Evaluating the Risk of Eye Injury using Experimental and Computational Research Methods

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Center for Injury Biomechanics

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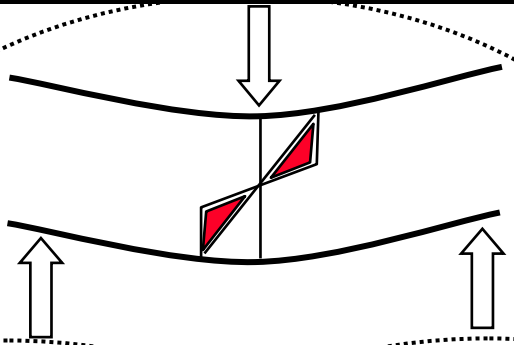
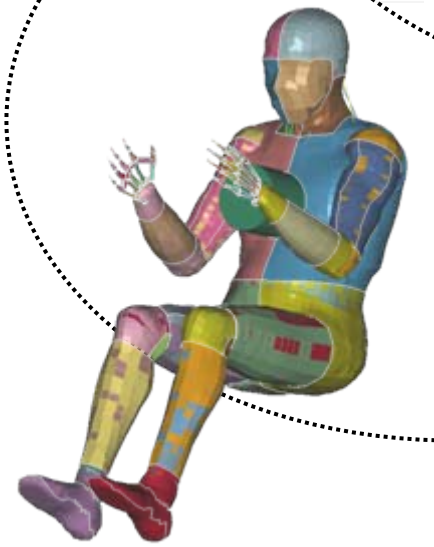
CIB Research Approach

Experimental Testing



Computational Modeling



CIB

Case Analysis

CIREN

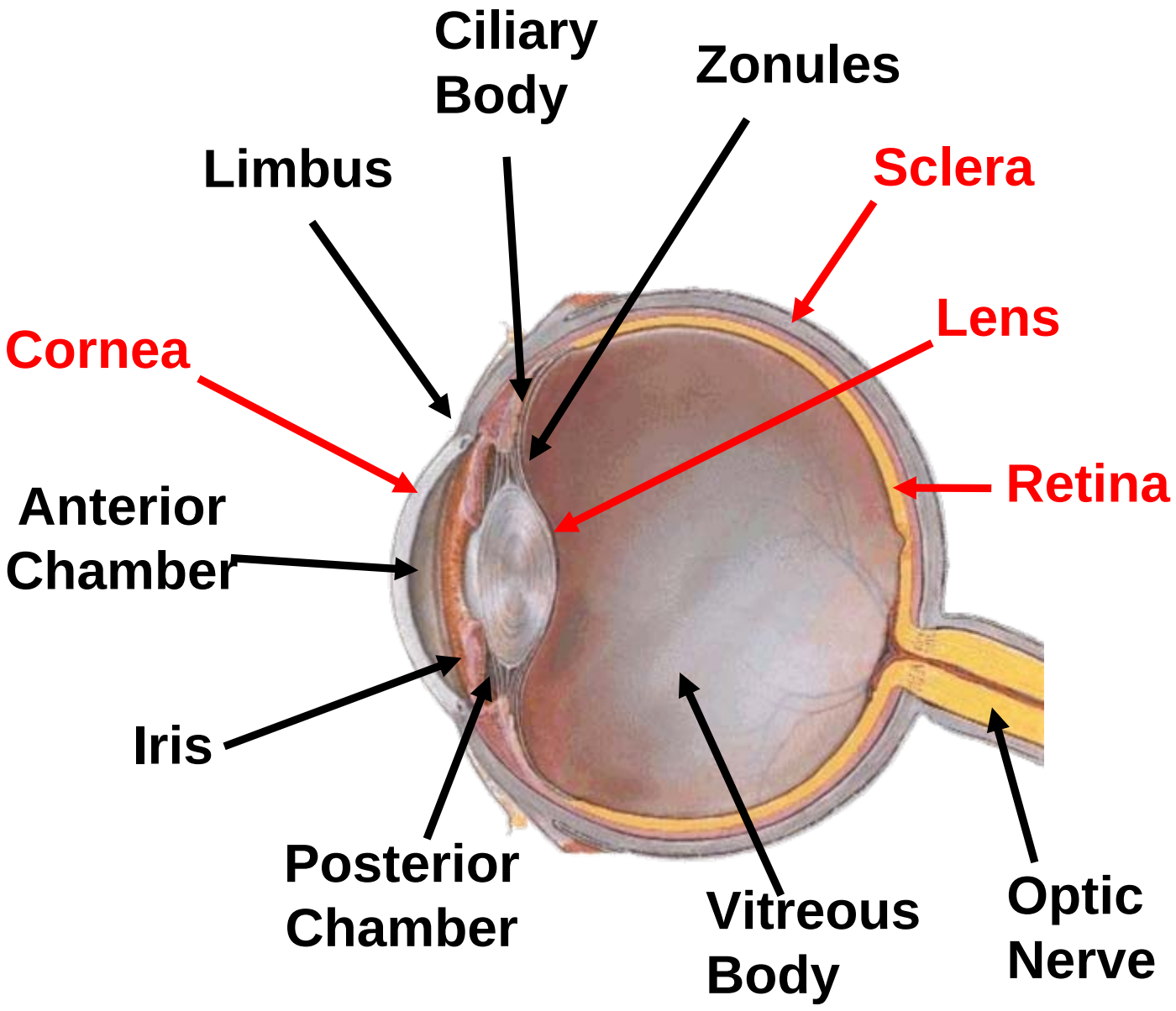
FARS

NASS-CDS

Research Areas

	Application			
Body Region	Automobile Safety	Military	Sports	*Other*
Head/Brain	FMVSS 208	Crash/Blast	Football	Treatment
Eye/face	Airbag/Particles	IED/Shrapnel	Softball	Products
Neck	Nij	Head Mass	Football	Stints
Thorax	Belt Loading	Restraints	Shoulder Pads	Treatment
Upper limb	Airbag Loading	Airbags	Brace Design	Surgery
Pregnant	Restraints	Work/time	Eligibility	Violence
Pelvis	Side Impact	Vehicle	Football	Pregnancy
Lower limb	Knee Bolster	Paratrooper	Brace Design	Prosthetics

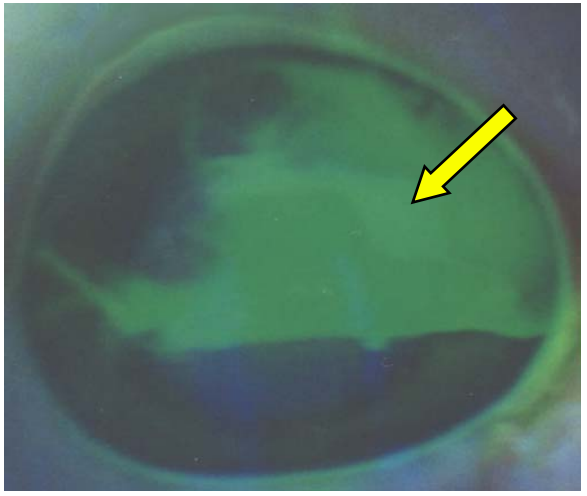
Eye Anatomy

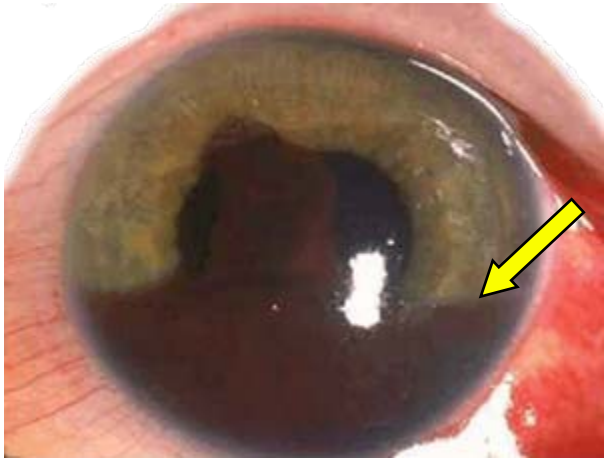

Ciliary Body
Zonules
Limbus
Sclera
Lens
Cornea
Retina
Anterior Chamber
Iris
Posterior Chamber
Vitreous Body
Optic Nerve

