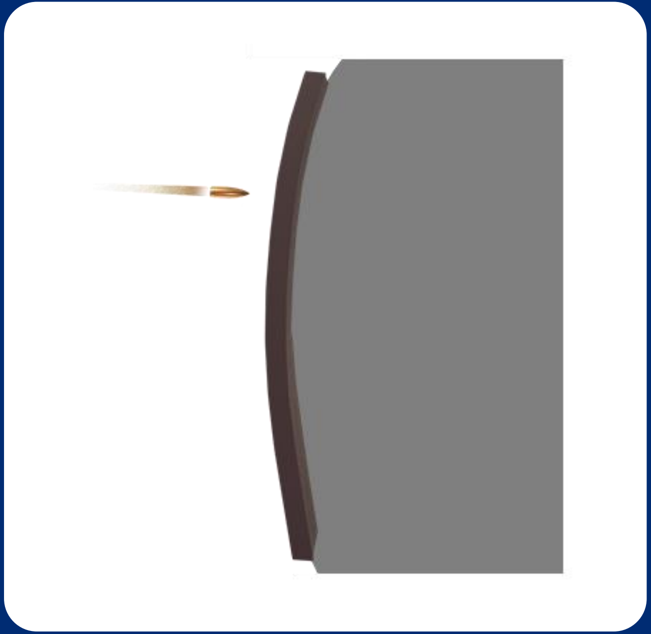
# Ballistic Conditions

- UHMWPE plates
- Threat: 7.62x51mm, M80 ball, 149-gr lead-core
- Tested ranges of interest mostly above 44mm
- Single lot, same as clay
- Custom carrier, no soft backing


| BABT Impact location | Weight (lb) | Thickness (mm) | Tested clay BFD range (mm) |
|---|---|---|---|
| **Sternum** | 2.24 | 14.56 | 40.1 - 60.8 |
| **Rear (spine)** | 2.24 | 14.72 | 41.7 - 61.0 |
| **Side** | 1.20 | 15.06 | 40.3 - 56.2 |
| **Lower Abdominal** | 1.24 | 11.86 | 48.0 - 58.4 |

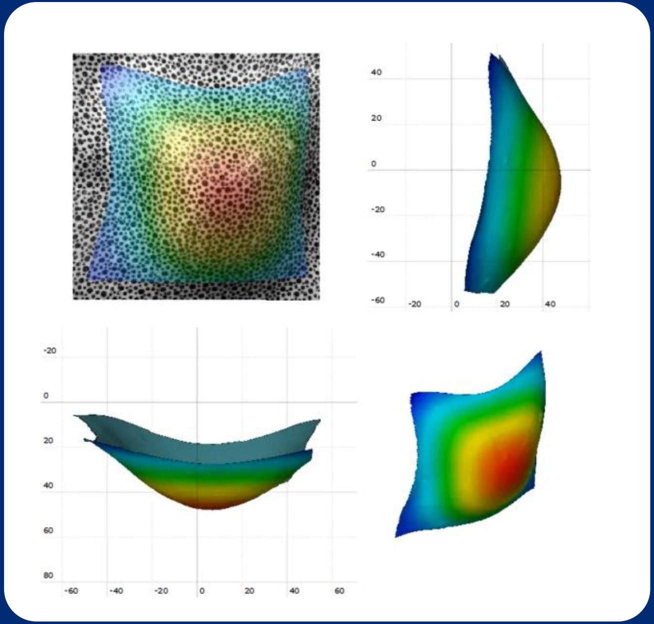
# Matched Pair Testing Performed

### Clay Standard Tests



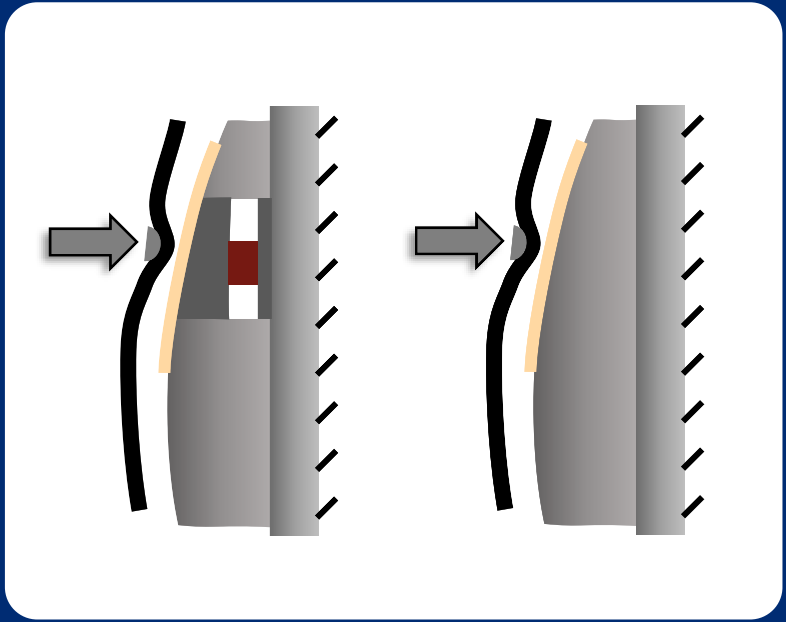
- Measured performance of UHWMPE plate using standard method for armor test and evaluation
- Developed injury risk curves based on clay deformation

### Unbacked Digital Image Correlation



- Characterized backface deformation (e.g., kinematics and shape) of UHWMPE plates
- Implemented findings to improve current injury risk curves

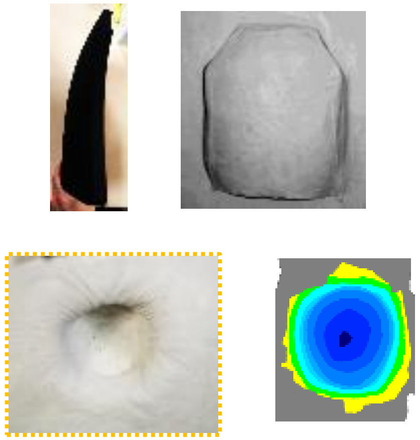
### Load Cell and Clay – Effect of Tissue Thickness and Air Gap



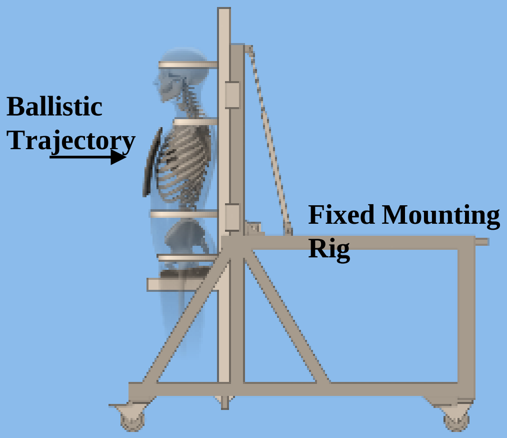
- Assessed effect of tissue thickness and standoff on armor backface deformation and load transmission
- Implemented findings to improve current injury risk curves

# Evaluating a Future Injury Threat

Matched clay standard testing to establish relevant backface loading



Simulate BABT events on instrumented postmortem human surrogates (PMHS)

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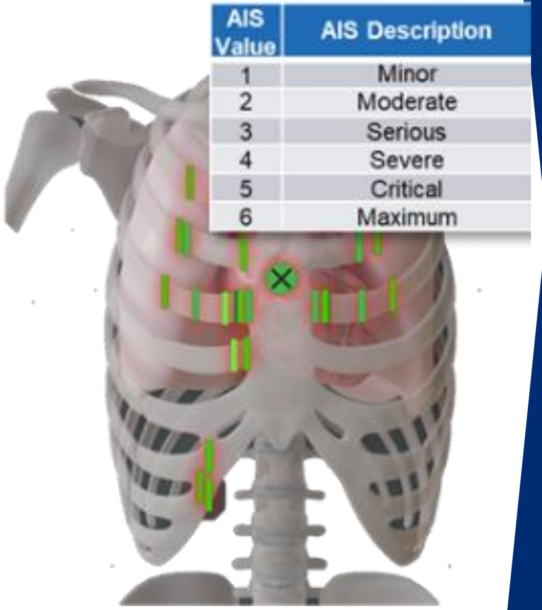
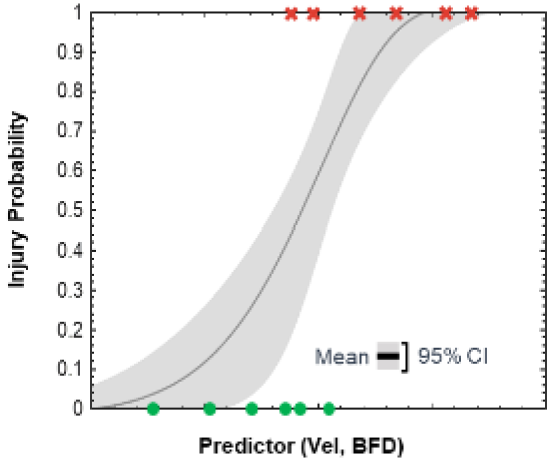
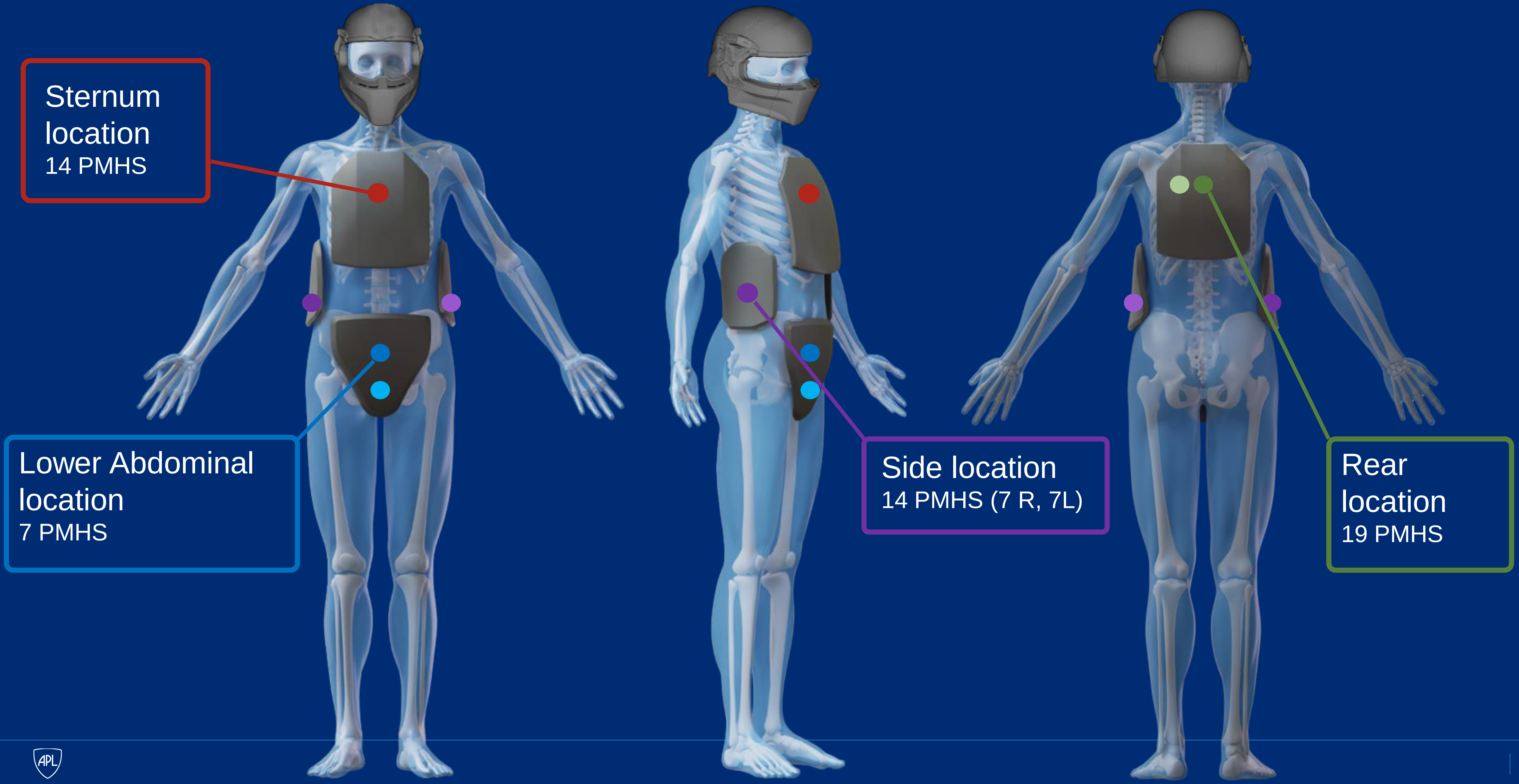


