Health Assessment of Non-lethal Munitions: Progress towards a testing standard

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BIOMEDICAL ENGINEERING

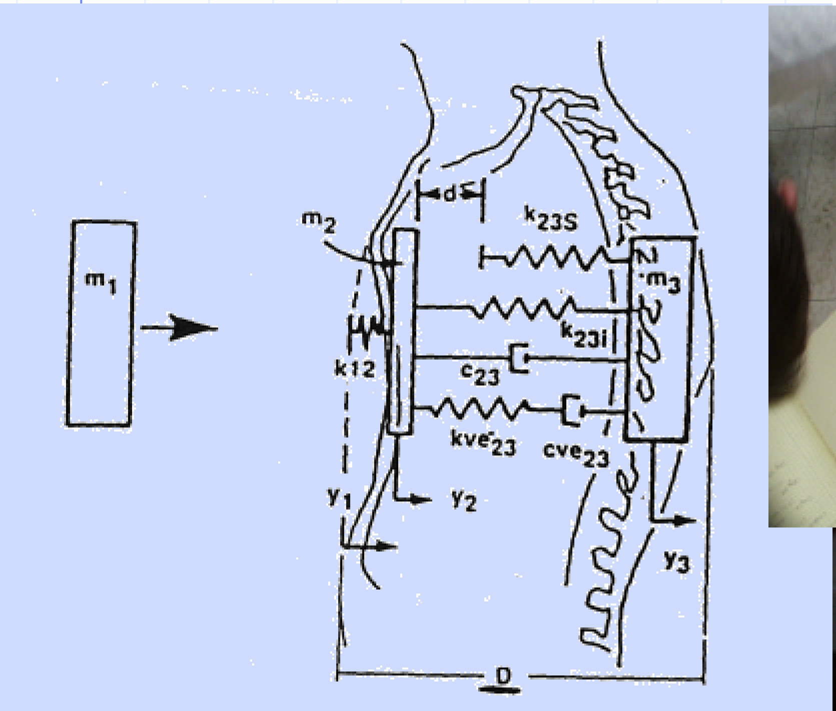
Effects of non-lethals

- Incapacitation - pain

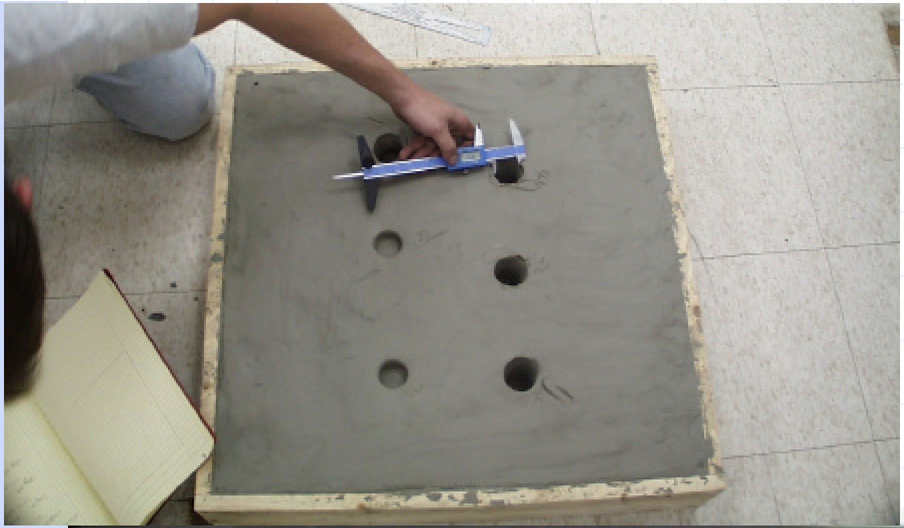
- Health Effects - injury

How do we assess for these effects?