Eye Injuries

AIS 1

- Corneal Abrasions
- Hyphema: blood in anterior chamber





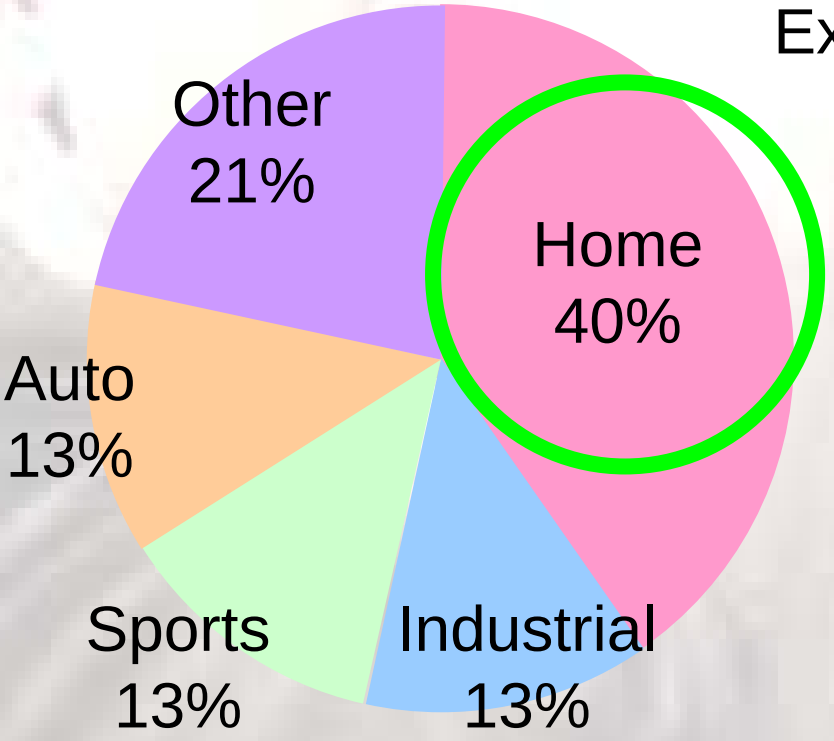
AIS 2

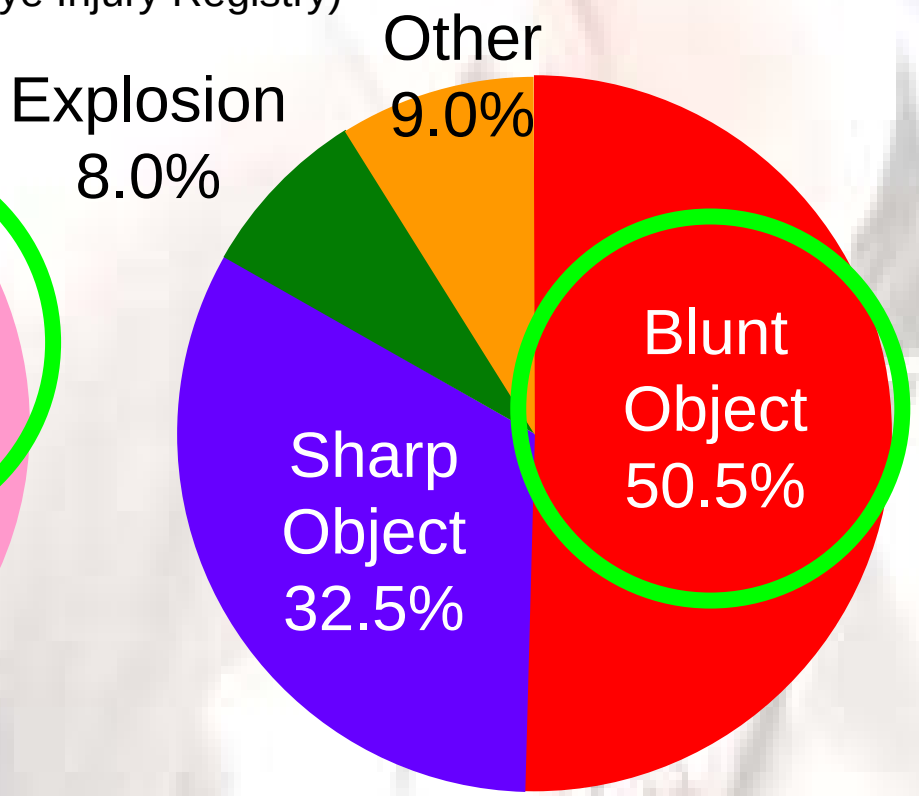
- Retinal Detachment
- Corneal/Scleral Laceration
- Globe Rupture
- Eye Enucleation

9000+ globe ruptures per year in US (Smith 2002)

Eye Injuries

- Over 1.9 million eye injuries per year in the United States (McGwin 2005, Lueder 2000, Parver 1986)
- Trauma is 2nd to cataracts as most common form of visual impairment
- 10,000 blind in one eye as a result of trauma per year in the United States (National Eye Injury Registry)





Alcohol and Eye Injuries

- Evidence of alcohol use in 24% of eye injury cases (Parver 1993)
- Corks account for 10.8% of ocular injury hospital admissions in Europe (Cavallini 2003)

Champagne bottle: ~ 90 psi

(8.8 m/s)

Recreational Gun Eye Injuries

- BB and Pellet Gun Injuries (CDC 1995)
  - 30,000 injuries/year
  - 3,000 eye injuries/year
  - 600 hospitalizations/year for severe eye injuries
  - 81% are children (<19 years)
- Paintball (Listman 2004)
  - 3,000 injuries/year
  - 1,200 eye injuries/year
  - 500 eye injuries/year for children (<15 years)

Airsoft Guns

- Relatively new “toy” gun
- Similar to BB gun
  - Plastic pellets
  - Spring or compressed gas powered
  - Less overall energy
- Documented cases of eye injury in literature
- No conclusive experimental test data
  - Porcine eyes are stronger than human eyes

Reported Injury Incidence

- Ocular injuries due to airsoft guns are becoming increasingly common in clinical scenarios (Fleischhauer 1999, Endo 2000, Endo 2001)

- Case Study (Endo 2001)
  - 7-year old boy accidentally shot in eye by his friend
  - Corneal abrasion, hyphema, retinal damage
  - Possible late-onset traumatic glaucoma
- Case Study (Fleischhauer 1999)
  - 8 cases of reported eye injury due to Airsoft guns
  - Corneal abrasion, hyphema, and retinal damage most common injuries (5+ each)

Predicting Eye Injuries

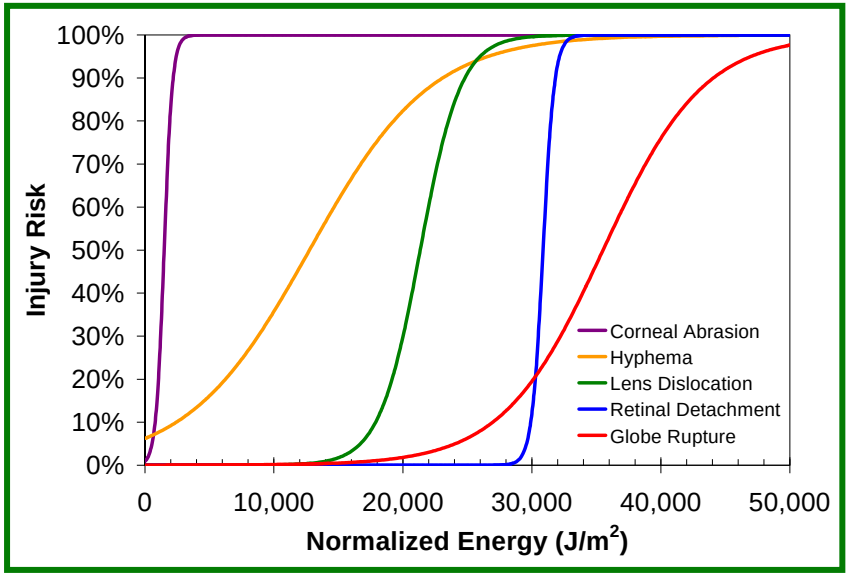
- Analytical Methods
- Experimental Cadaver Tests
- Computational Modeling
- Physical Dummy Headform (FOCUS) Tests

