Injury Assessment with Physical Surrogates

Injury Assessment

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Presented for:
Blast Injury Testing Conference IV
Arlington, VA April 6, 2005

Biokinetics

Injury Assessment Considerations

Injury
- *-type*
- *-severity*
- *-mechanisms*

Threat environment
- *-external body loading*
- *-temporal*
- *-magnitude*

Prioritization
- *-exposure + severity*
- *-trade-offs vs. consequences*

Requirements

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Surrogate Development

Types
- *-biological samples*
- *-biological models*
- *-physical models*
- *-numerical models*
- *-hybrid models*

Considerations
- *-accuracy*
- *-3R (repeatability, reproducibility, robustness)*
- *-cost, ease of use*
- *-maintenance*
- *-calibration*
- *-validation*

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Surrogate Development

What is known?
- *-injury vs. insult*
- *-response data:*
  - *biomechanical*
  - *physiological*

Simplifications
- *-abs/rel measures*
- *-biofidelity*
- *-anthropometry*
- *-anthropomorphism*

Design Specifications
- *-biofidelity*
- *-measures and instrumentation*
- *-accuracy*
- *-geometric*

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Physical Surrogates – Head Injury

DEFENCE ballistic

Injuries:
-focal and diffuse
-acute/mild
-skull fracture, tissue disruption

Threats:
-ballistic impacts
-blunt impact
-global acceleration

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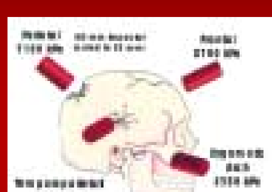
Head Surrogate for Ballistic Impact

Biomechanics

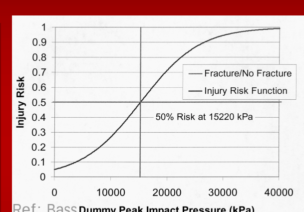


Ref: Bass

Cranial and facial bone fracture tolerances

Ref: Bass

Pressure measurement with Hybrid III skull compared to cadaver impacts



Ref: Bass

Injury risk associated with measured skull pressure

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Head Surrogate for Ballistic Impact

Surrogate

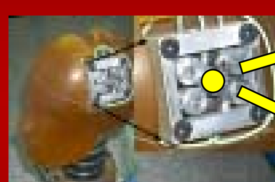
Test method for ballistic helmet injury risk assessment

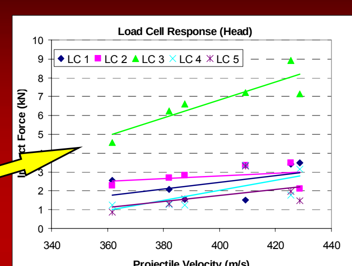
Headform capable of measuring applied force

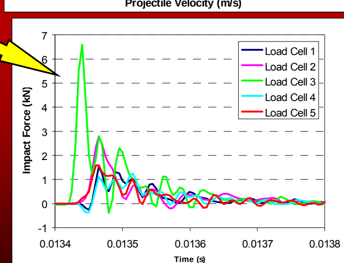
Forces from force transducers correlated to injury risk relationship

Head Surrogate for Ballistic Impact

Surrogate







Headform response to ballistic impact with 9 mm FMJ on flat plate

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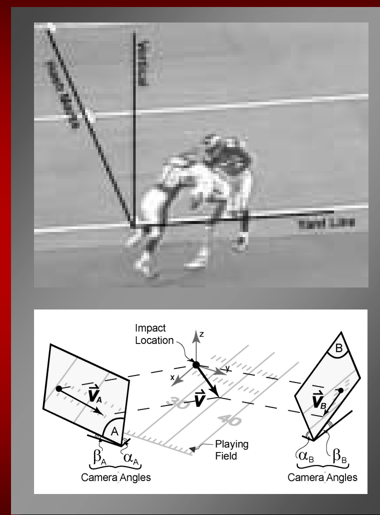
Head Surrogate for Concussions

SPORTS Football

Head to head collisions resulting in concussed and non-concussed player

No injury tolerances available for mild head injuries



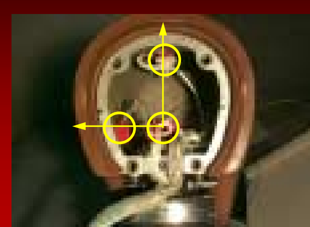
Kinematics obtained from field

Head Surrogate for Concussions

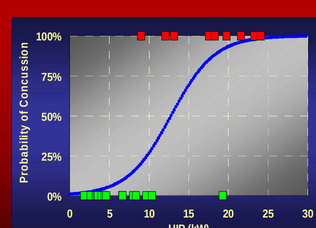
SPORTS Football

Inertial head response measured in lab re-enactments

$$HIP = 4.50\,a_x \int a_x\,dt + 4.50\,a_y \int a_y\,dt + 4.50\,a_z \int a_z\,dt + 0.016\,\alpha_x \int \alpha_x\,dt + 0.024\,\alpha_y \int \alpha_y\,dt + 0.022\,\alpha_z \int \alpha_z\,dt$$