Previous Methods



Mathematical modeling



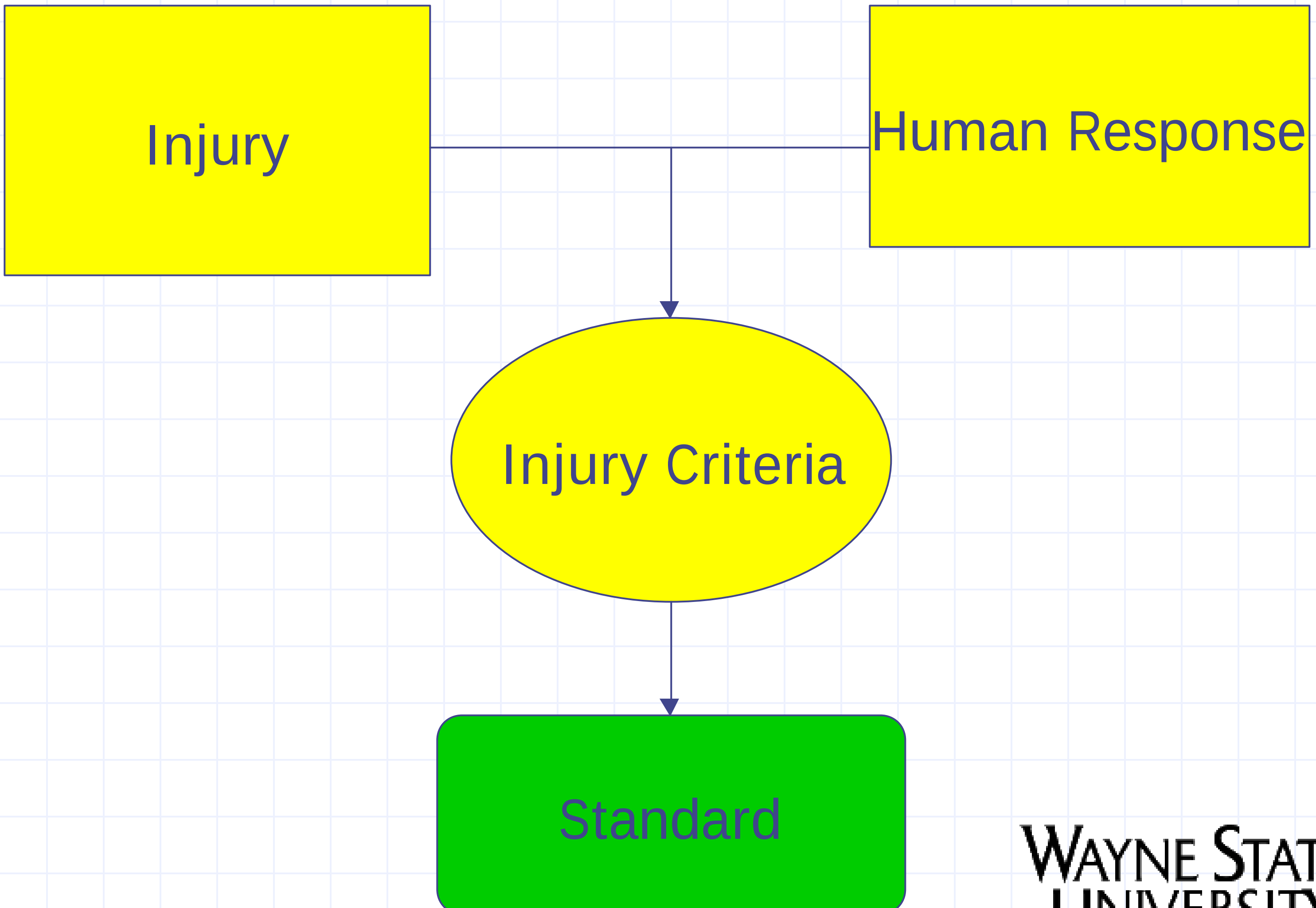
Clay

Gelatin

Impact Biomechanics

- How does the human body respond to a given impact?
- What injuries are the result of that impact?
- How can we predict these injuries? What tolerance level are we going to set?

Impact Biomechanics



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AIS (Abbreviated Injury Scale)

- 0 - Not injured
- 1 - Minor
- 2 - Moderate
- 3 - Serious
- 4 - Severe (33% threat to life)
- 5 - Critical (58% threat to life)
- 6 - Maximum (99% threat to life)

Areas of concern

- Thorax
- Abdomen
- Head/face
- Eye
- Extremities

What do we know and what data is available?

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Thorax

- Blunt impact ≠ blast injury
- Area above diaphragm contained in bony structure of rib cage
- Injuries

THORAX	
1	superficial penetrating chest injury
2	sternum fracture
3	penetrating chest injury with > 20% blood loss by volume
4	severe heart contusion; bilateral lung contusion
5	lung laceration with tension pneumothorax
6	heart laceration with ventricular rupture

Preliminary data indicates 19.1% of impacts occur to the thorax resulting in 19.28% of injuries.

-Hubbs et al.