| AIS Value | AIS Description |
|---|---|
| 1 | Minor |
| 2 | Moderate |
| 3 | Serious |
| 4 | Severe |
| 5 | Critical |
| 6 | Maximum |

Generate injury risk curve with survival analysis

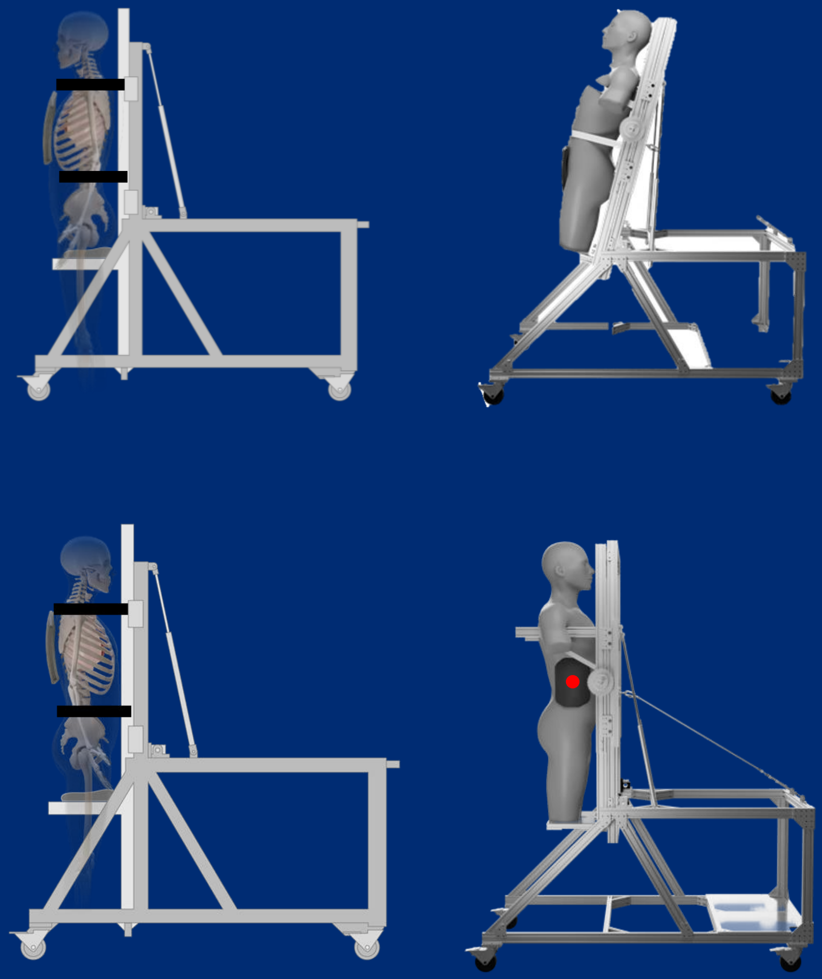


# PMHS Testing Summary

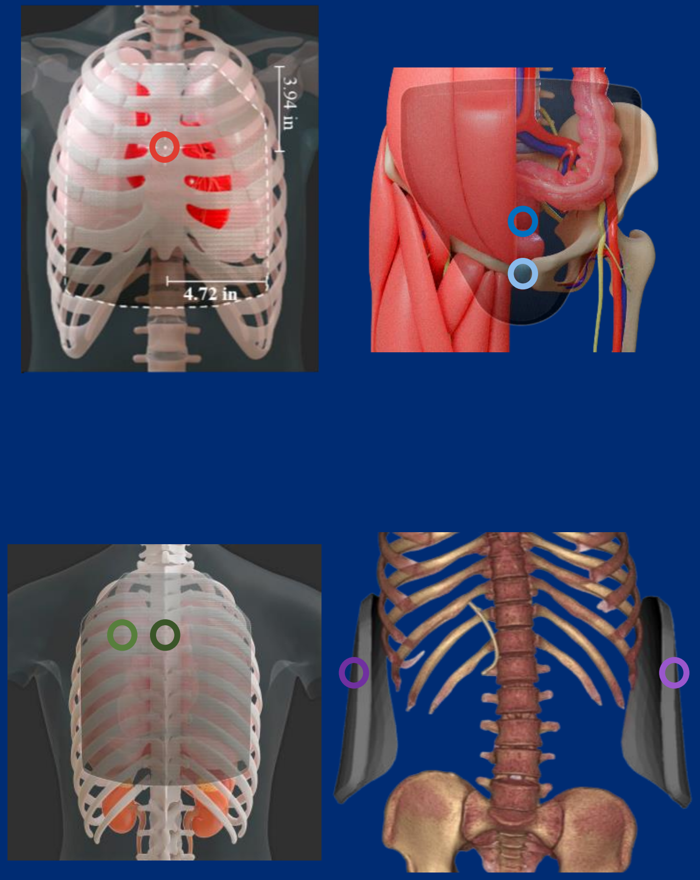


# Simulating BABT Events on PMHS

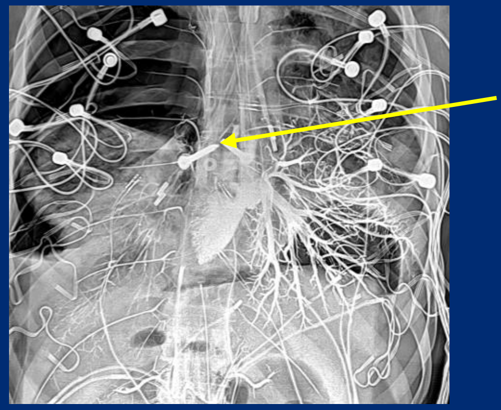
Fixturing



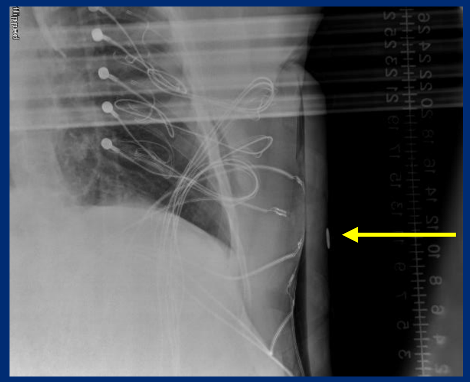
Armor Alignment




Pre-Test X-rays




***Shot view – Sternum***



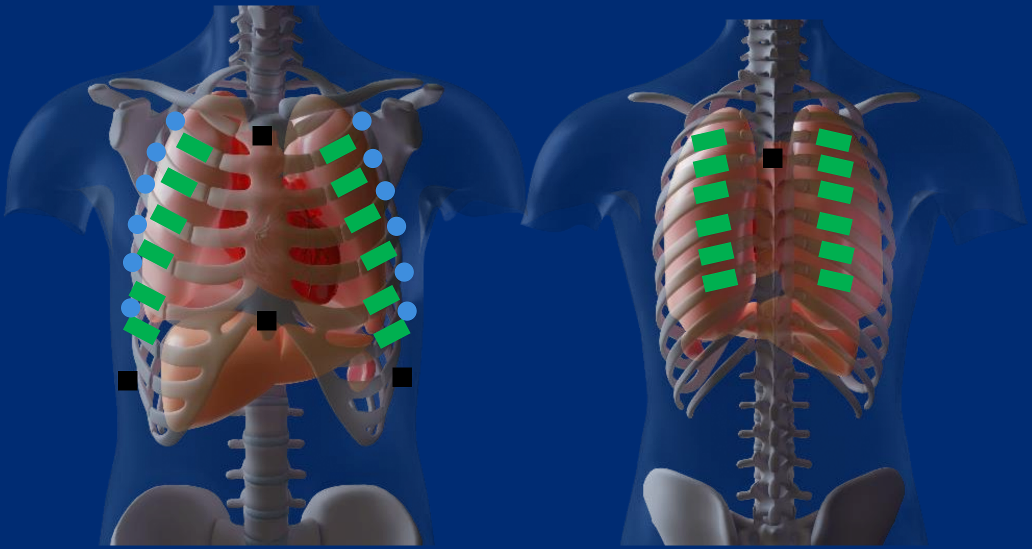

***Lateral view – Lateral rib cage***

# Simulating BABT Events on PMHS

## External Instrumentation

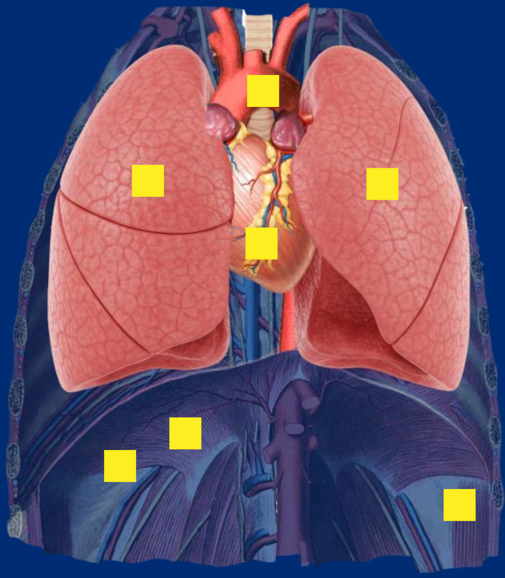
Contact Force Sensors

## Skeletal Instrumentation



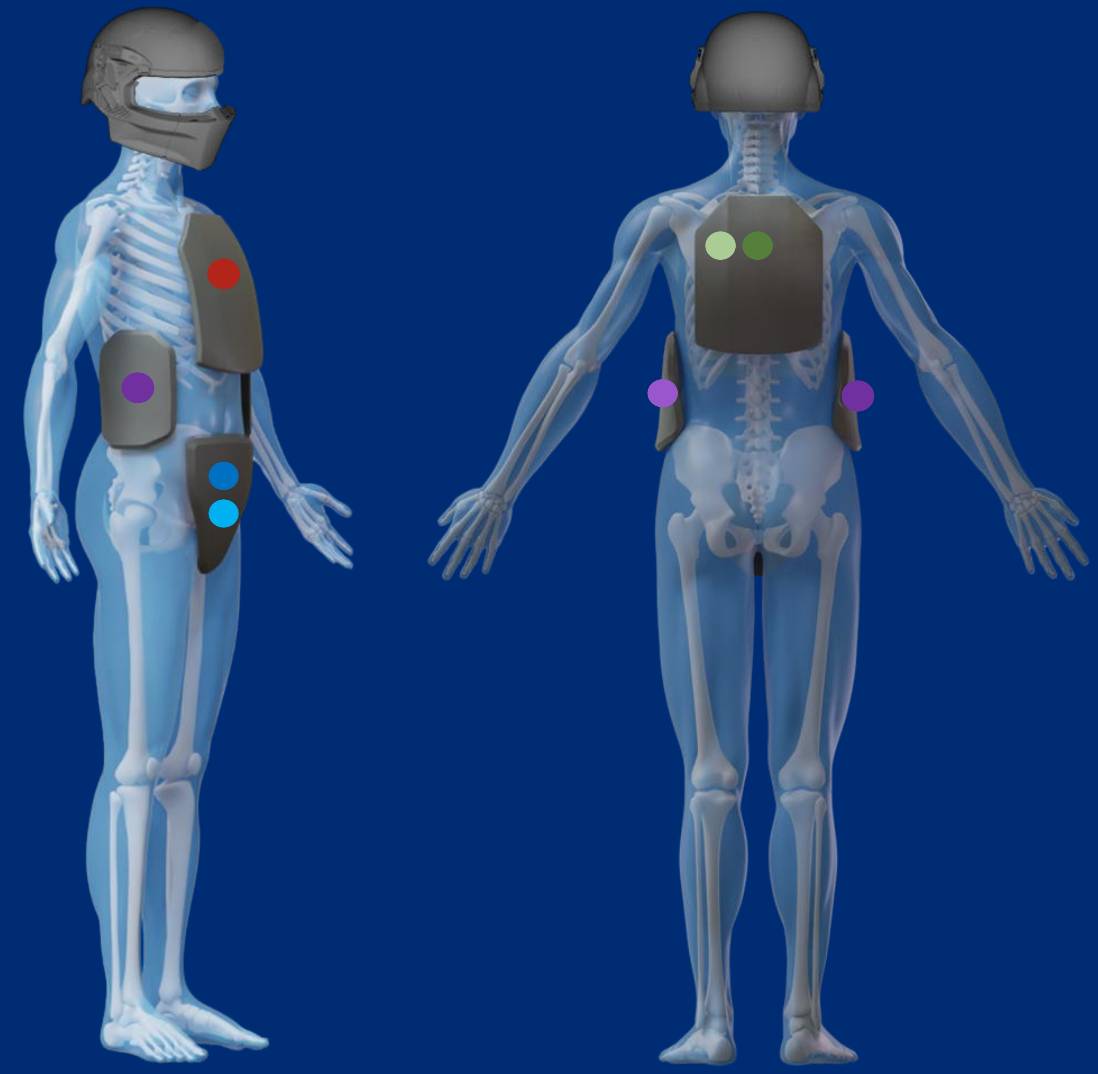
- Single Axis Strain Gauge
- Acoustic Emissions Sensors
- Single Axis Accelerometers