3-2-2-2 linear/angular data

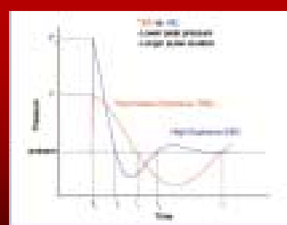


Strong correlation between HIP and concussion

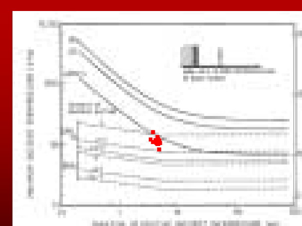
Head Surrogate for Blast Loading

DEFENCE EBW

Mannequin for Assessment of Blast Incapacitation and Lethality



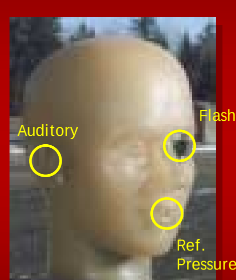
Threat characterization



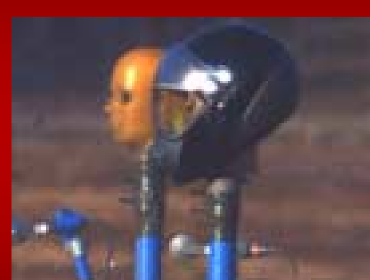
Injury tolerance

Head Surrogate for Blast Loading

DEFENCE EBW

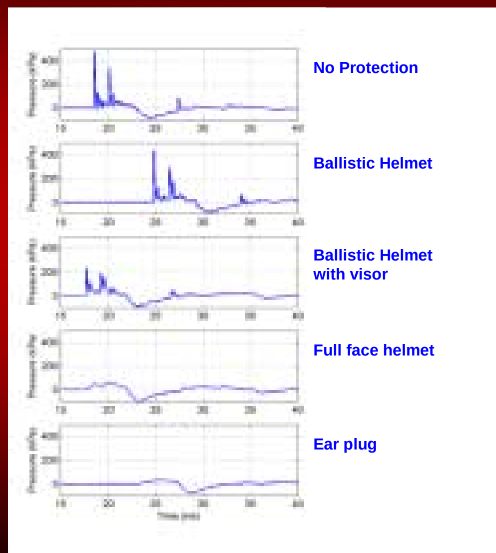


MABIL
Instrumented head to measure peak pressure and impulse + optical



Video of blast loading with MABIL protected and unprotected

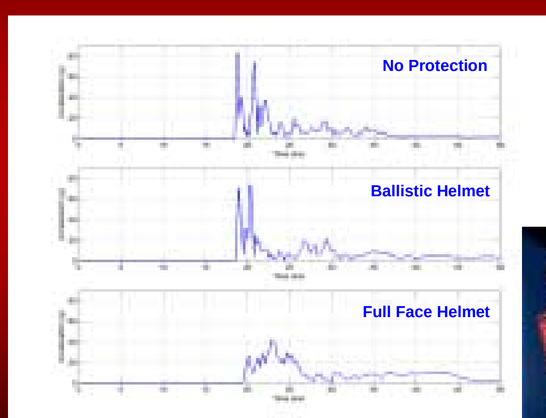
Head Surrogate for Blast Loading



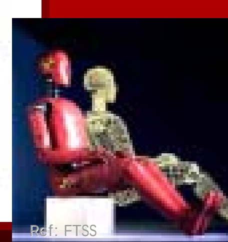
MABIL head ear canal pressures for various protective equipment

Head Surrogate for Blast Loading

DEFENCE EBW



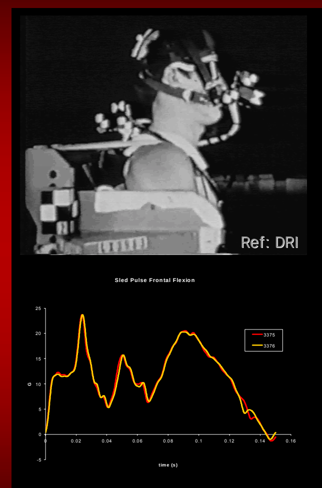
Hybrid III linear head accelerations for various protective equipment