Parametric Risk Analysis

- Eye injury database from projectile tests (experimental and in literature)
- Statistical analysis of projectile characteristics related to eye injury risk
- Developed parametric risk functions for corneal abrasion, hyphema, lens dislocation, globe rupture

8 Studies, 251 Individual Tests:
Corneal abrasion (21), Hyphema (63),
Lens Dislocation (60), Retinal Detachment (26),
Globe rupture (227)

Normalized Energy (p-value/Goodman-Kruskal Gamma):
Corneal Abrasion (0.001/0.94),
Hyphema (0.001/0.83),
Lens Dislocation (0.001/0.99),
Retinal Detachment (0.001/1.00),
Globe Rupture (0.001/0.98)



Combined Injury Risk Functions

Lens Dislocation:
50% Risk = 21,344 J/m²

Injury Risk
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

0
10,000
20,000
30,000
40,000
50,000
60,000

Normalized Energy (J/m²)

Corneal Abrasion
Hyphema
Lens Dislocation
Retinal Detachment
Globe Rupture

Predicting Eye Injuries

- Analytical Methods
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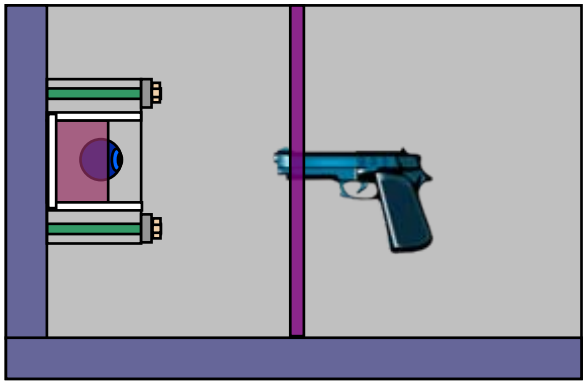
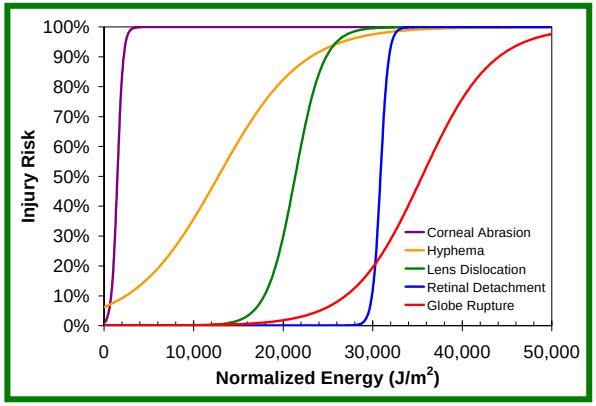
Airsoft Gun Injury Study

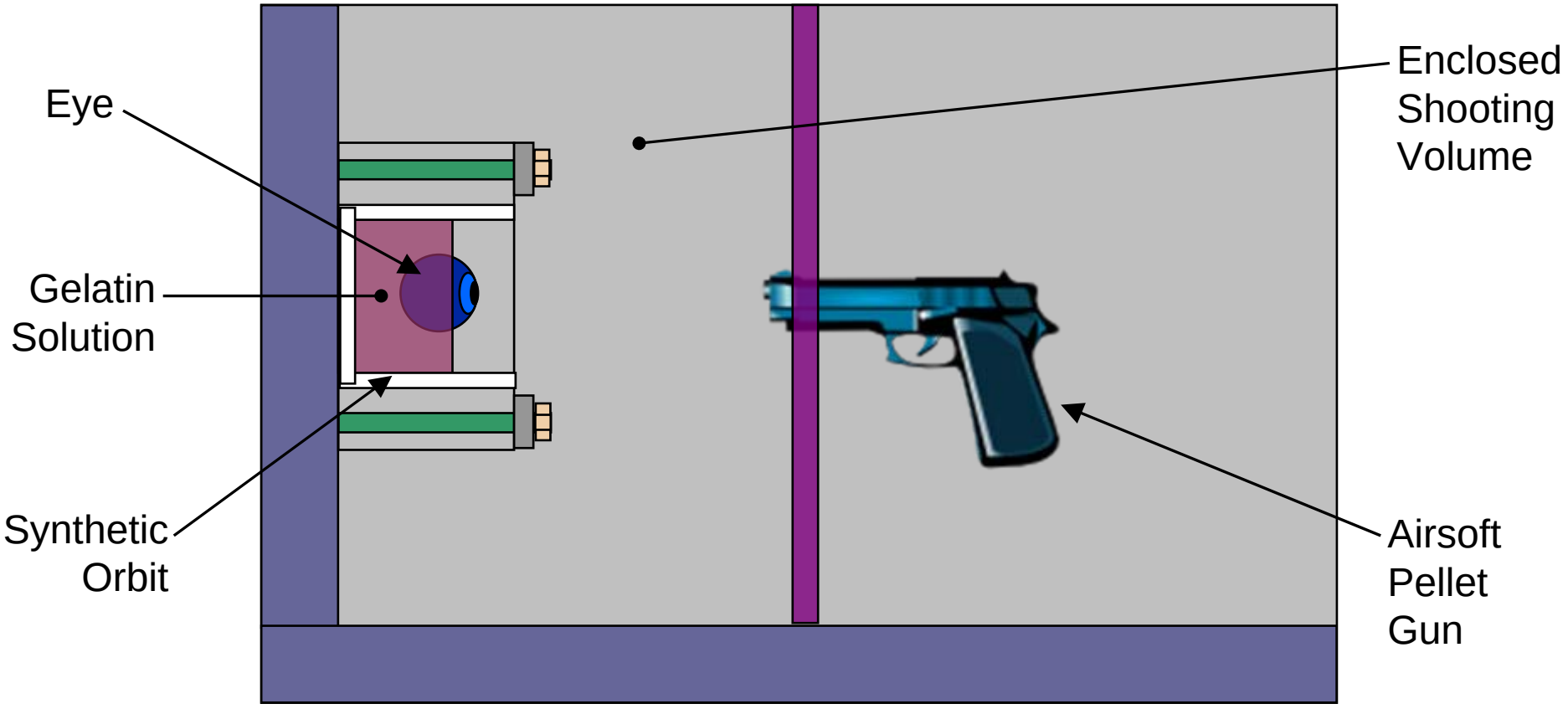
- Perform experimental tests to quantify projectile energy from Airsoft pellet guns
- Quantify the risk of eye injury from Airsoft pellet guns
  - Corneal abrasion
  - Lens dislocation
  - Hyphema
  - Retinal detachment
  - Globe rupture
- Compare predicted injury outcome with clinical data from Airsoft eye injury cases