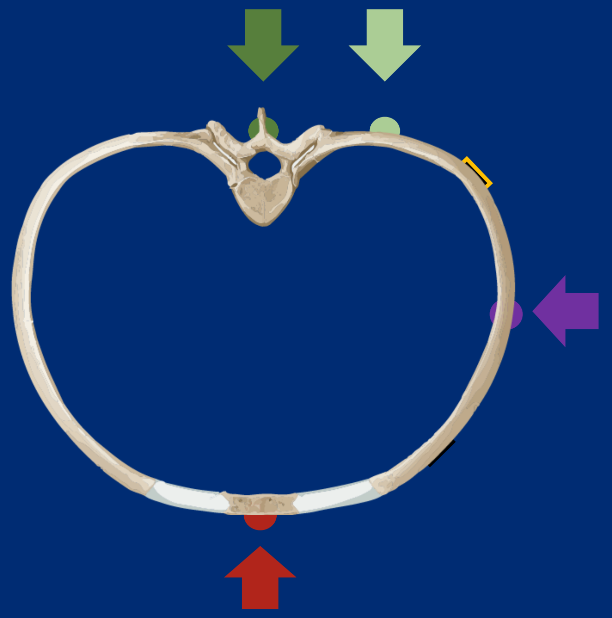
## Organ Instrumentation

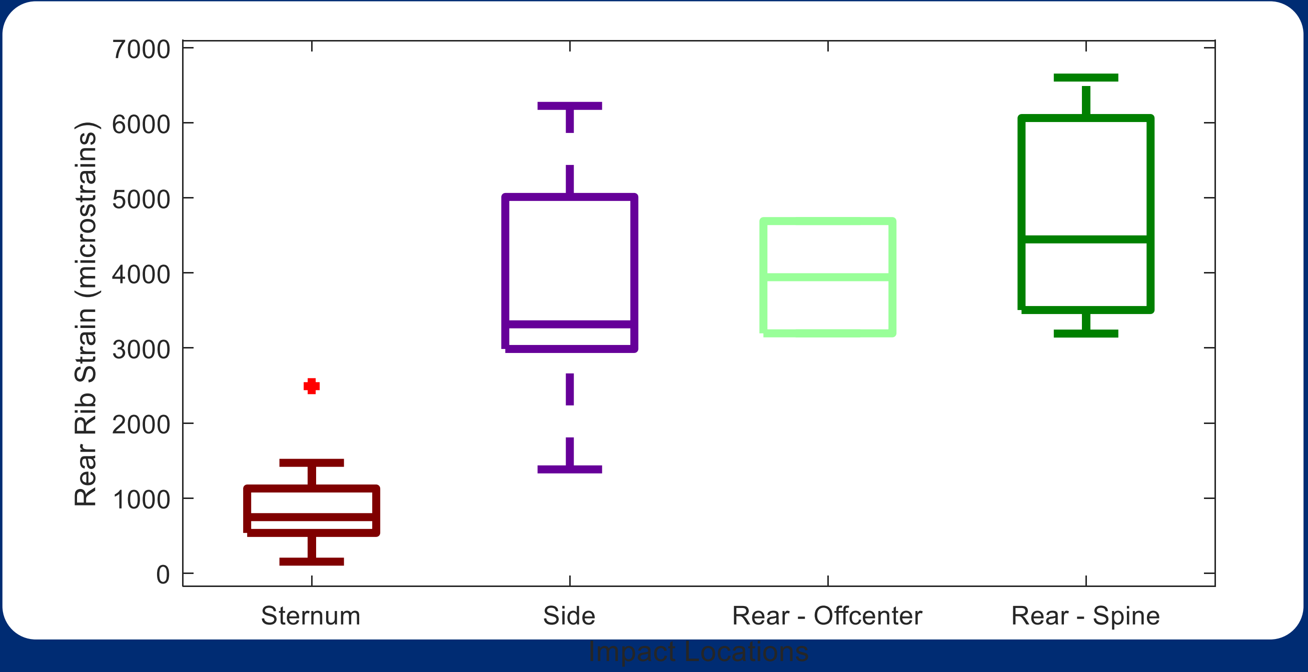


Pressure Sensors

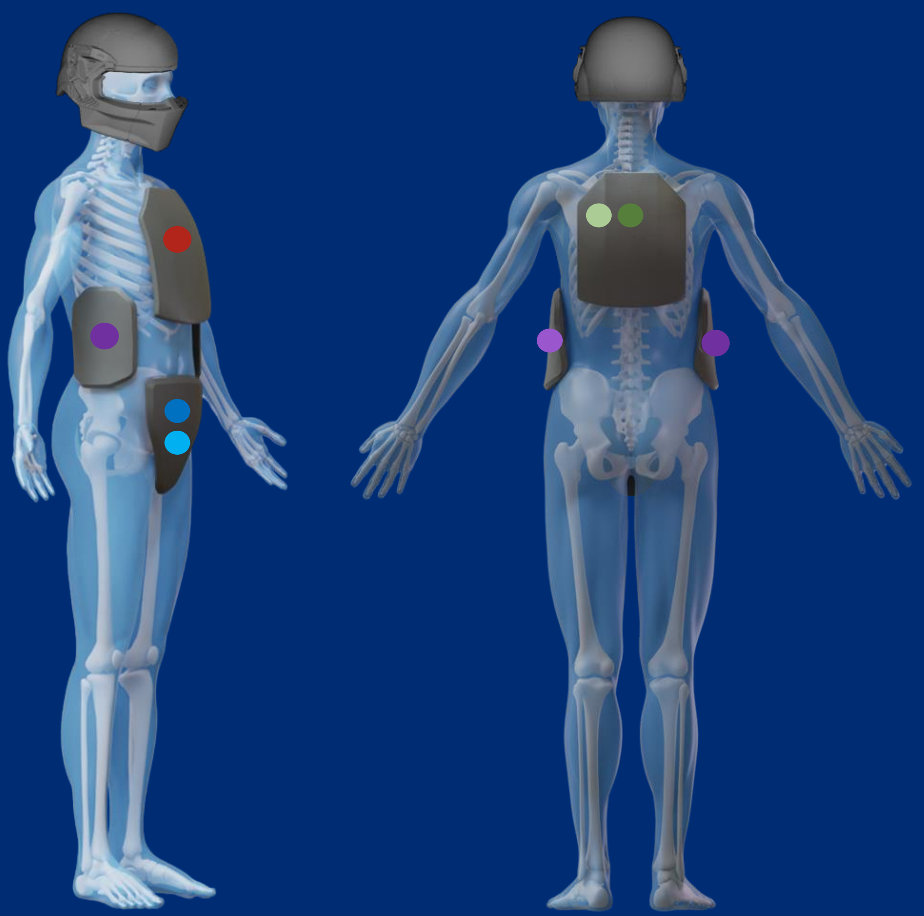
# Regional Response

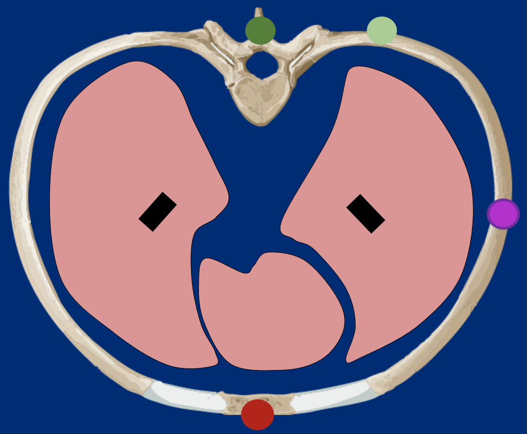


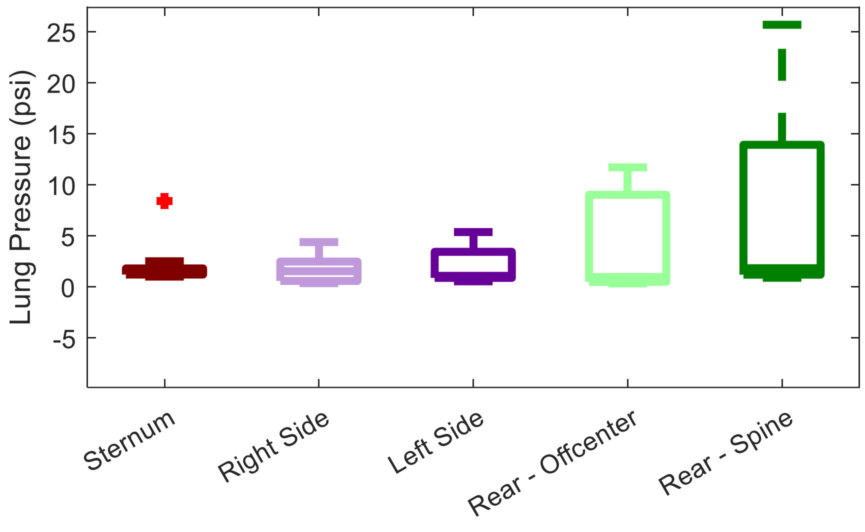


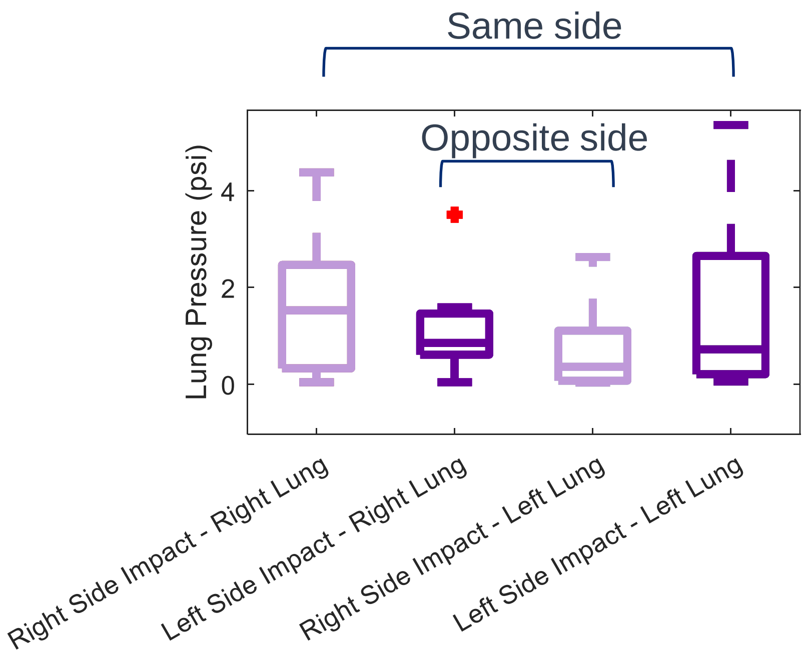


# Regional Response



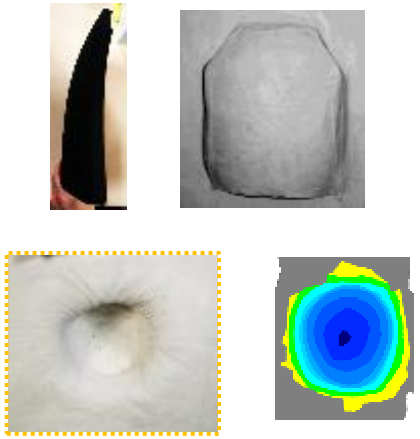




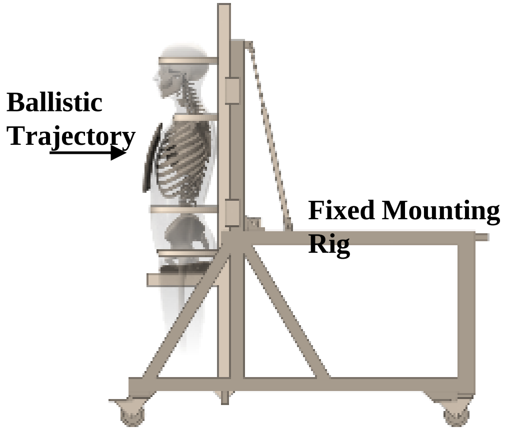



# Evaluating a Future Injury Threat

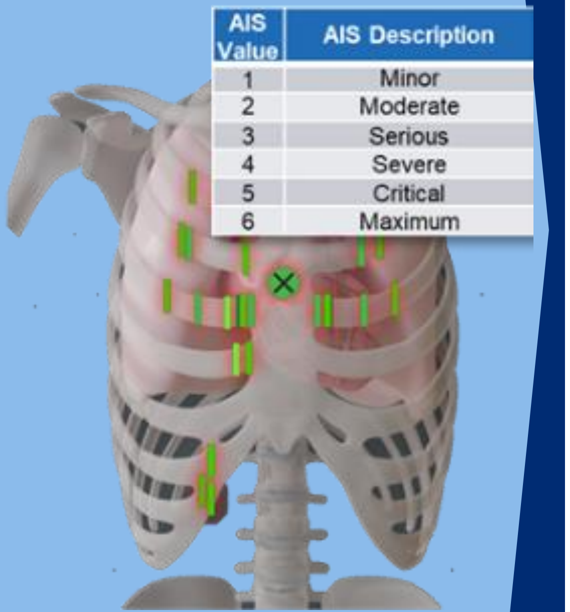
Matched clay standard testing to establish relevant backface loading



Simulate BABT events on instrumented postmortem human surrogates (PMHS)




Establish Projected Operational Injury Outcome (POIO)