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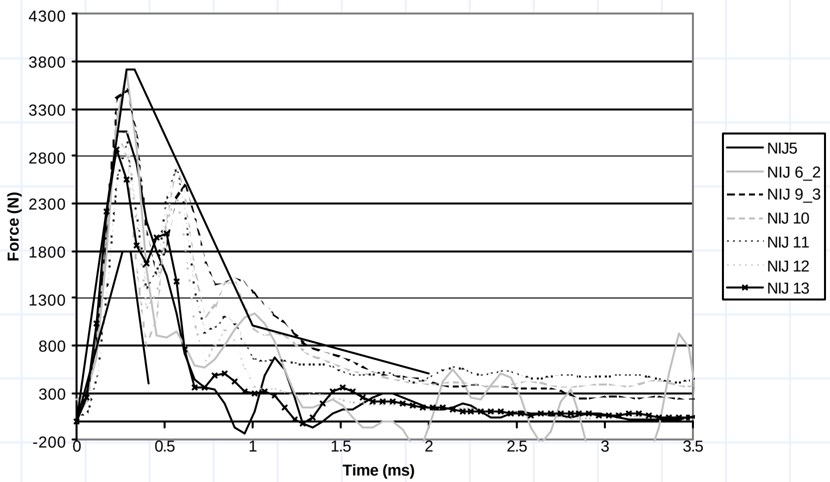
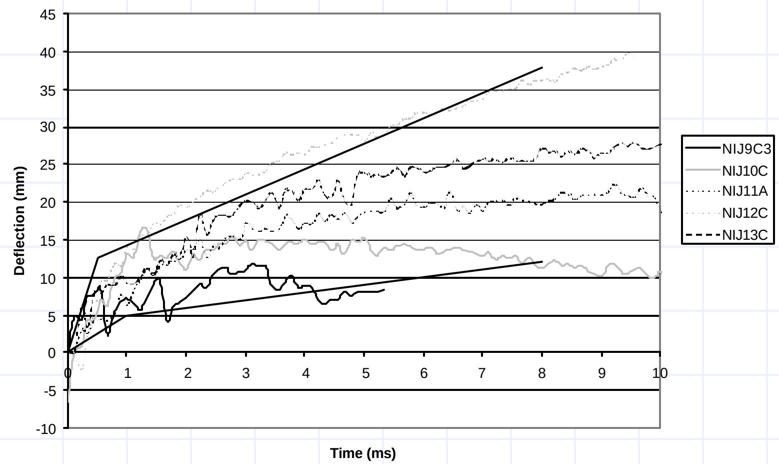
Biomechanical Response