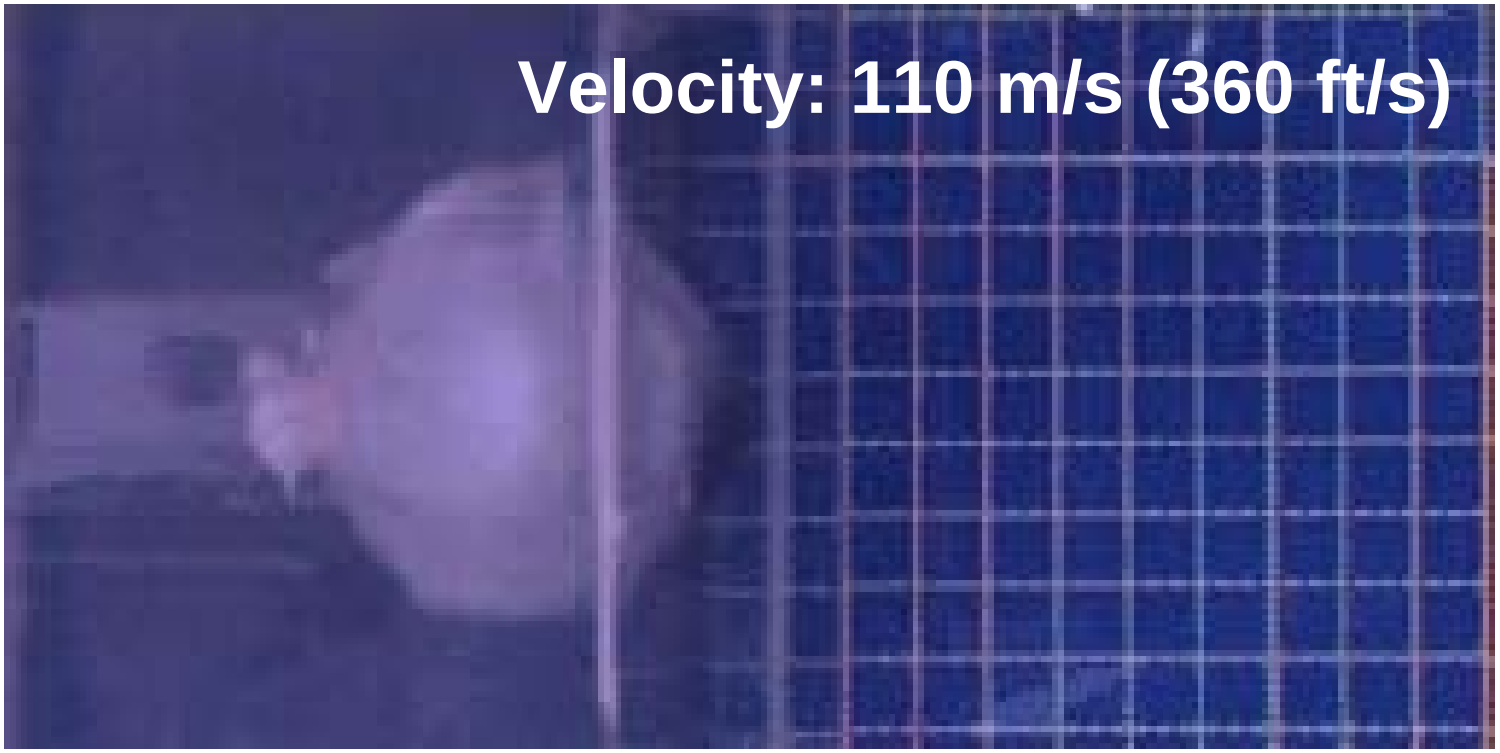


Experimental Test Methods

- 13 Human and 13 Porcine eyes in synthetic orbit
- Spring and compressed-gas powered Airsoft guns
- Determine velocity, mass, diameter and injury response



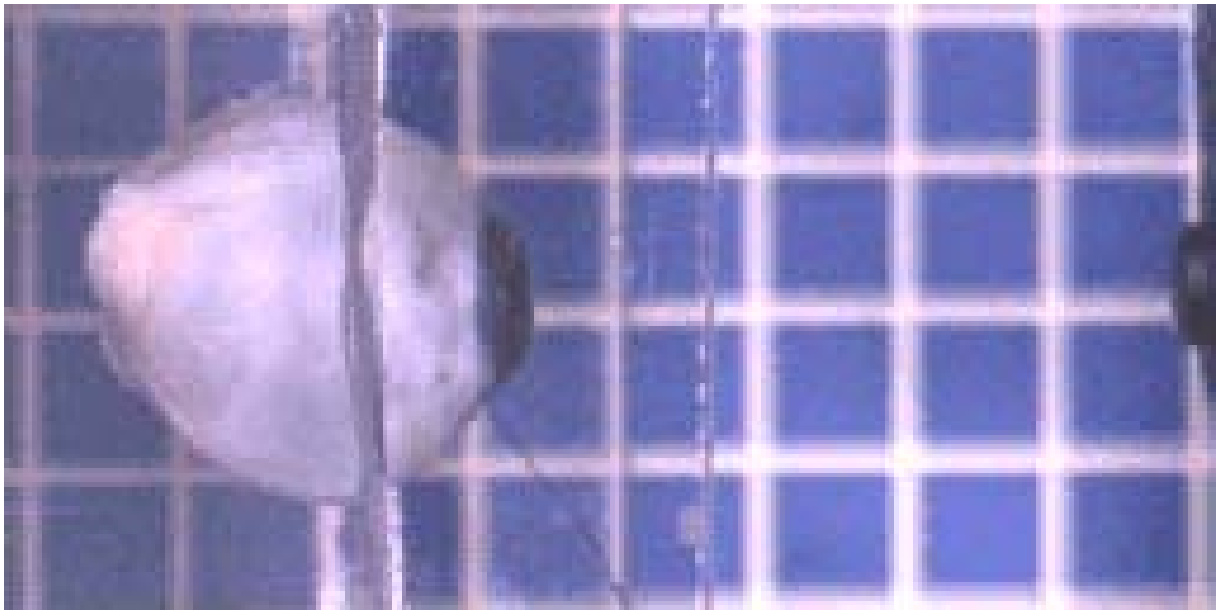
Experimental Tests

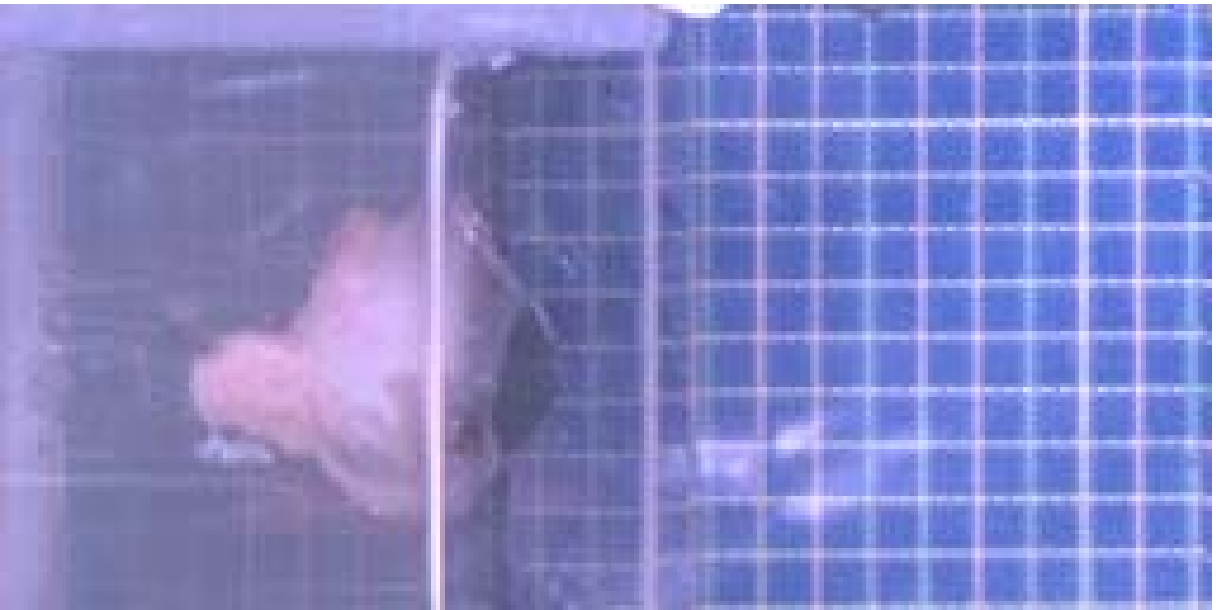


- Velocity Range: 67 m/s to 118 m/s
- Energy Range: 0.45 J to 0.80 J
- No globe rupture (human or porcine)

