



JENSEN HUGHES

Advancing the Science of Safety

I've Fallen and I Do Not Want to Get Up and Other Injury Stories from a Biomechanical Engineer

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Senior Biomechanical Engineer



Professional

Accident reconstruction, injury biomechanics and injury mechanism/causation analysis. Works on cases across the country.

Provides analysis of injuries in automotive collisions, industrial accidents, workers compensation claims, premises liability claims, slip / trip and falls, and sport / recreation accidents. He provides litigation support to insurance.

Testifies on vehicle speeds, impact severities (delta-Vs), collision sequence, mechanism of injury, seat belt use and effectiveness, timing of injuries in multiple collision events.

Differentiating acute traumatic injuries from chronic/degenerative conditions.

Explanation of complex concepts in a manner that juries can understand.

Forensic Injury Biomechanics: A Simplified View

Topics

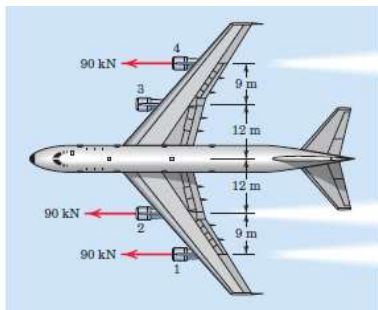
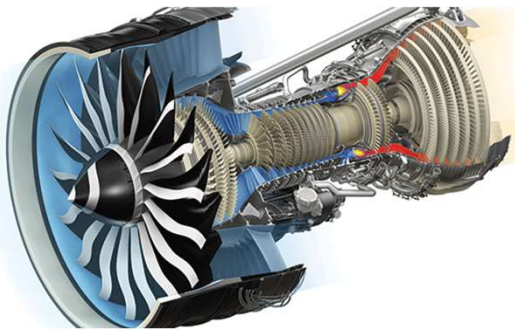
- + What is Biomechanics?
- + Injury Biomechanist vs. Medical Doctor
- + Mechanisms of Injury
- + Case Studies

What is Biomechanics?

What is Biomechanics?

Mechanical Engineering:

+ The study of **motions** and **forces**



What is Biomechanics?

Mechanical Engineering:

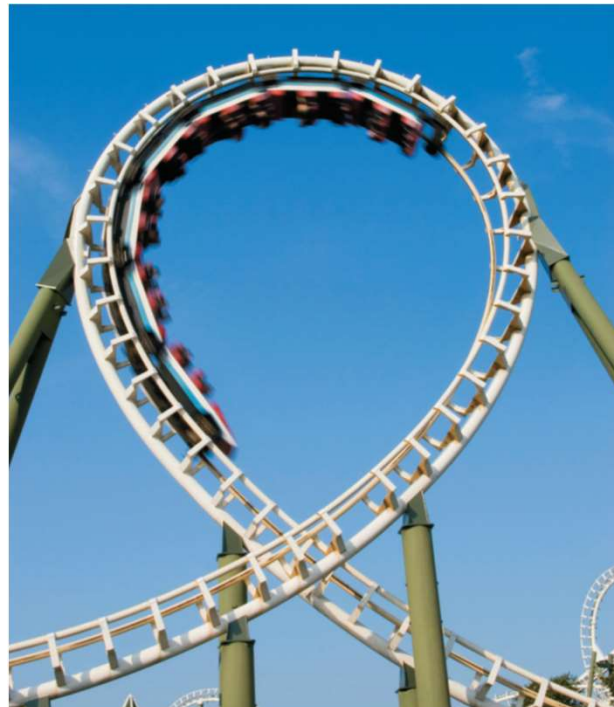
+ If motions and forces $>$ structure's strength/tolerance \rightarrow Failure



What is Biomechanics?

Biomechanics:

- + Bio + Mechanics: Application of mechanical engineering principles to the body
- + Study of body motions and forces



What is Biomechanics?