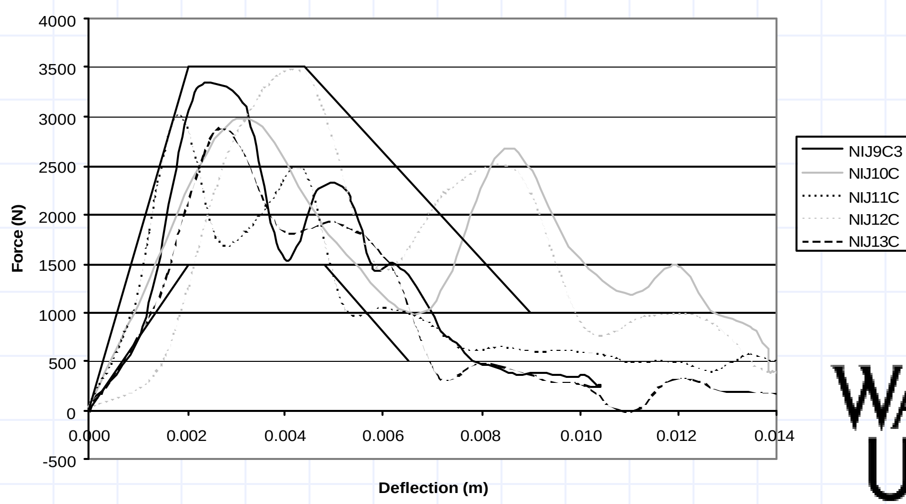
Force corridors- 30 g @ 60 m/s



Deflection-time corridors - 30 g @ 60 m/s



Force-deflection corridors- 30 g @ 60 m/s



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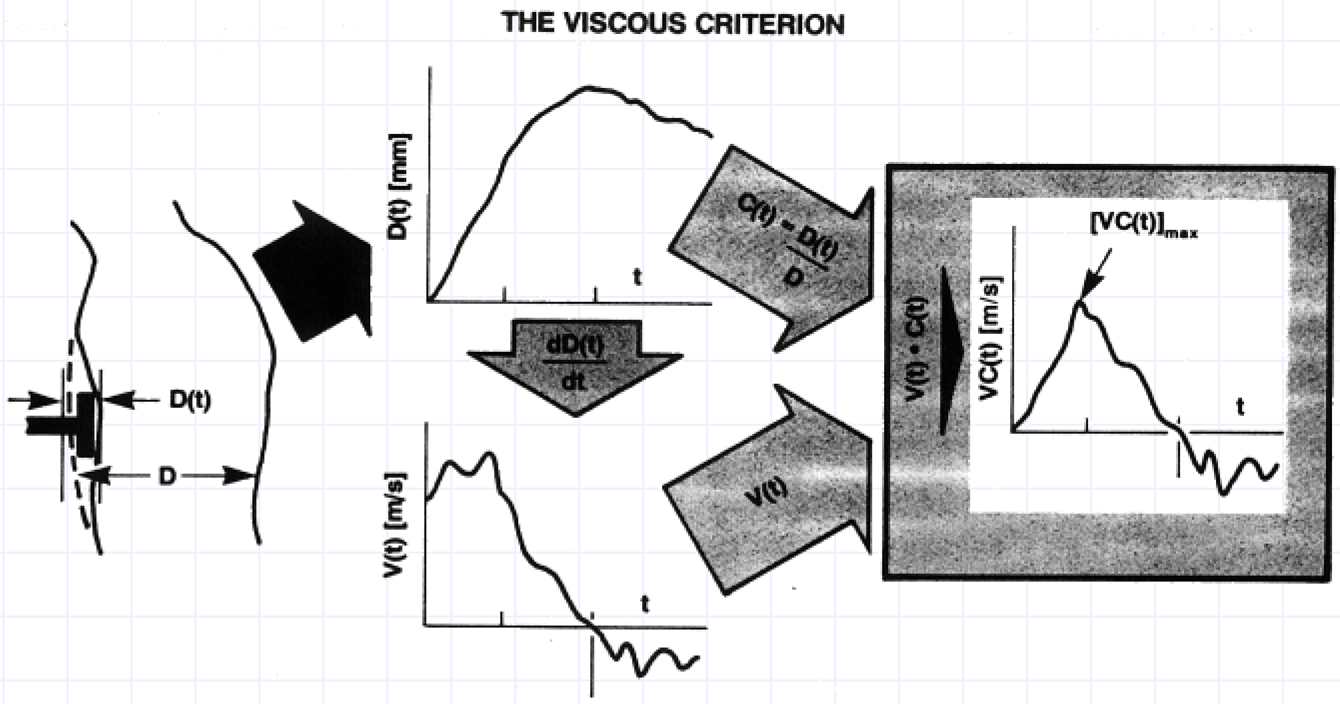
Human Injury Tolerance



Logistic regression analysis

- Provides ability to determine the probability of event occurring given the value of an independent variable.
- Dichotomous state of occurrence vs. nonoccurrence
- $P(x) = 1/(1+\exp(-a-bX))$

Cooper and Maynard, 1986

- Porcine animal surrogate
- Right lateral thorax
- Stiff PVC cylindrical impactor
- 37 mm in diameter
- .069 to 3.0 kg
- Impact velocity 5.8 to 81.2 m/s

Parameters studied

- Peak deformation
- Time to 95% reduction in impact velocity
- Quotient of lung injury Q_i
  - ratio of lung weight to predicted lung weight

Reanalysis of data

- Deflection versus time
- Viscous Criterion
- $Q_i > 1.5$ was considered severe
- Logistic Regression performed:
  - dependent variable = occurrence or non-occurrence of $Q_i>1.5$
  - independent variable = VC_{max}