| AIS Value | AIS Description |
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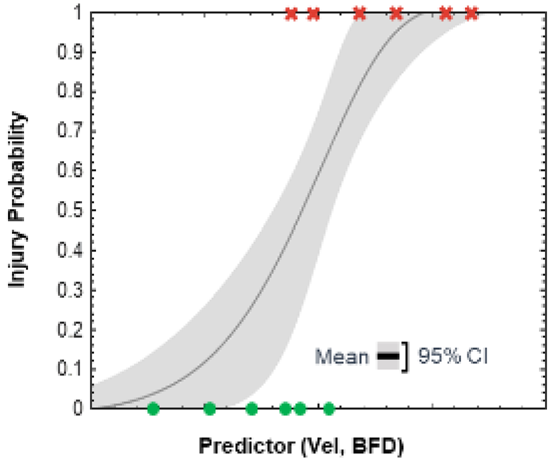
Generate injury risk curve with survival analysis



# BABT Injuries and Forensics

**Pre Test**


**Post Test**


**Post Test Procedures**

- X-rays and photos were taken in place
- CT scans were taken with insufflated lungs with armor on, armor off, and skeletal instrumentation removed
- Board-certified forensic pathologist reviewed CT and led an anatomical dissection of the PMHS
- A detailed report, with associated pictures, for each PMHS was created to characterize and preliminarily assess severity of any injuries sustained as a result of the BABT.