Physical Surrogates - Neck

VEHICLE SAFETY

Surrogate kinematics crucial to head/neck injury assessment



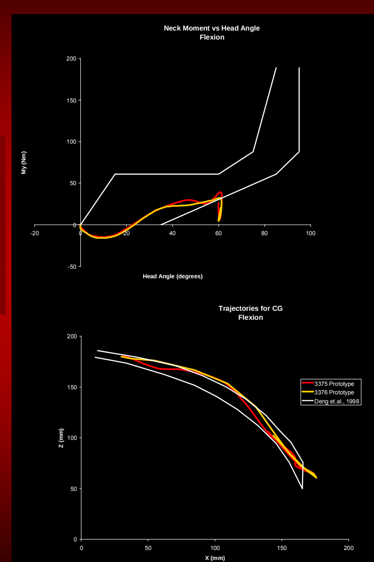
Neck biofidelity based on kinematics of volunteers

Physical Surrogates - Neck

VEHICLE SAFETY

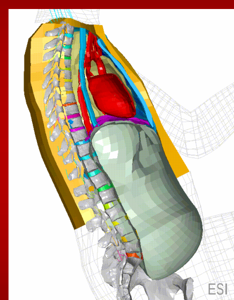
Surrogate neck allows for change in position

Neck to meet flexion, extension, lateral and torsional biofidelity corridors



Torso Surrogate for Ballistics

DEFENCE ballistic



Threat: Ballistic loading provides combined focal and distributed loading depending on projectile and armour

Mechanism: Chest wall motion transfers impact energy to internal organs

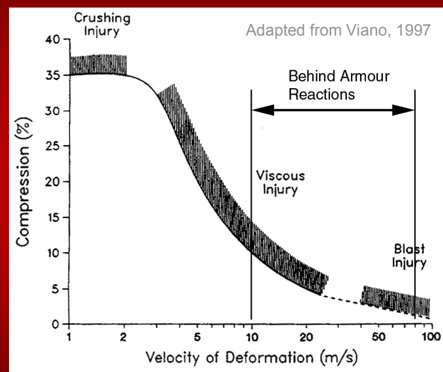
Biomechanics: Animal models and PMHS, injuries and biofidelity

Torso Surrogate for Ballistics

Current biomechanical studies compared to anticipated threats

Parameter	Min.	Max.
Mass (g)	100	1000
Velocity (m/s)	10	80
Diameter (mm)	50	125

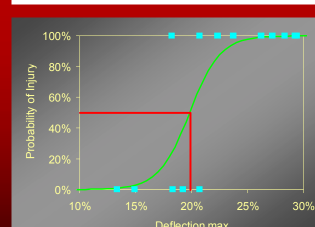
Torso Surrogate for Ballistics



Injury criteria compared to behind armour loading conditions

Torso Surrogate for Ballistics

- Reproduce biomechanical response of chest wall
  → as simple as possible
- Define injury thresholds
  - *deflection max*
  - *velocity / acceleration max*
  - *viscous criterion*
  - *energy/momentum transfer*



Torso Surrogate for Ballisitcs

- Approach: Reproduce the biomechanical response of the human thorax for behind armour loading conditions

projectile (m,v,d,T) → body armour → behind armour reactions (m,v,d,...) → thorax → injury outcome

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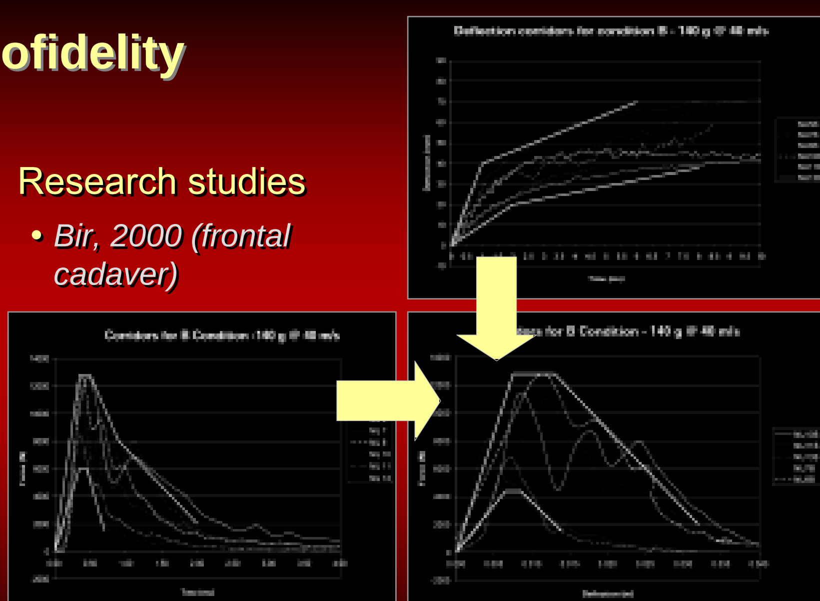
Biofidelity