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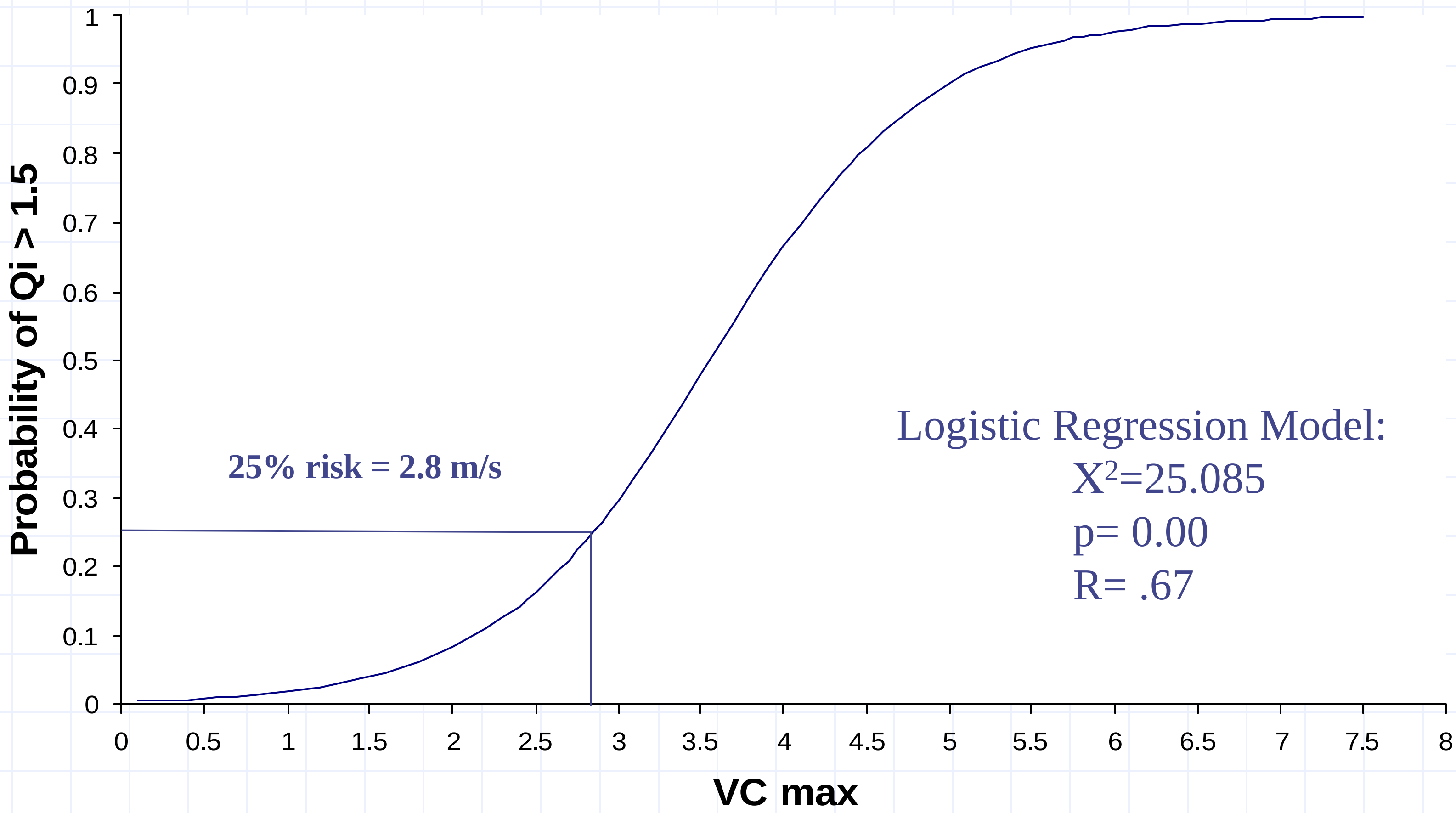
Probability of Q_i predicted by VC_{max}



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Injury data from Cadaveric Specimens

Specimen ID	Impact condition	VCmax	AIS
NIJ10	A	.51	0
NIJ11	A	.24	0
NIJ12	A	.46	0
NIJ13	A	.24	0
NIJ8	A	.26	0
NIJ7	B	1.97	2
NIJ8	B	2.35	2
NIJ10	B	2.18	2
NIJ11	B	1.01	3
NIJ13	B	.65	2
NIJ9	C	.14	0
NIJ10	C	.59	0
NIJ11	C	.24	0
NIJ12	C	.60	2
NIJ13	C	.30	0