# GRAPHIC IMAGES

# Characteristic Injuries: Sternum

Lateral In situ xray

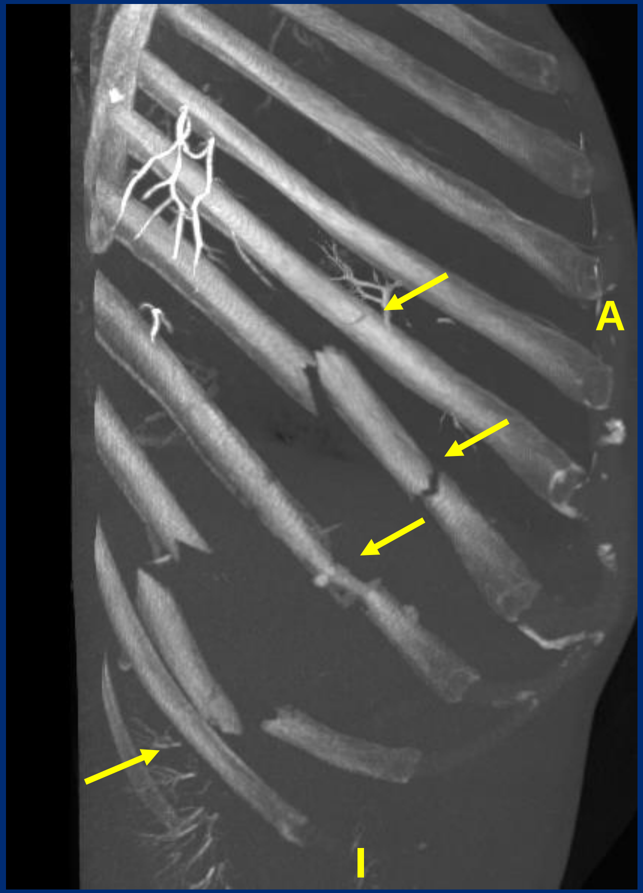

Overview

Sternum and Rib Fractures

# Characteristic Injuries: Lateral Ribcage

Overview

Sagittal

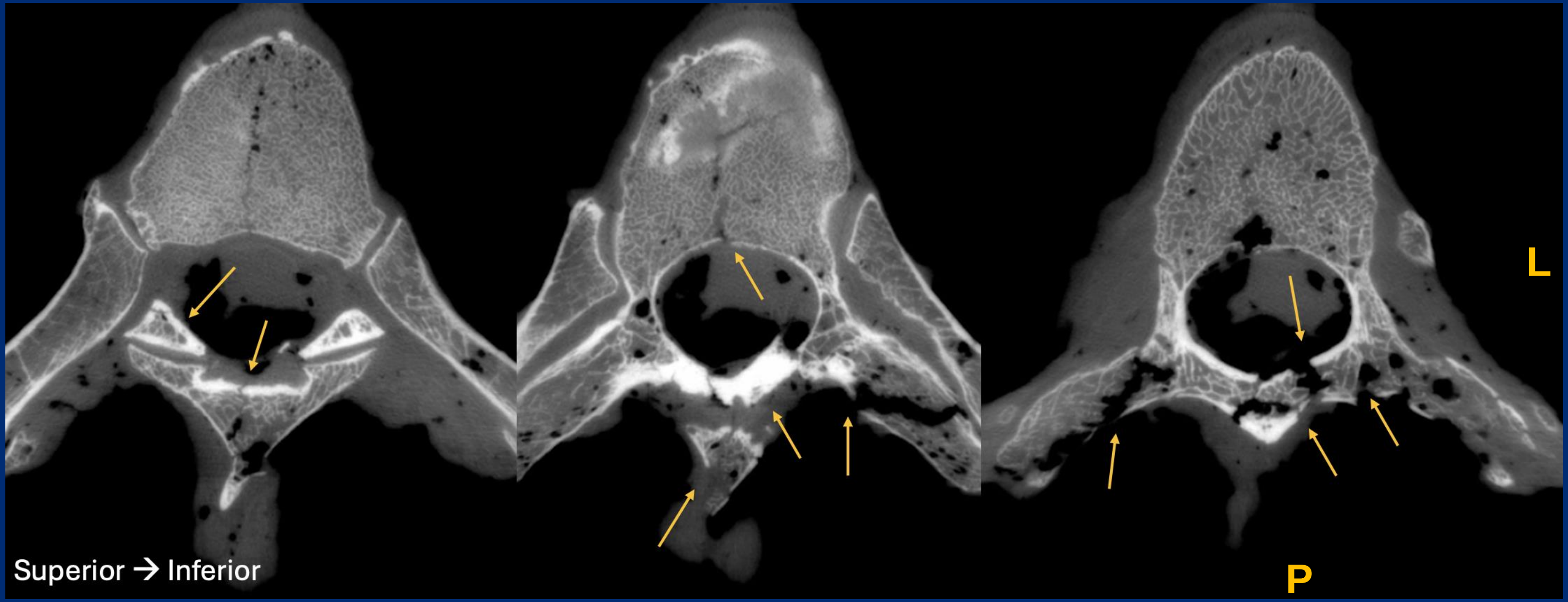



Maximum intensity projection CT – left rib fractures

Liver pulpifaction

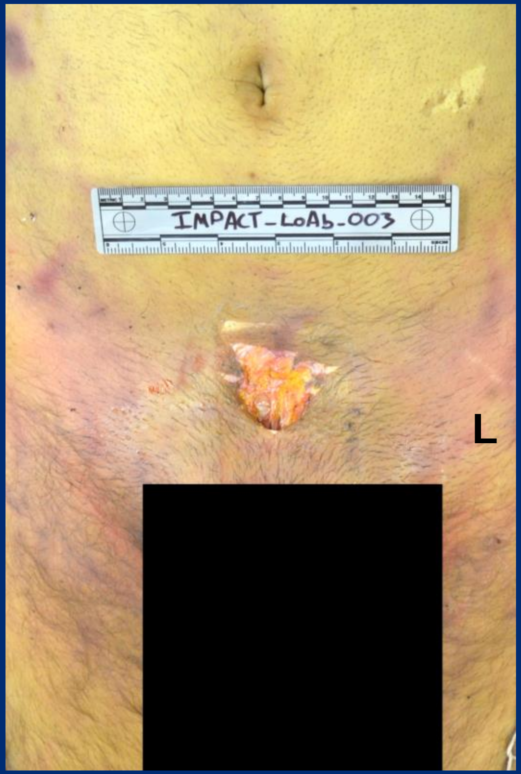
# Characteristic Injuries: Spine


Overview




**T6 Fractures**
Superior articular process
L/R Transverse process
Vertebral body
Lamina
Spinous process

# Characteristic Injuries: Low Abdomen

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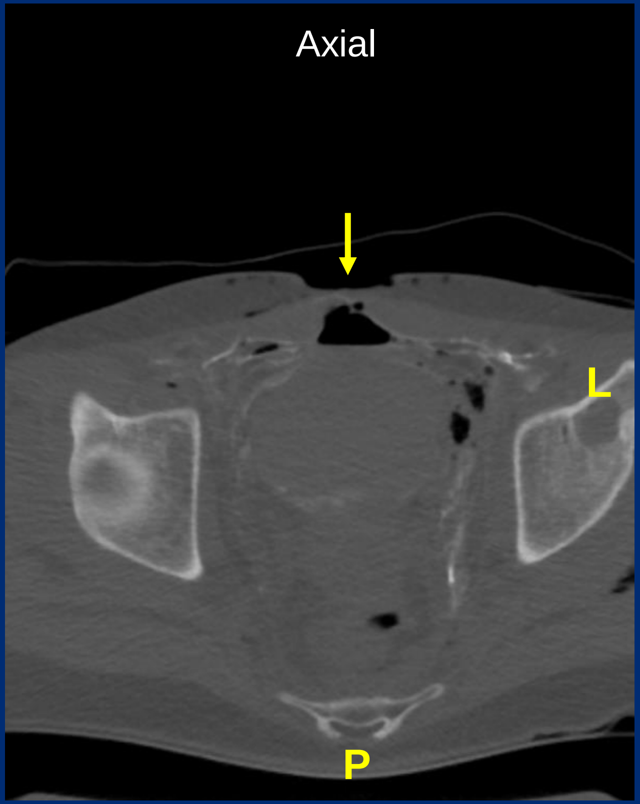



Impact location and laceration post impact

# Analysis

## Clinical Implications: Medical Panel

| | |
|---|---|
| Col (Dr) Andrew Rohrer, USAF, MC, Chair | Chief, Forensic Services |
| Lt Col (ret) (Dr) Ed Mazuchowski, USAF, MC, Chair | Chief, Forensic Services |

# POIO: Projected Operational Injury Outcomes

## Clinical Implications: Trauma Scores

| Injury Description | Level of Trauma | Projected Operational Injury Outcome |
|---|---|---|
| • Skin abrasions/lacerations | I | Return to Duty within 72 Hours |
| • Rib fractures<br>• Minor lung laceration<br>• Plural defect | II | Non-Return to Duty within 72 Hours |
| • Extensive rib fractures | III | Non-Return to Duty within 72 Hours, Potential Duty-Limiting Conditions |
| • Major lung laceration with communication with plural cavity<br>• Organ damage (Heart, Liver, Spleen, Colon) | IV | Non-Return to Duty within 72 Hours, Potentially Fatal |
| | V | Non-Return to Duty within 72 Hours, Probably Fatal |
| | VI | Fatal |

[8] C. Howes, E. Mazuchowski, A. Rohrer, M. Clark, Q. Luong, D. Drewry, A. Iwaskiw, Injuries and Operational Implications Caused by Behind Amor Blunt Trauma Across Various Impact Locations. PASS 2023.

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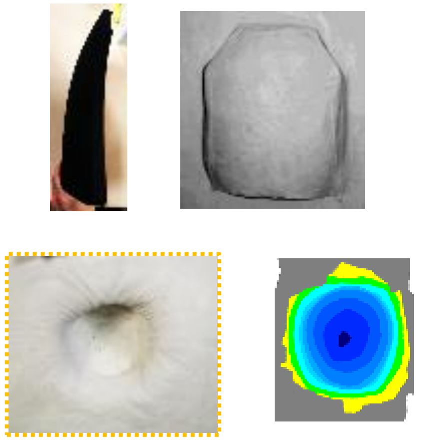

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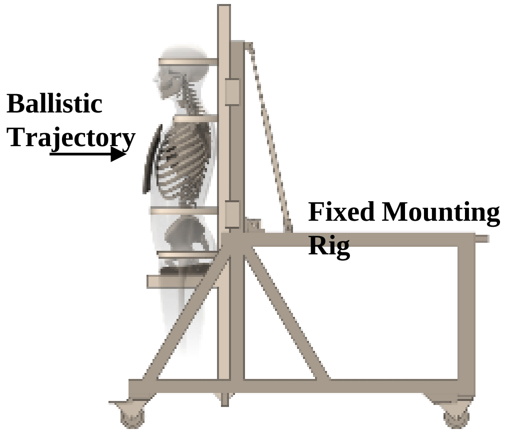
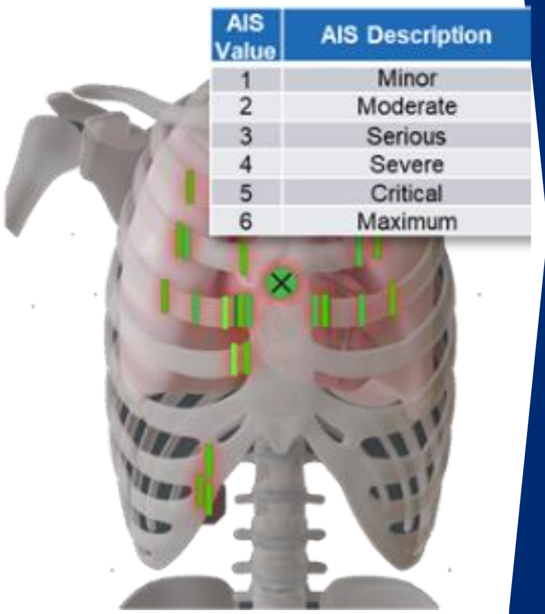
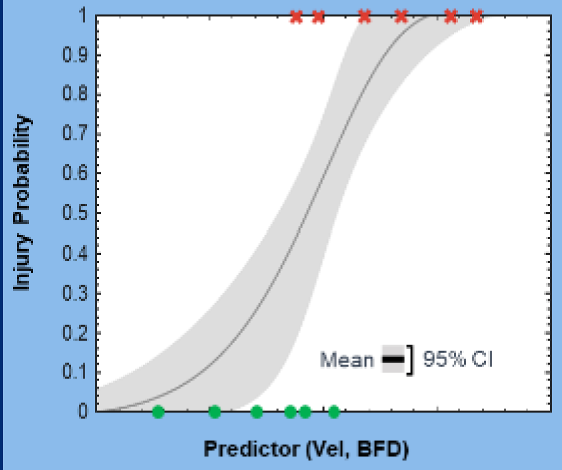



Establish Projected Operational Injury Outcome (POIO)