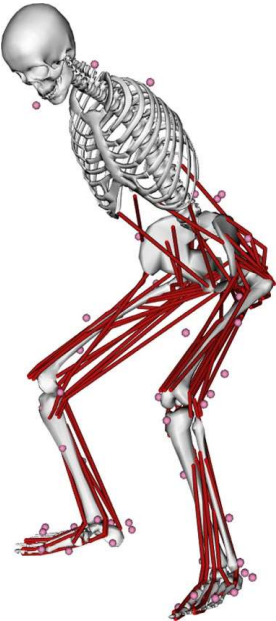
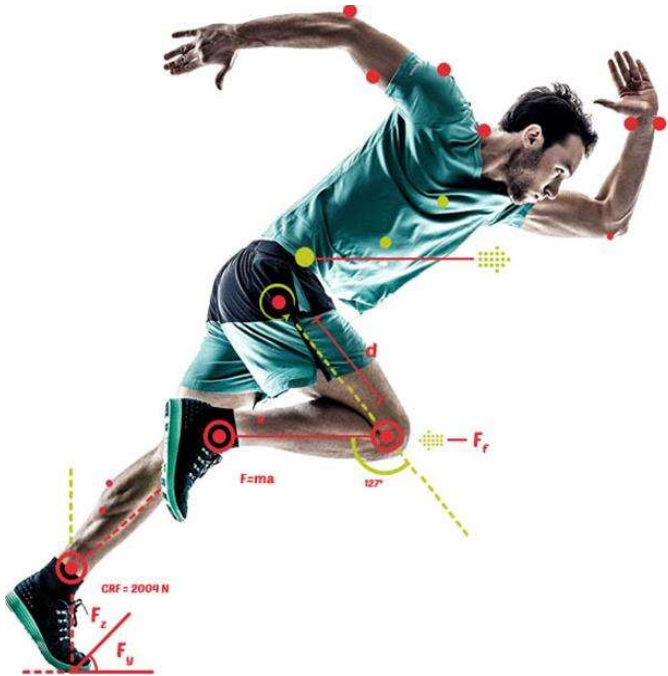
Vehicle-Pedestrian Dummy Crash Test:



What is Biomechanics?

Injury Biomechanics:

+ If motions/forces > human tolerance \rightarrow injury



What is Biomechanics?

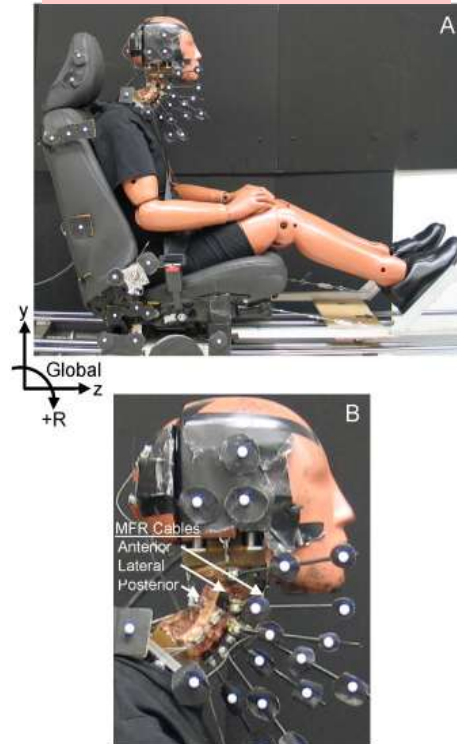
Injury Biomechanics:

+ Human Injury Tolerance/Threshold: Biomechanical Testing

PMHS



Crash Dummies (ATDs)



Human Volunteers



What is Biomechanics?

Crash testing using ATDs:



**Injury Biomechanist
vs.
Medical Doctor**

Injury Biomechanist vs. Medical Doctor

Injury Biomechanist:

- + Understanding of “event” **physics**: motions (kinematics) and forces (kinetics/dynamics)
- + Knowledge of anatomy, physiology and **mechanical properties** of biological tissues

+ Is there a **causal relationship** between the diagnosed injuries and the events alleged to have caused them?

- **Exposure**: Loads applied to the body
- **Tolerance**: Loads required to cause injury

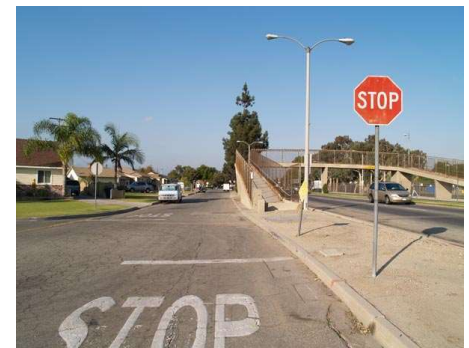
+ Had the circumstances been different, could the injuries have been **mitigated** or **eliminated** (helmets, seatbelts, etc.)?