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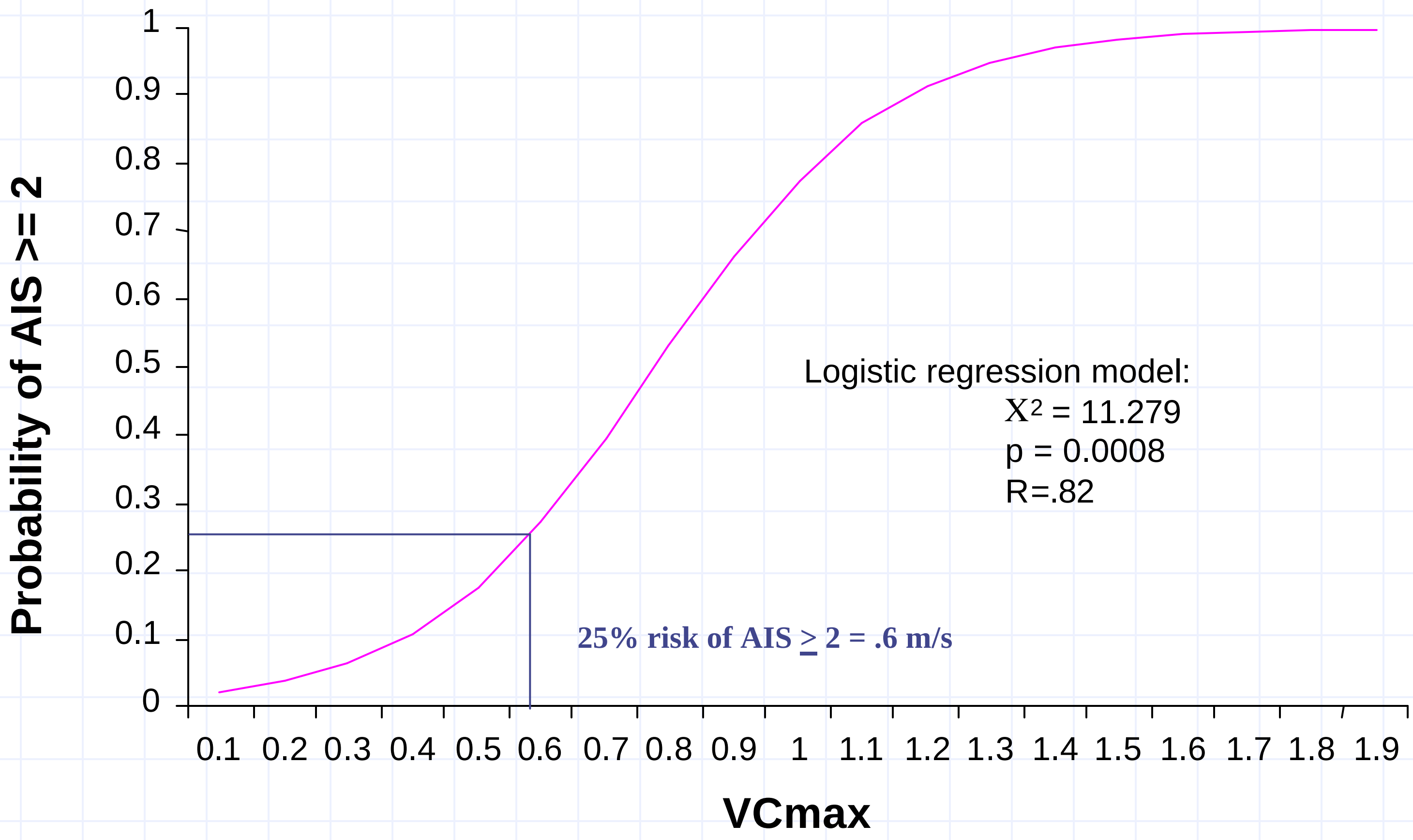
Probability of AIS $\geq$ 2 predicted by VC max



Injury tolerance

- VC of 2.8 m/s gives a 25% risk of severe lung injury (AIS=4+)
- VC of .6 m/s gives a 25% risk of skeletal injury (AIS = 2)
- VC less than .6 m/s results in less than a 25% risk of minor injury

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Abdomen

- Each area of abdomen gives unique response
- Injuries

	ABDOMEN
1	superficial penetrating injury
2	minor spleen laceration (<= 3 cm deep); no major vessel involvement
3	colon perforation
4	major kidney laceration (main renal vessel involvement)
5	massive liver laceration (disruption of > 50% of hepatic vascular system)
6	hepatic avulsion

Preliminary data indicates 33.1% of impacts occur to the thorax resulting in 33.15% of injuries.

-Hubbs et al.

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Abdomen

- Data has been collected for liver injuries by WRAIR
- No biomechanical data
- Injury criteria of VC and TTI have been proven for automotive impacts

Head Injury

- Several levels of injury – some mechanisms still being determined
- Injuries

HEAD	
1	scalp contusion or laceration
2	major scalp laceration
3	superficial penetrating injury (<= 2 cm below entrance)
4	basilar skull fracture (open or comminuted)
5	major penetrating injury (> 2 cm penetration)
6	crush--destruction of skull and brain

Preliminary data indicates 2.4% of impacts occur to the thorax resulting in 2.64% of injuries.

-Hubbs et al.

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Head Injury

- Head Injury Criteria (HIC)
- Severity Index (SI)

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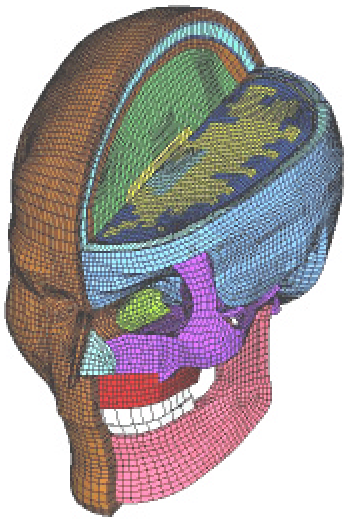
Facial Fracture

- Several bones make up face
- Each bone has specific tolerance level
- Injuries

	FACE
1	mandible fracture (location not specified)
2	zygoma fracture
3	maxilla fracture in which maxilla and one or more facial bones are separated from the skull
4	maxilla fracture with > 20% blood loss
5	none
6	none