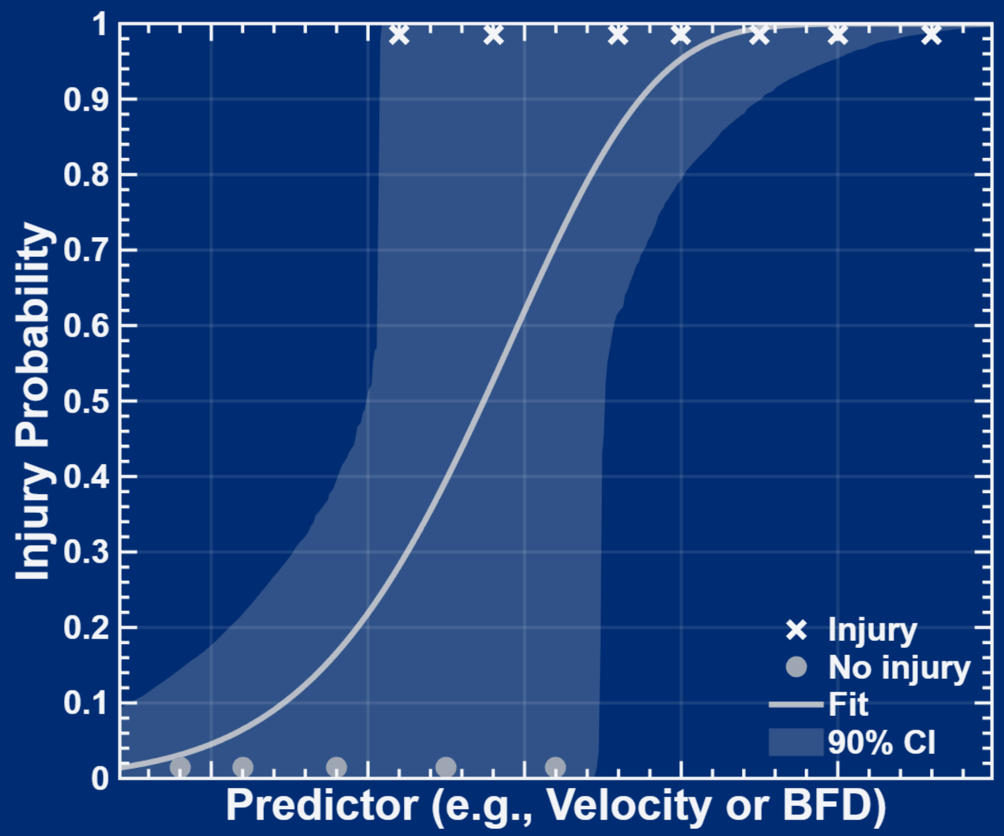
| AIS Value | AIS Description |
|---|---|
| 1 | Minor |
| 2 | Moderate |
| 3 | Serious |
| 4 | Severe |
| 5 | Critical |
| 6 | Maximum |

Generate injury risk curve with survival analysis



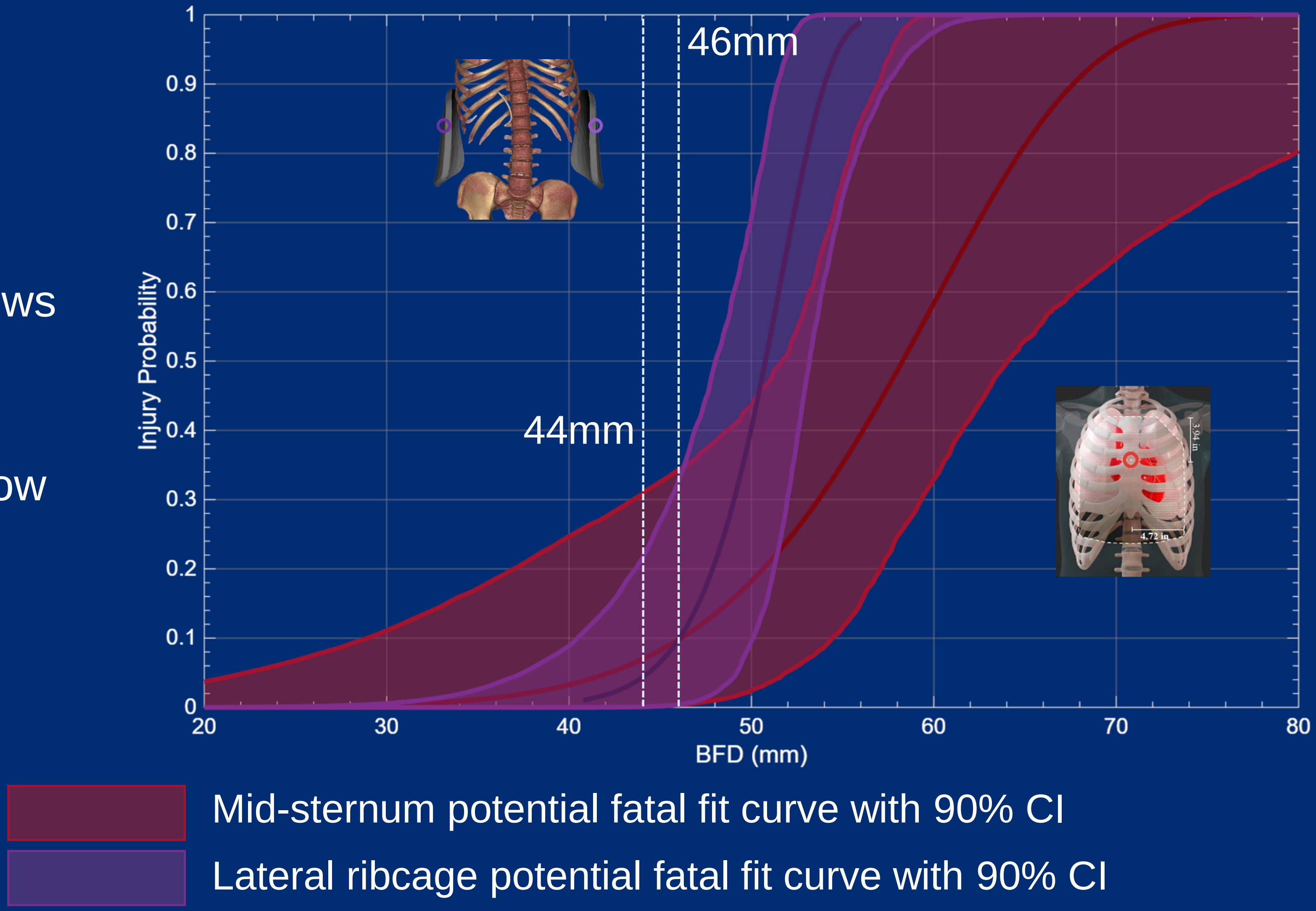
# Injury Risk Curve (IRC) Generation

- Survival Analysis (SA) implemented to fit an injury response curve to binary experimental data (injured vs not injured)
  - Purpose: Map equivalent clay BFD to probability of injury
- Fit curve represents the response that is mathematically most likely to have produced the observed data
- Confidence intervals (CI) express uncertainty in fit at each point along curve
  - Uncertainty is due to combination of limited sample size, PMHS variance, experimental variance
  - Current intervals convey a 90% confidence that the true value is contained within the interval



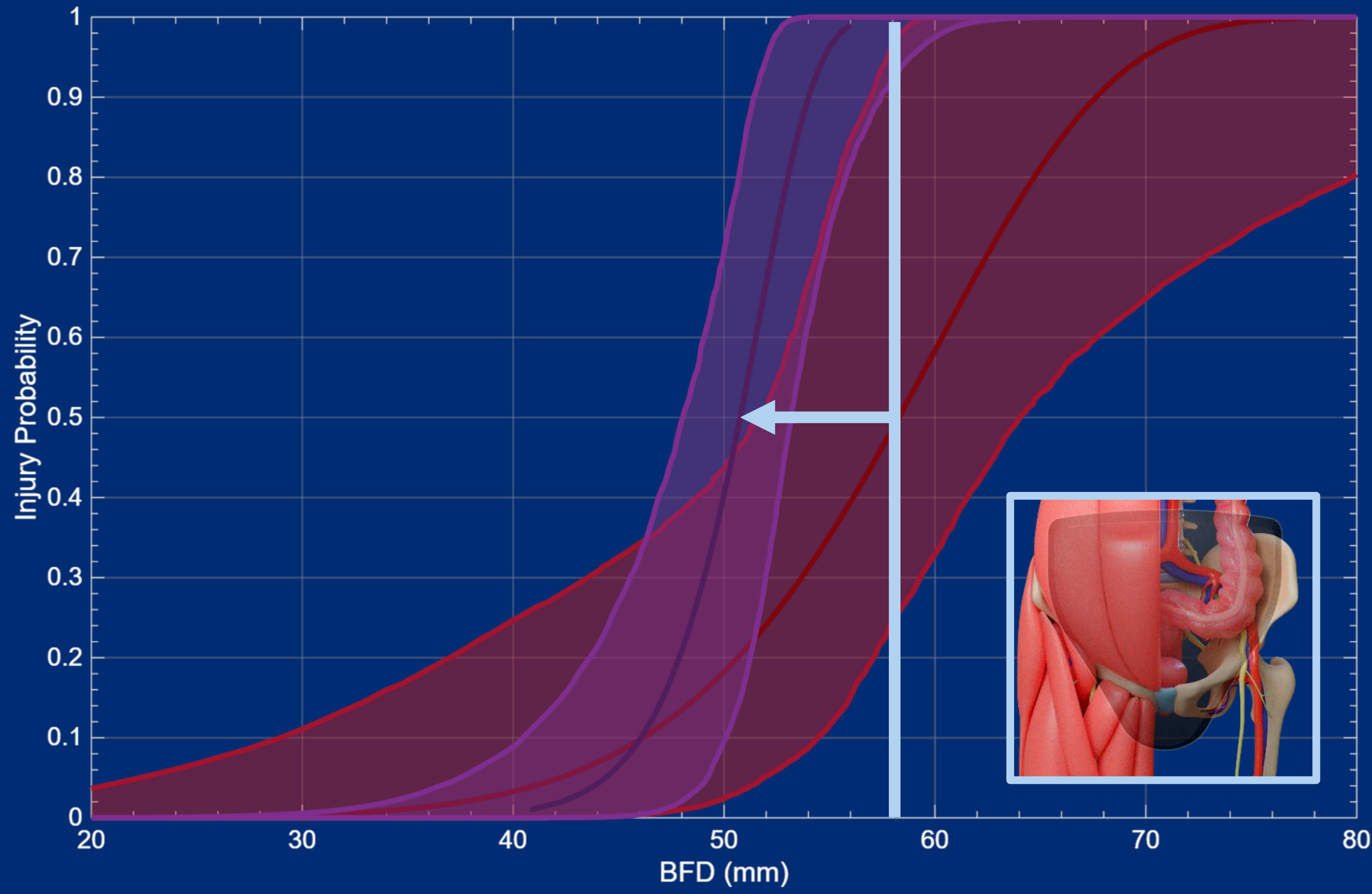
# IRC for Sternum and Side

- Potentially fatal injury risk is low around 44mm of clay deformation
- After 46 mm of deformation, the side impact location shows higher probabilities of potentially fatal injury
- Conservative thresholds show similar sternum and side performance
- Severe thresholds suggest stricter side armor requirements