Experimental Test Videos

BB
92 m/s



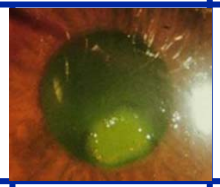
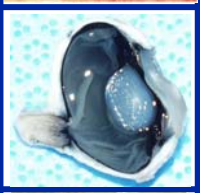


BB
98 m/s

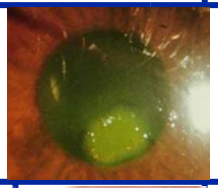
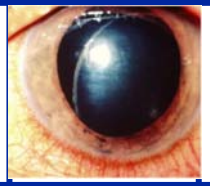
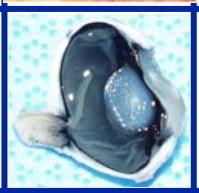
Airsoft vs. BB Guns

	Airsoft	**Airsoft**	**BB**
Energy Source	Pneumatic	Spring	Pneumatic
Mass	0.12 g 0.20 g	0.12 g 0.20 g	0.34 g
Diameter	6 mm	6 mm	4.5 mm
Velocity			
Kinetic Energy			
Normalized Energy			

Airsoft vs. BB Guns

		Airsoft (Pneumatic)	**Airsoft** (Spring)	**BB**
Normalized Energy		19,060 J/m^2	26,364 J/m^2	79,000 J/m^2
Corneal Abrasion		100 %	100 %	100 %
Hyphema		79 %	95 %	100 %
Lens Dislocation		24 %	94 %	100 %
Retinal Detachment		0 %	0 %	100 %
Globe Rupture		2 %	9 %	100 %

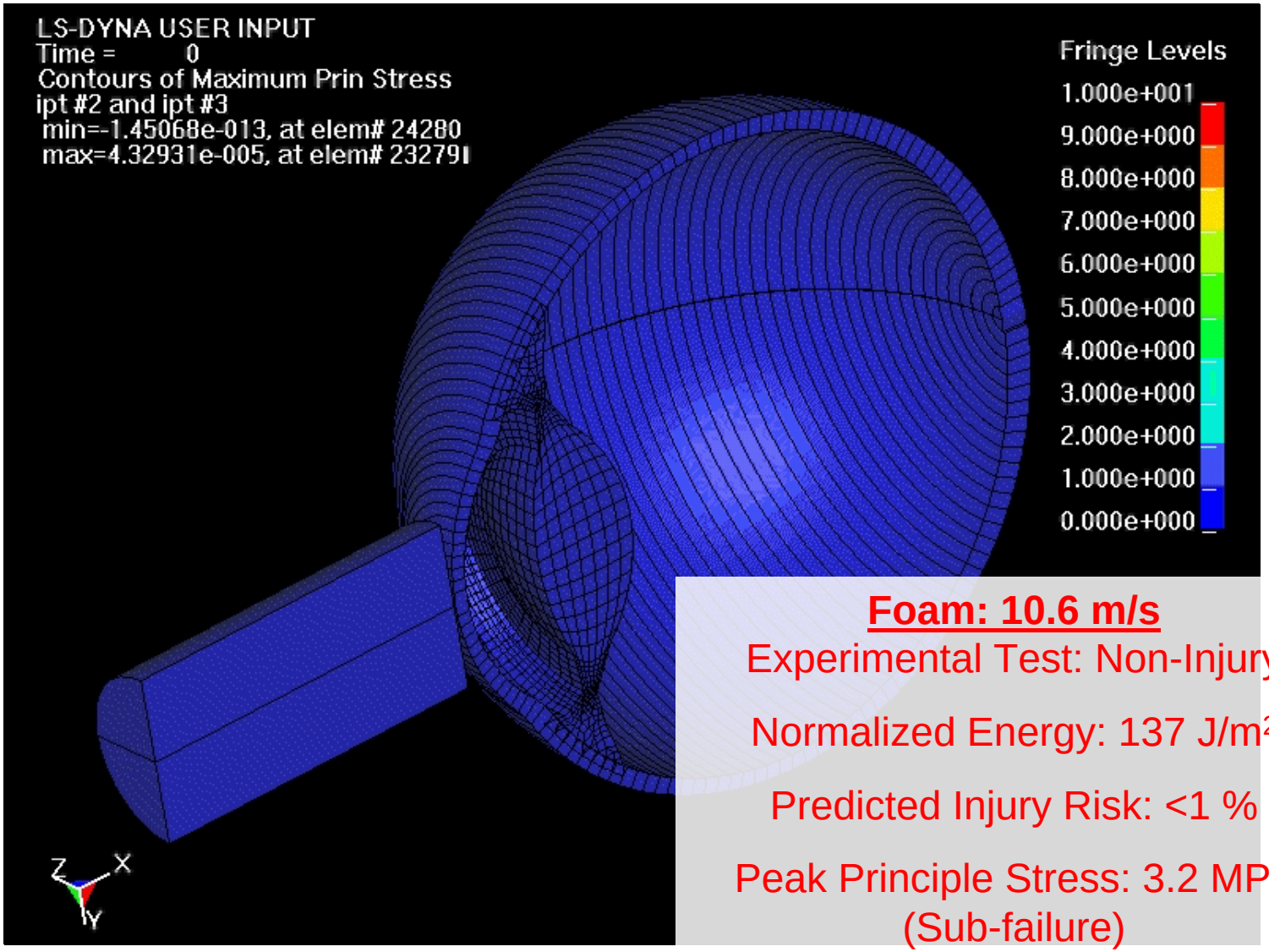
Injury Risk vs. Case Studies

		Airsoft (Pneum.)	Airsoft (Spring)	Case Study (Endo 2001)	8 Cases (Fleischhauer 1999)
Corneal Abrasion		100 %	100 %	✓	6x ✓
Hyphema		79 %	95 %	✓	7x ✓
Lens Dislocation		24 %	94 %	Late Onset Traumatic Cataract	
Retinal Detachment		0 %	0 %	✓	5x ✓
Globe Rupture		2 %	9 %	No Injuries	

Predicting Eye Injuries

- Analytical Methods
- Experimental Cadaver Tests
- Computational Modeling
- Physical Dummy Headform (FOCUS) Tests