- Research studies
  - *Bir, 2000 (frontal cadaver)*



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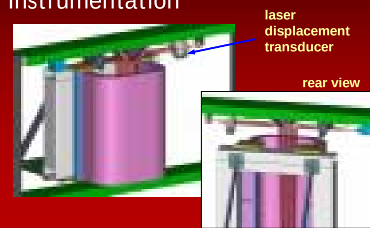
Torso Surrogate for Ballistics

DEFENCE ballistic

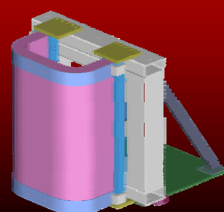
Other considerations:

-targeting
-fitment
-support
-ease of use
-durability

Instrumentation



Evaluation of body armour performance for ballistics



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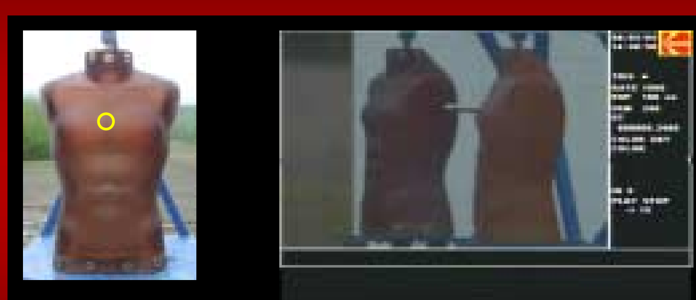
Torso Surrogate for Blast

DEFENCE EBW



MABIL: Evaluation of body response to blast loading by measurement of chest wall acceleration and applied pressure

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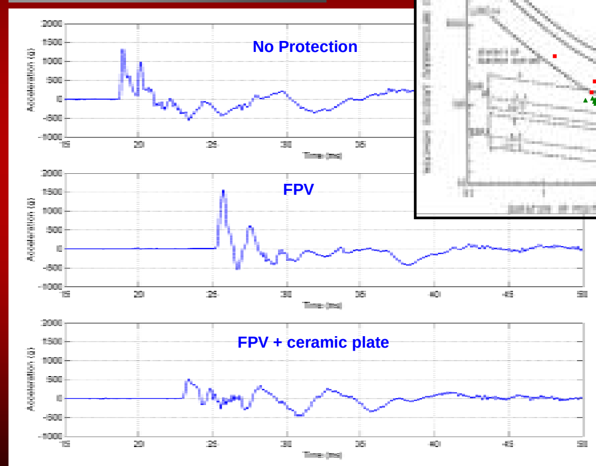
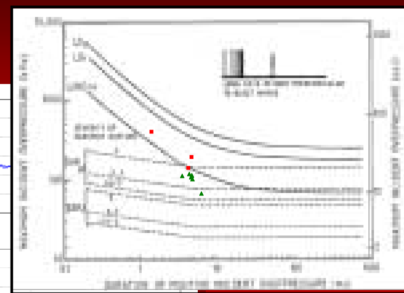
Torso Surrogate for Blast

DEFENCE blast



MABIL torso response to blast loading

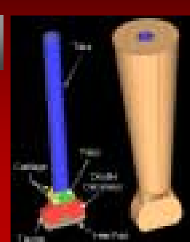


Prediction of lung injury

Leg Surrogate for Blast Protection

DEFENCE blast AP

- CLL (Complex Lower Leg)
- For development and evaluation of protective footwear against AP blast
- Produced under license with DRDC
- recognized by the NATO HFM-089 / TG-024