# Lower Abdominal Injury Assessments

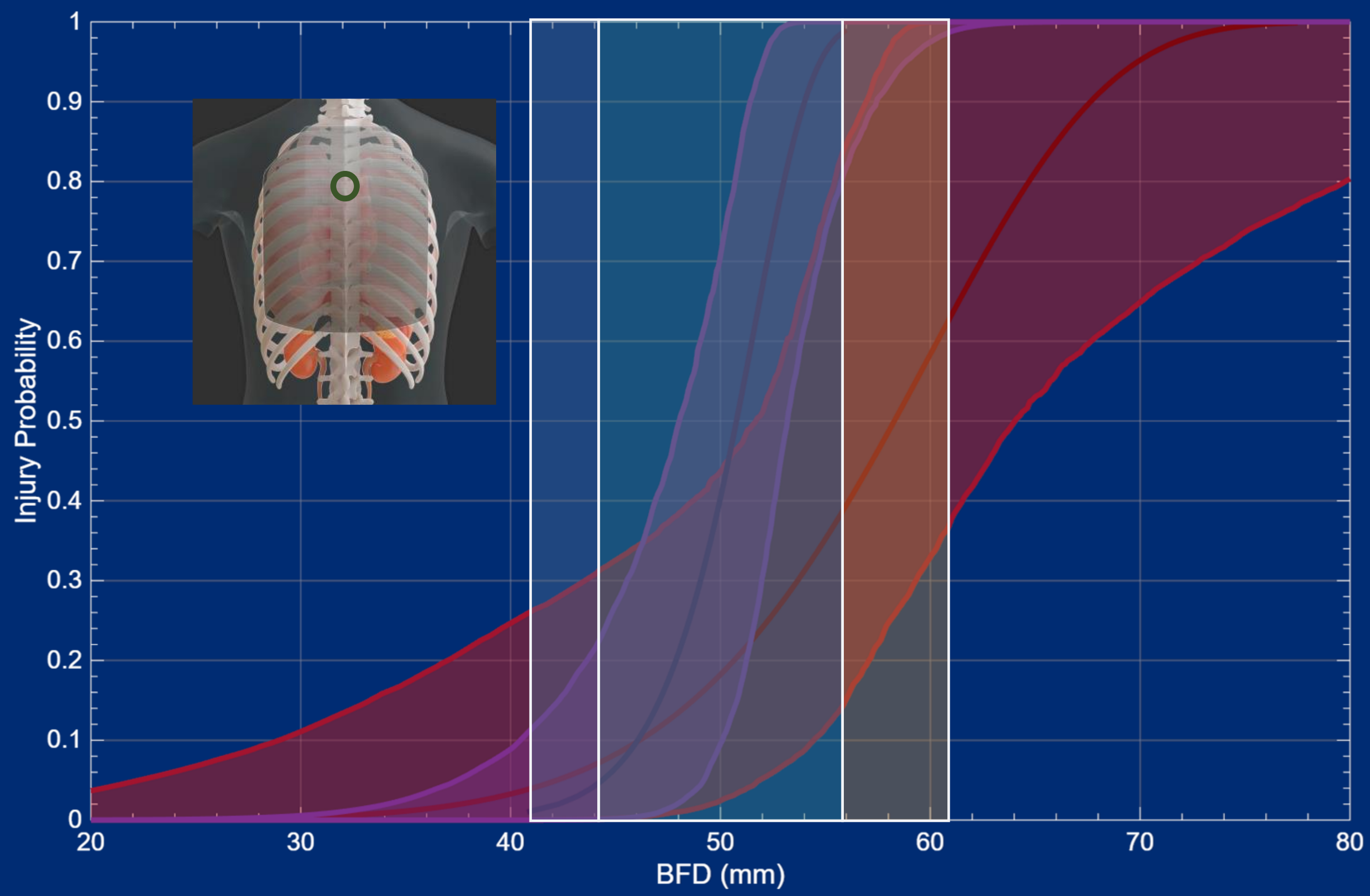
- Lower abdominal injury studies failed to result in continuous injury prediction
- All allowable BFDs resulted in survivable injuries




Largest BFD achievable with tested armor plate

# Spine Injury Assessments

- Rear injury study failed to result in continuous injury prediction
- BFDs were separated into regions with anterior vertebral body fractures




no anterior vertebral body fracture observed: 41.7 → 44.7 mm

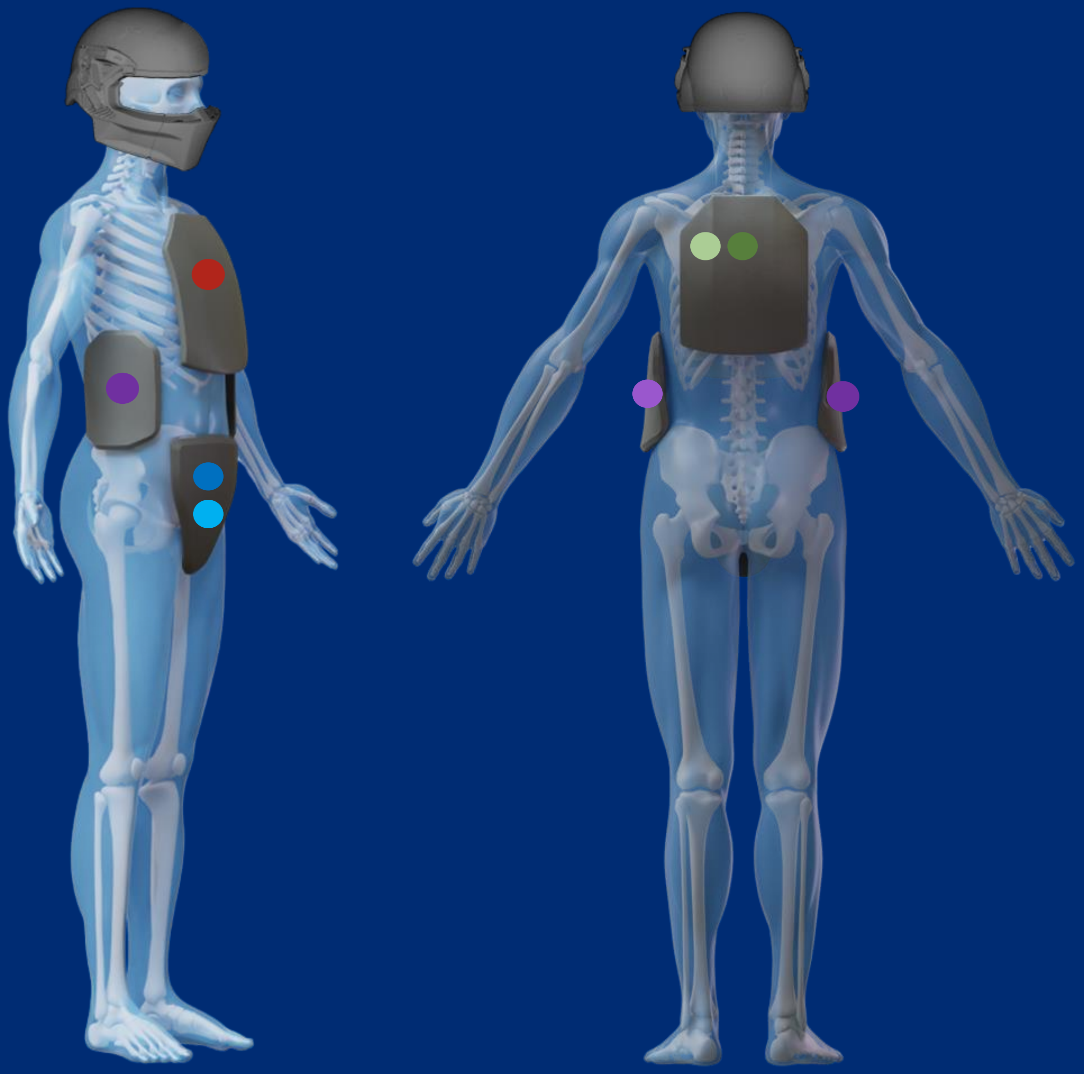
≤1 anterior vertebral body fracture observed: 44.7 → 56.1 mm

>1 anterior vertebral body fracture observed: 56.1 → 61.0 mm

# Program Strengths

- Test methods
  - Size and quality
  - Live fire
  - Single shot
  - Operationally relevant impact location

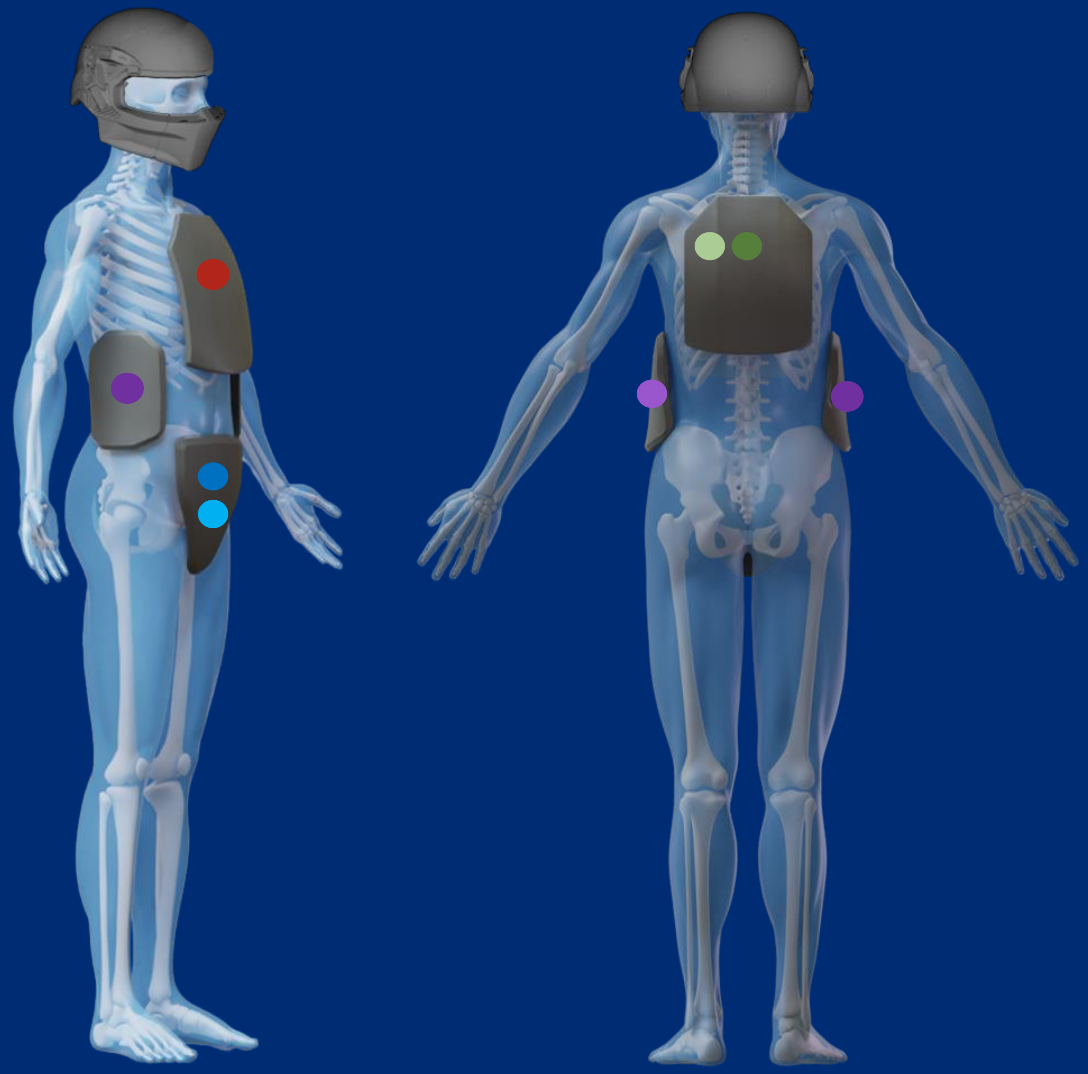
- Operational relevance
  - BABT specific injury predictions
  - Operationally relevant injury predictions