Computational Eye Modeling



Foam: 10.6 m/s

Experimental Test: Non-Injury

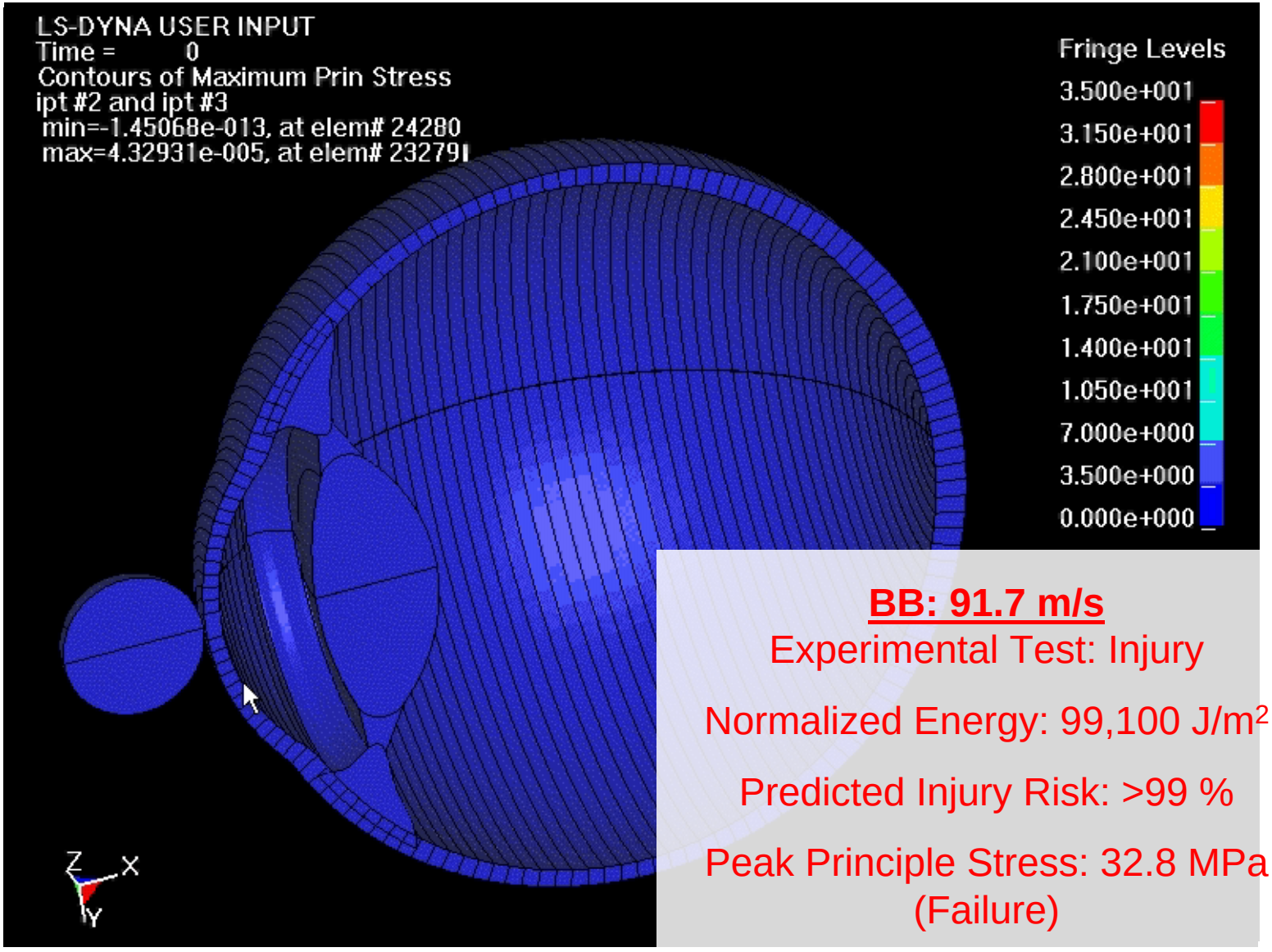
Normalized Energy: 137 J/m^2

Predicted Injury Risk: <1 %

Peak Principle Stress: 3.2 MPa (Sub-failure)

Stitzel 2002

Computational Eye Modeling



BB: 91.7 m/s

Experimental Test: Injury

Normalized Energy: 99,100 J/m^2

Predicted Injury Risk: >99 %

Peak Principle Stress: 32.8 MPa (Failure)

(Stitzel 2002)

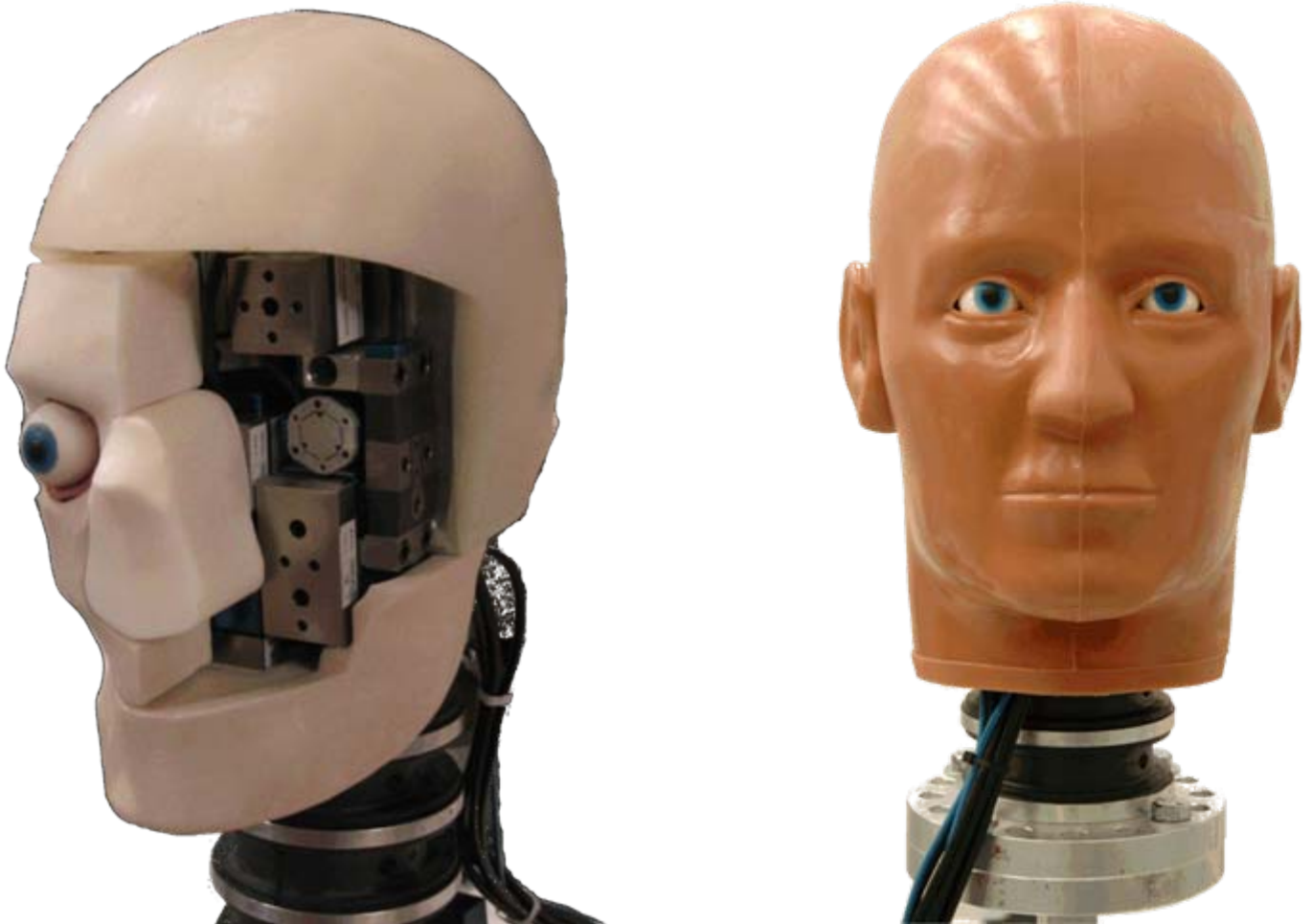
Predicting Eye Injuries

- Analytical Methods
- Experimental Cadaver Tests
- Computational Modeling
- Physical Dummy Headform (FOCUS) Tests