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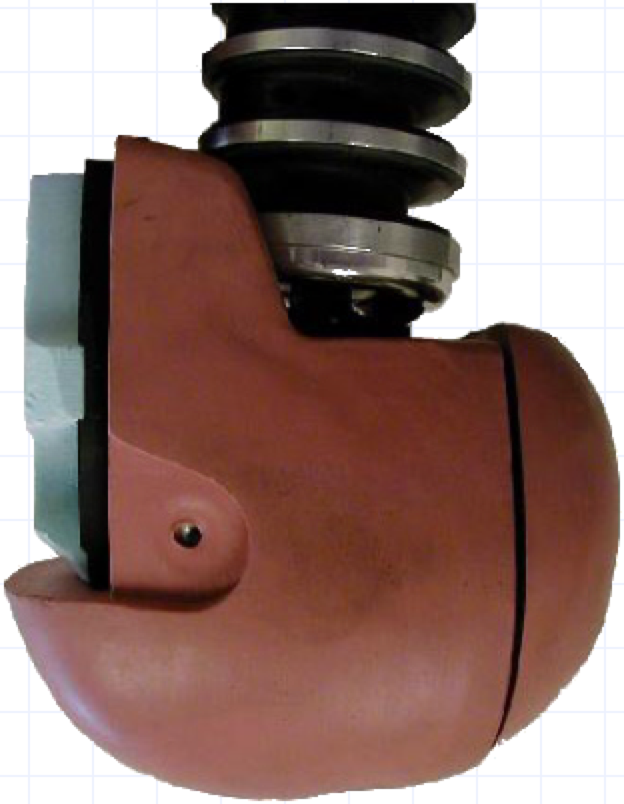
Facial Fracture

Cadaver #	Imp Loc	Vel (m/s)	En (J)	Fx	Peak F (N)	Max P(mm)
UM001	Front	69.26	84.40	No	3190	1
UM007	Front	37.90	17.72	No	1787	8
28292	Front	33.21	13.60	No	1647	1
UM002	Front			No	2450	
AVE	**Front**	**46.79**	**38.57**		**2269**	**3**
UM001	Zygo	53.54	50.44	Yes	1668	7
UM007	Zygo	38.30	18.09	Yes	1179	23
28292	Zygo	28.43	9.97	Yes	985	13
UM002	Zygo			Yes	972	
945	Zygo			Yes	1510	
AVE	**Zygo**	**33.37**	**14.03**		**1263**	**14**
UM001	Mand			Yes	3920	
O30	Mand	47.14	27.41	No	1552	25
UM007	Mand	44.90	24.87	No	1873	8
28292	Mand	35.92	15.92	No	943	19
UM002	Mand			No	1816	
945	Mand			No	2278	
AVE	**Mand**	**40.41**	**20.39**		**2064**	**17**