# Program Limitations

- PMHS model limitations
  - Living response
  - Biological variability

- Generalization
  - Single location
  - Single armor
  - Single threat
  - Severe BABT



# BABT Landscape

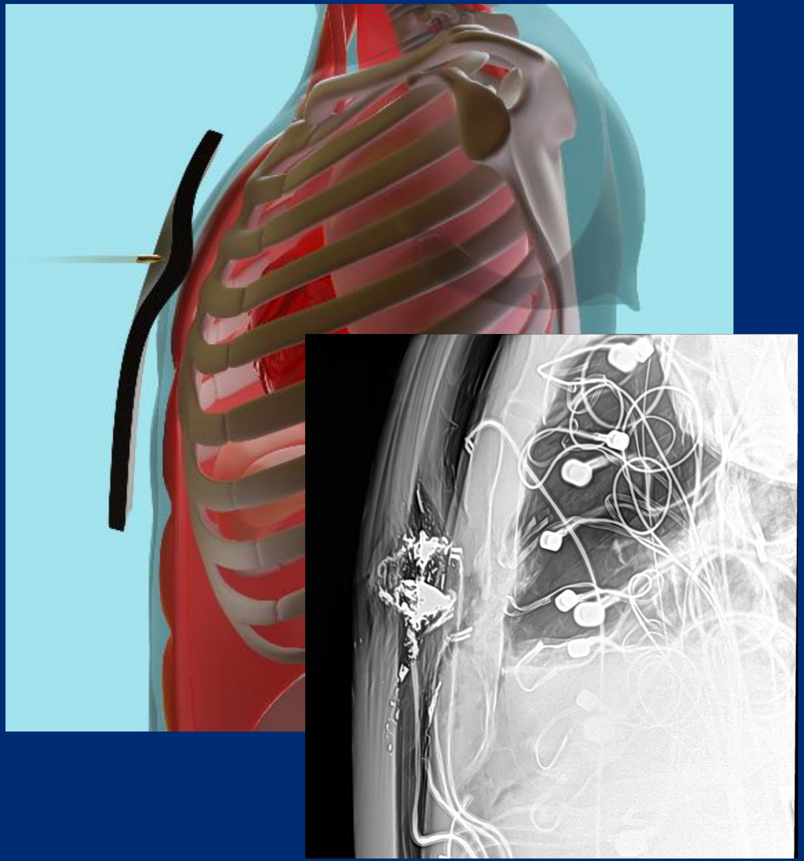
Motivating Conditions

1. Desire to lighten the load
2. Modern materials leading to high energy threats defeated
3. Unknown type and risk of BABT injuries with modern armor

High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# Program Conclusions

- Testing was conducted on PMHS using live fire rounds to simulate BABT
- Injuries were characterized, scaled with dose, and some were potentially fatal



High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# Program Conclusions

- Testing was conducted on PMHS using live fire rounds to simulate BABT
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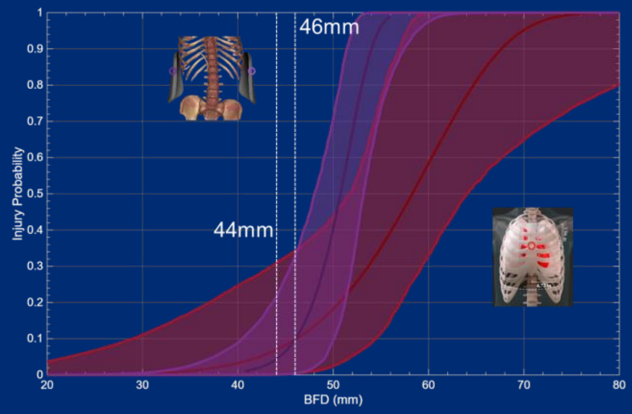


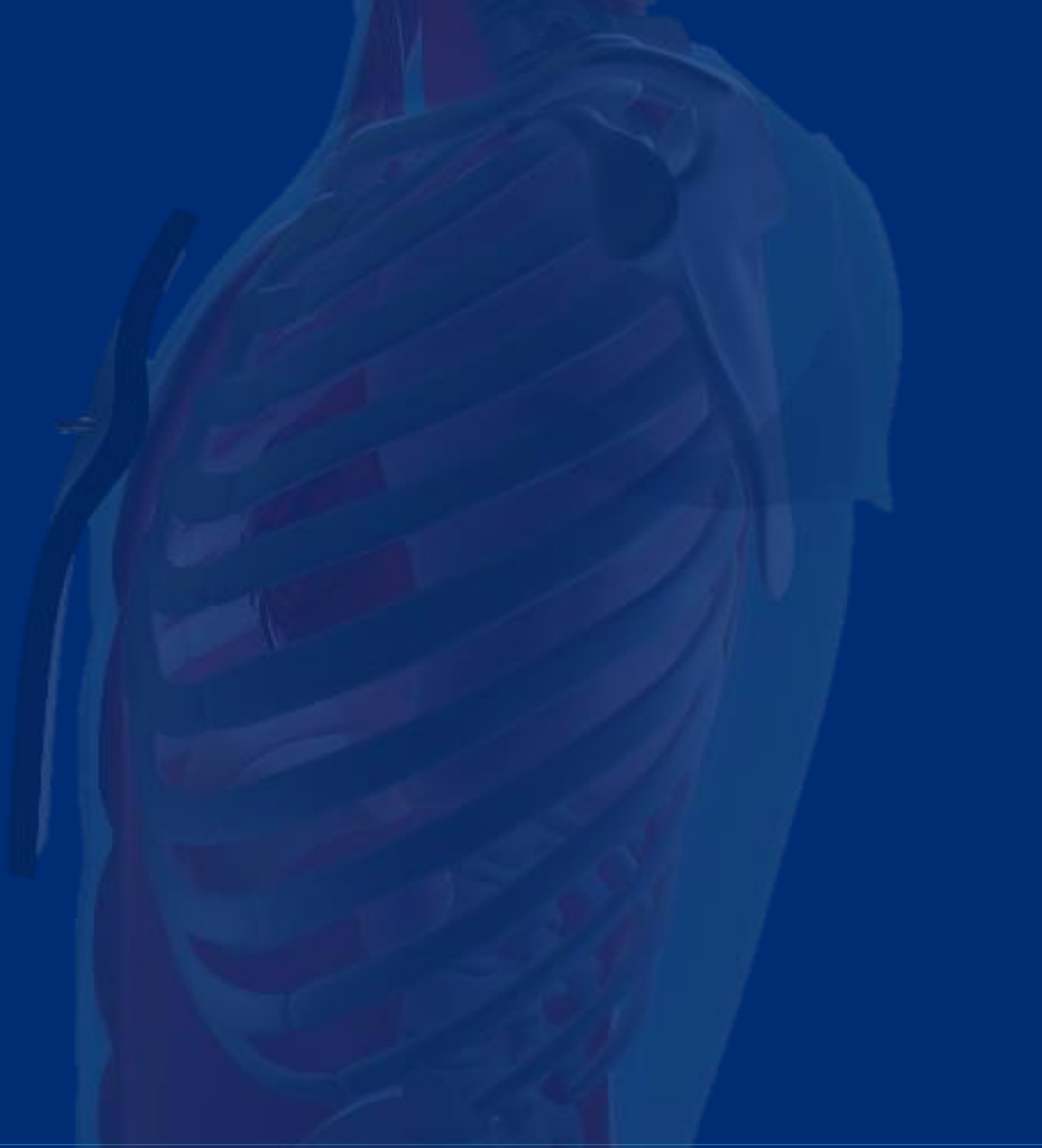

High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# Program Conclusions

- Testing was conducted on PMHS using live fire rounds to simulate BABT
- Injuries were characterized, scaled with dose, and some were potentially fatal
- Matched pair testing was conducted to establish relationships from standard armor performance metrics and injury
- Results from this study led to accepted 67% lighter armor than previously fielded plate

High fidelity modern BABT injury study → Optimized standard → High performing armor systems

# Next Steps



- Expansion of threats and armor plates to verify existing predictions and make more generalizable models
- Development of a next-gen BABT assessment method to capture dynamics related to injury
- Human-injury guided armor design requirements to accelerate innovation for next-gen armor technologies to prevent BABT at lighter weights
- Decision-support tool for optimizing armor system selection based on desired operational risk

# Program Achievements

- 9 conference proceedings and presentations
- 69 BABT PMHS tests
- 241 BABT armor matched pair tests
- 3 armor plate types tested on PMHS
- 1 Sternum BABT IRC
- 1 Side BABT IRC
- 1 injury risk assessment for LoAb
- 1 injury risk assessment for Spine
- 4 final reports
- 1 new operational scoring scheme to address the need for a BABT trauma injury classification scale (POIO)
- 3 in-person medical panels organized
- 2 asynchronous medical panels facilitated
- Armor procured with reduced weight
- BABT data/work transitioned to other DoW stakeholders

# References


1. Army Field Manual 21-18, Procedures and Techniques of Foot Marches, page 5-5
2. J. Q. Zheng and S. M. Walsh, “Materials, manufacturing, and enablers for future soldier protection,” in Lightweight Ballistic Composites, 2nd ed., Woodhead Publishing, 2016.
3. Dyneema Armor Panels | Bulldog Direct Protective Systems
4. Joshi, Ashish, Ashish Mishra, and Vikas Kumar Saxena. "Impact response and energy absorption mechanisms of UHMWPE fabric and composites in ballistic applications: A comprehensive review." Composites Part A: Applied Science and Manufacturing 185 (2024): 108314.
5. Crouch, Ian G. "Body armour–New materials, new systems." Defence Technology 15.3 (2019): 241-253.
6. Prather R, Swann C, Hawkins C; Backface Signatures of Soft Body Armors and the Associated Trauma Effects. ARCSL-TR-77055. Aberdeen Proving Ground, MD, Edgewood Arsenal, 1977.
7. Hanlon, Erin, and Patrick Gillich. "Origin of the 44-mm behind-armor blunt trauma standard." Military medicine 177.3 (2012): 333-339.
8. C. Howes, E. Mazuchowski, A. Rohrer, M. Clark, Q. Luong, D. Drewry, A. Iwaskiw, Injuries and Operational Implications Caused by Behind Amor Blunt Trauma Across Various Impact Locations. PASS 2023.

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Thank you!

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