FOCUS Headform

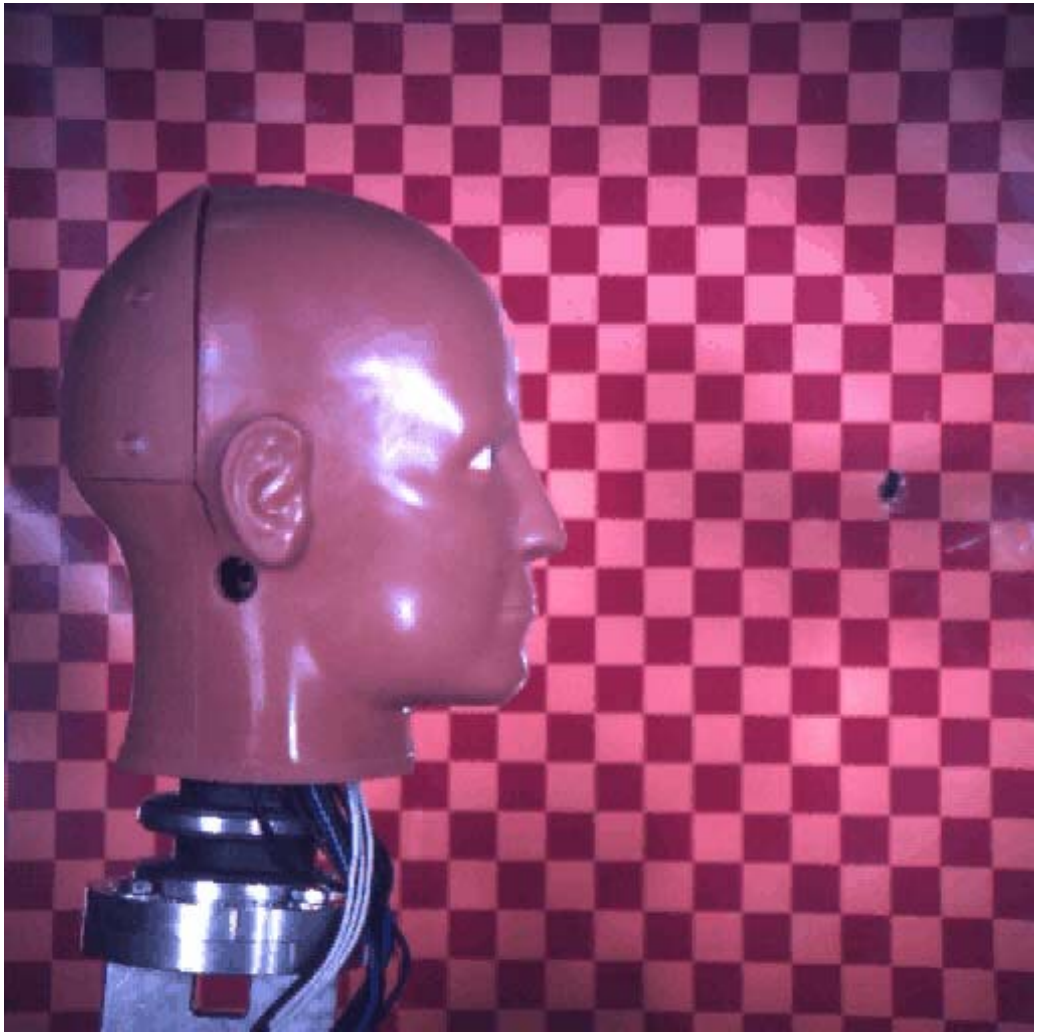
Facial and Ocular CountermeasUre Safety Headform

- **Fully Instrumented Headform for Assessing Eye and Facial Injury Risk**



FOCUS Impact Test

- Soft Baseball
- 80 mph
- 500 lb on Right Frontal Bone (subfailure)



Applications

- Assess eye injury risk from potential eye impacts
  - Consumer products
  - Automotive
  - Military

Take home message…

Acknowledgements

United States Army Aeromedical Research Laboratory

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Center for Injury Biomechanics

Virginia Tech

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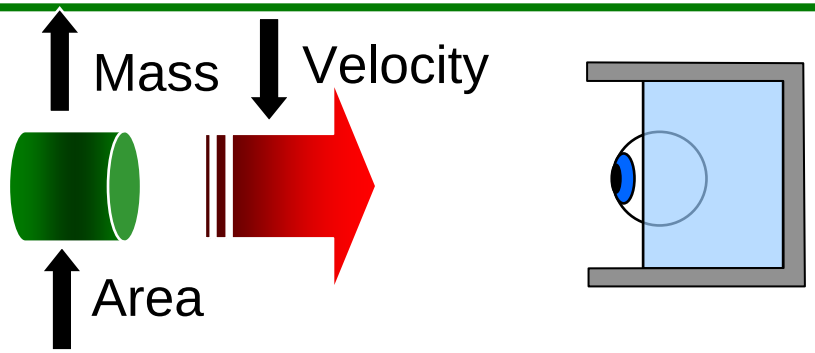
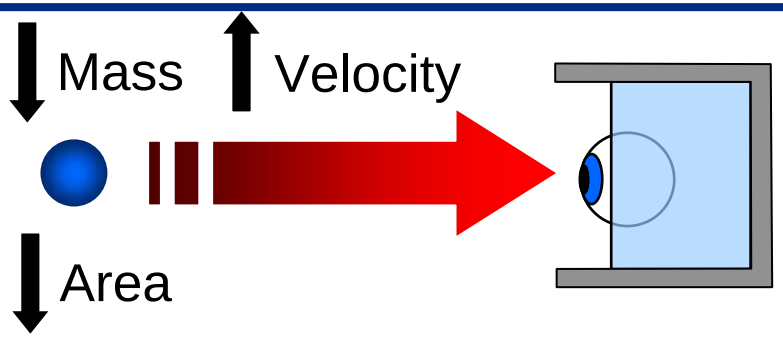
Kinetic vs. Normalized Energy



Steel Rod Impact



BB Impact

$$\text{Kinetic Energy} = \frac{1}{2}mv^2$$

$KE_{\text{Steel Rod}} = 1.4\ \text{J}$

KE Injury $\text{Risk}_{\text{Steel Rod}}$: 26%

$$\text{Kinetic Energy} = \frac{1}{2}mv^2$$

$KE_{BB} = 1.4\ \text{J}$

KE Injury Risk_{BB}: 26%

$$\text{Normalized Energy} = \frac{KE}{\text{Area}} = \frac{mv^2}{2\pi r^2}$$

$NE_{\text{Steel Rod}} = 7{,}000\ \text{J/m}^2$

NE Injury $\text{Risk}_{\text{Steel Rod}}$: <1%

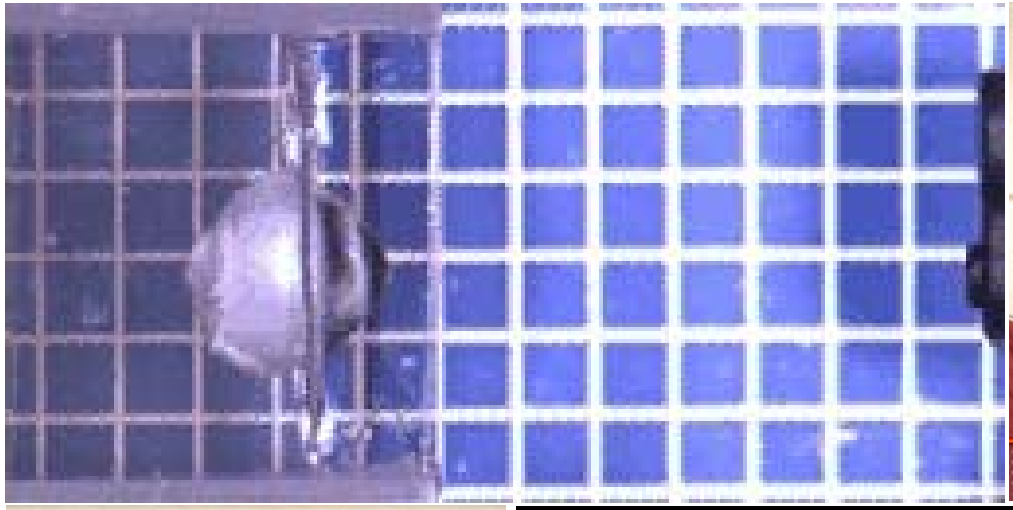
$$\text{Normalized Energy} = \frac{KE}{\text{Area}} = \frac{mv^2}{2\pi r^2}$$