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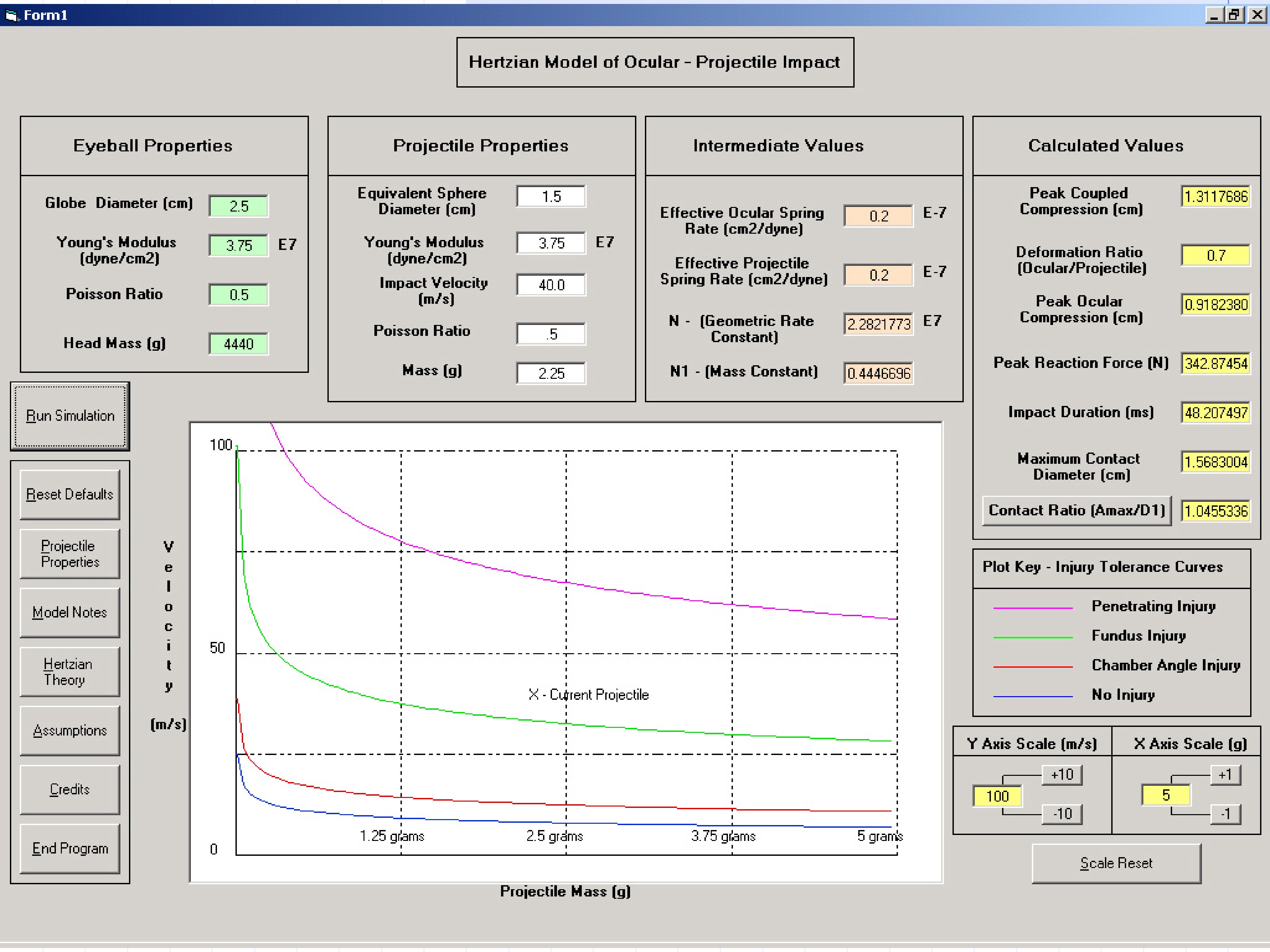
Eye

- Once the eye is impacted, hard to prevent injuries
- Injuries
  - Chamber angle injury
  - Fundus Injury
  - Penetrating Injury


Form1
Hertzian Model of Ocular - Projectile Impact
Eyeball Properties
Globe Diameter (cm) 2.5
Young's Modulus (dyne/cm2) 3.75 E7
Poisson Ratio 0.5
Head Mass (g) 4440
Projectile Properties
Equivalent Sphere Diameter (cm) 1.5
Young's Modulus (dyne/cm2) 3.75 E7
Impact Velocity (m/s) 40.0
Poisson Ratio .5
Mass (g) 2.25
Intermediate Values
Effective Ocular Spring Rate (cm2/dyne) 0.2 E-7
Effective Projectile Spring Rate (cm2/dyne) 0.2 E-7
N - (Geometric Rate Constant) 2.2821773 E7
N1 - (Mass Constant) 0.4446696
Calculated Values
Peak Coupled Compression (cm) 1.3117686
Deformation Ratio (Ocular/Projectile) 0.7
Peak Ocular Compression (cm) 0.9182380
Peak Reaction Force (N) 342.87454
Impact Duration (ms) 48.207497
Maximum Contact Diameter (cm) 1.5683004
Contact Ratio (Amax/D1) 1.0455336
Run Simulation
Reset Defaults
Projectile Properties
Model Notes
Hertzian Theory
Assumptions
Credits
End Program
100
50
0
Velocity
(m/s)
X - Current Projectile
1.25 grams
2.5 grams
3.75 grams
5 grams
Projectile Mass (g)
Plot Key - Injury Tolerance Curves
Penetrating Injury
Fundus Injury
Chamber Angle Injury
No Injury
Y Axis Scale (m/s)
100
+10
-10
X Axis Scale (g)
5
+1
-1
Scale Reset

Proposed limits for each area

- Thorax
  - VC < .6
  - .6 < VC<2.8
  - 2.8 < VC
- Abdominal
  - VC < ?
  - ? < VC < ?
  - ? < VC

- HIC
  - HIC < 700
  - 700 < HIC < 1000
  - 1000 < HIC
- Facial Fracture
  - Mandible Fx
  - Zygomatic Fx
  - Fracture with separation
- Eye
  - Chamber angle
  - Fundus
  - Penetrating injury

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What does all this mean to the end-user?

Potential Standard

- Thoracic Injury
- Abdominal Injury
- Accuracy Assessment

Thank you to the National Institute of Justice and Joe Cecconi.