CLL components and test methodology


Leg Surrogate for Blast Protection
DEFENCE blast
DRDC
CLL response to AP mine blast
CLL standardized test methodology
Biokinetics
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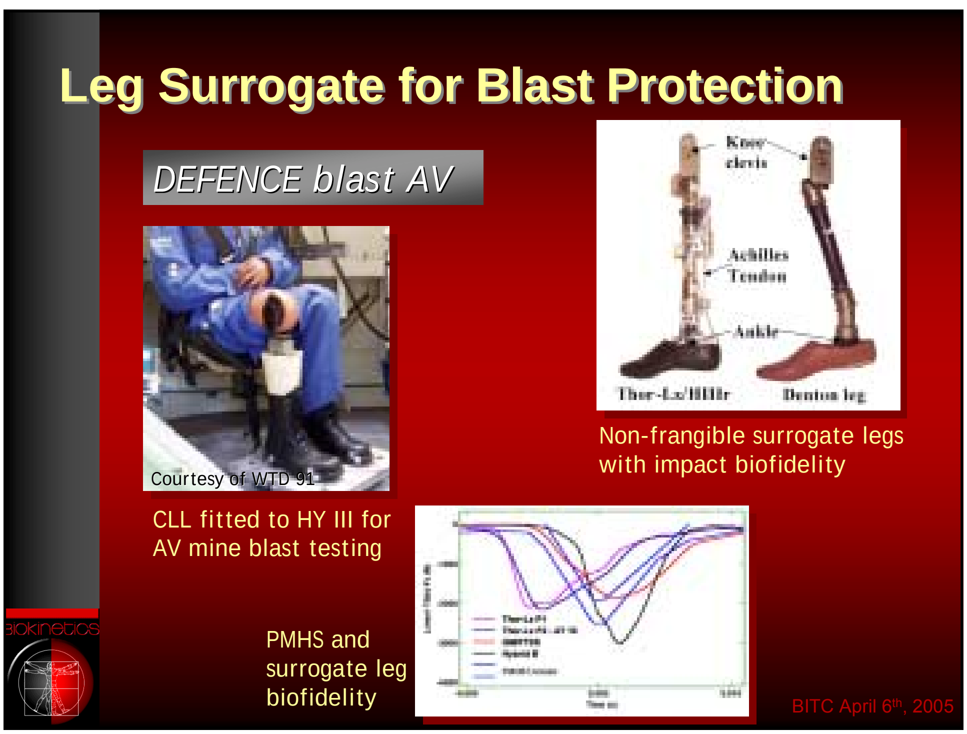
Leg Surrogate for Blast Protection
DEFENCE blast AV
Courtesy of WTD 91
CLL fitted to HY III for AV mine blast testing
Knee clevis
Achilles Tendon
Ankle
Thor-Lx/HIIIr
Denton leg
Non-frangible surrogate legs with impact biofidelity
PMHS and surrogate leg biofidelity
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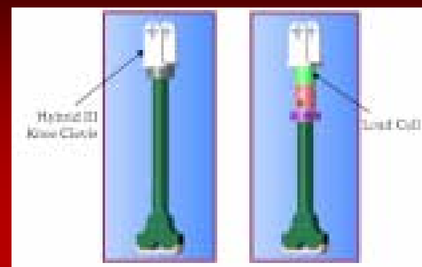
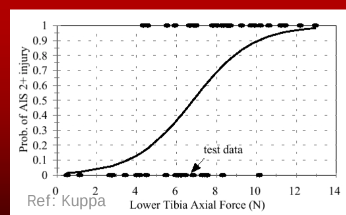
Leg Surrogate for Blast Protection

DEFENCE blast AV

CLL response to simulated AV mine blast



CLL with upper tibia load transducer



Ref: Kuppa

Typical injury tolerance data for vehicle safety studies

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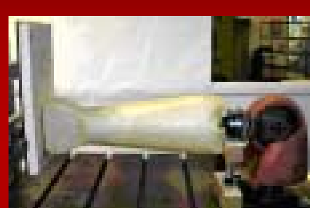
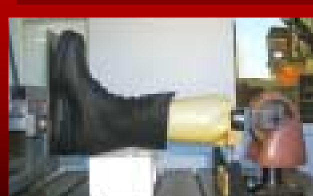
Leg Surrogate for Blast Protection

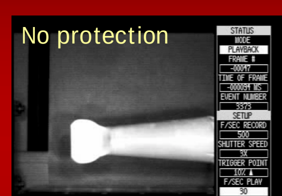
DEFENCE blast AV





Surrogate validation

No protection



With protection

Test results with CLL

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Surrogate Development - Summary

- Define the problem (injuries, threats)
- Prioritize requirements and define constraints
- Quantify biofidelity needs
- Quantify injury criteria based on tolerance
- Define biomechanical predictors of injury
- Identify transducer and measurement needs
- Develop and validate surrogate
- Use surrogate for validated loading regimes