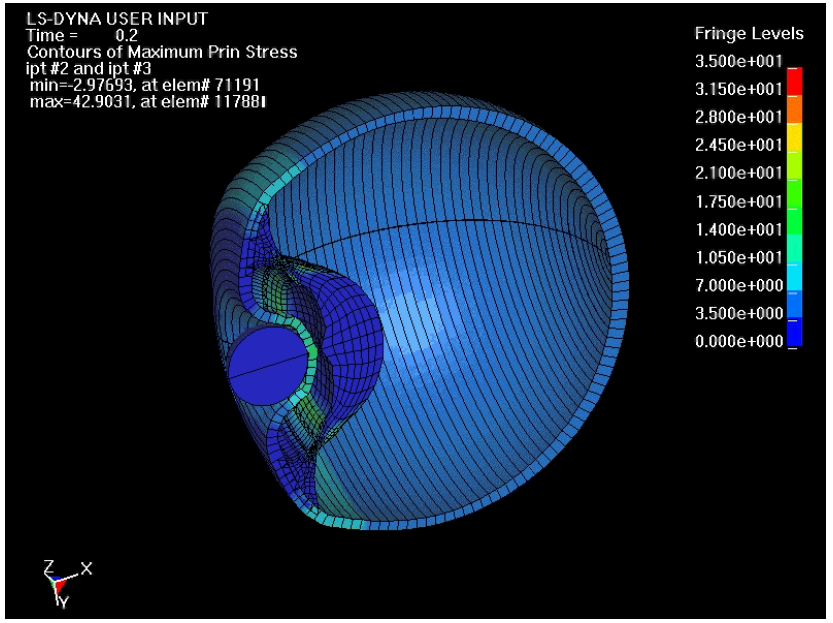
$NE_{BB} = 85{,}500\ \text{J/m}^2$

NE Injury Risk_{BB}: >99%

This is a “toy” gun

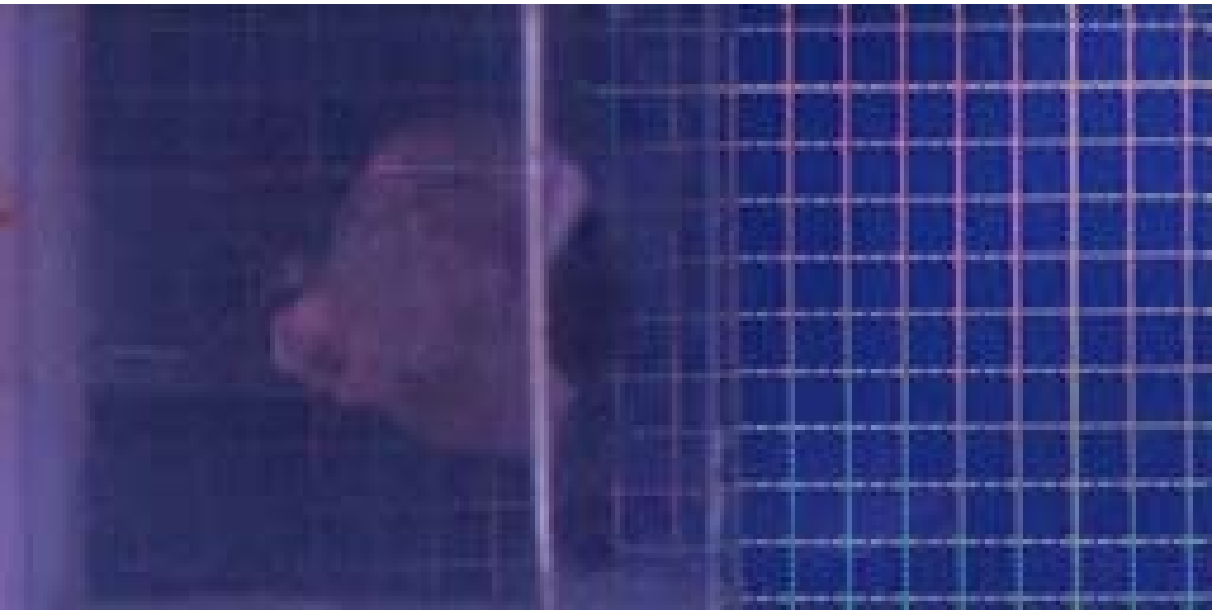
Eye Injury Evaluation





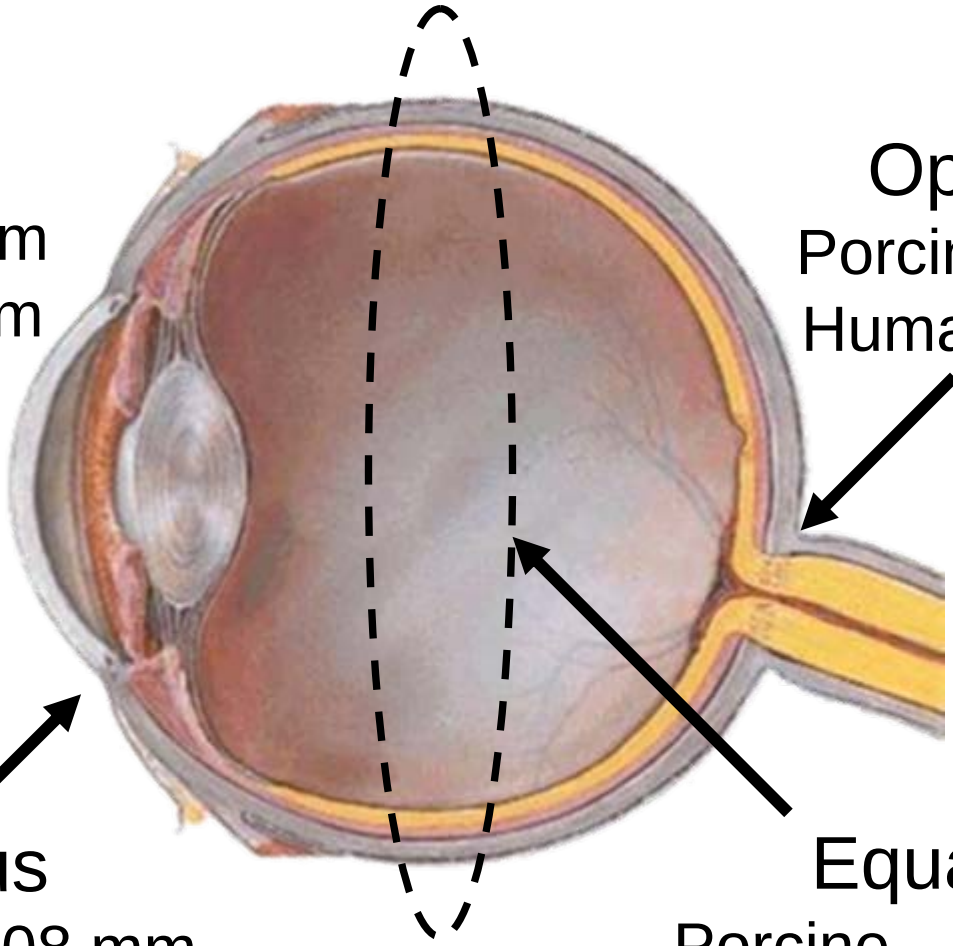
Experimental Test Videos

Paintball
71 m/s*
*(below regulation)



Paintball
107 m/s

Human vs. Porcine Histology



Cornea
Porcine – 0.97 mm
Human – 0.75 mm

Optic Nerve
Porcine – 1.17 mm
Human – 0.92 mm

Limbus
Porcine – 1.08 mm
Human – 0.71 mm

Equator
Porcine – 0.87 mm
Human – 0.62 mm