Injury Biomechanist vs. Medical Doctor

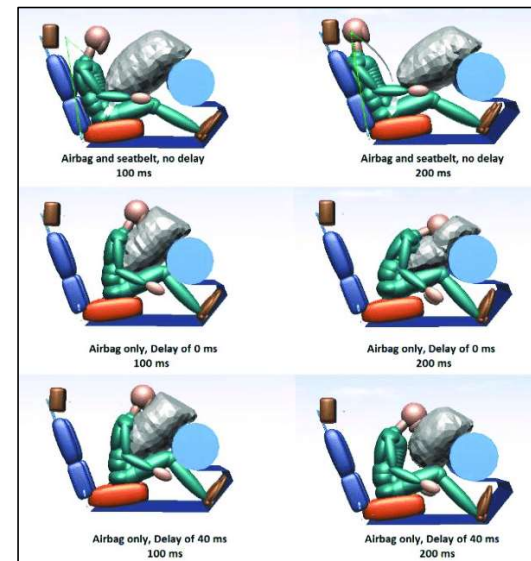
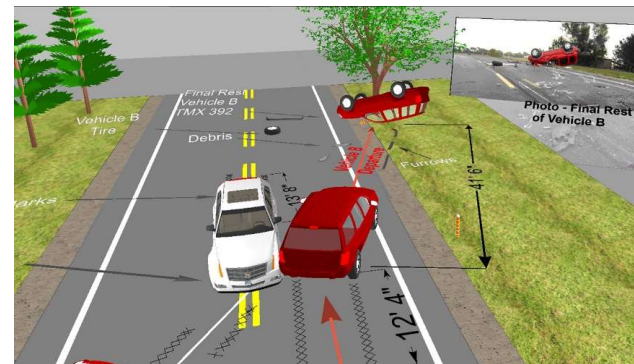
Injury Biomechanist:

- + Review of incident descriptions, photos, etc.
- + Review of Medical Records
 - Diagnoses (X-rays, CT scans, MRIs) by MD
 - Treatments (PT, surgeries) by MD
 - Pre-existing conditions
- + Inspection/Accident Reconstruction
 - To be performed prior to injury analysis
 - Physical evidence: human, vehicle, environment
- + Determine forces/motions of the body during the event
 - Analytical tools: hand calculations
 - Simulation software: PC-Crash, MADYMO, LS-Dyna
 - Laboratory testing: Using cadavers, ATDs, human volunteers
 - Published biomechanics literature



Injury Biomechanist vs. Medical Doctor

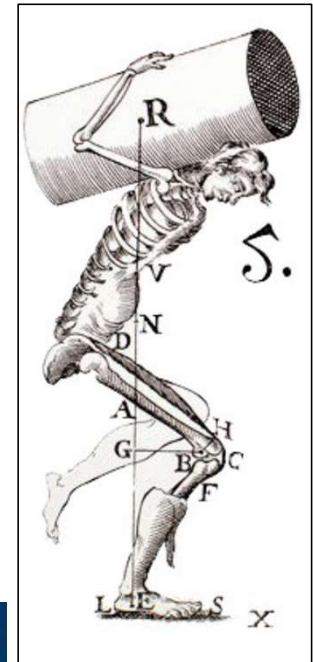
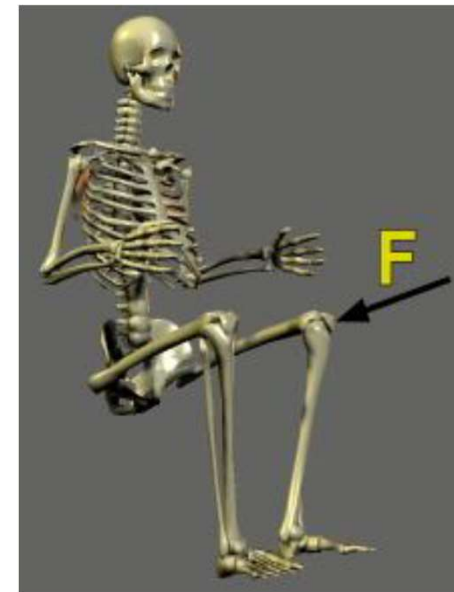
- + Accident Reconstruction (vehicle motions/forces):
 - Vehicle Speeds
 - **Collision Severity (change-in-velocity, delta-V)**
 - **Principal Direction of Force (PDOF)**
 - **Impact Duration**
 - Sightline Analysis
 - Collision Sequence
 - Driver Perception-Reaction
- + Injury Biomechanics (body motions/forces):
 - Delta-V, PDOF, Impact Duration (from AR)
 - Occupant Kinematics and Dynamics
 - Injury Mechanism/Causation Analysis



Injury Biomechanist vs. Medical Doctor

Injury Biomechanist:

- + Mechanism of injury
 - Direct contact
 - Indirect forces
 - Exceeding range of motion
 - Acceleration/deceleration (brain injuries)
- + Loads sustained by tissue vs. tolerance
 - Pre-existing conditions (tissue attenuation)
- + Differentiate **acute/traumatic** from **chronic/degenerative**



Injury Biomechanist vs. Medical Doctor

Injury Biomechanist:

- + Injury Tolerance
- + ADL Loads (g-force)

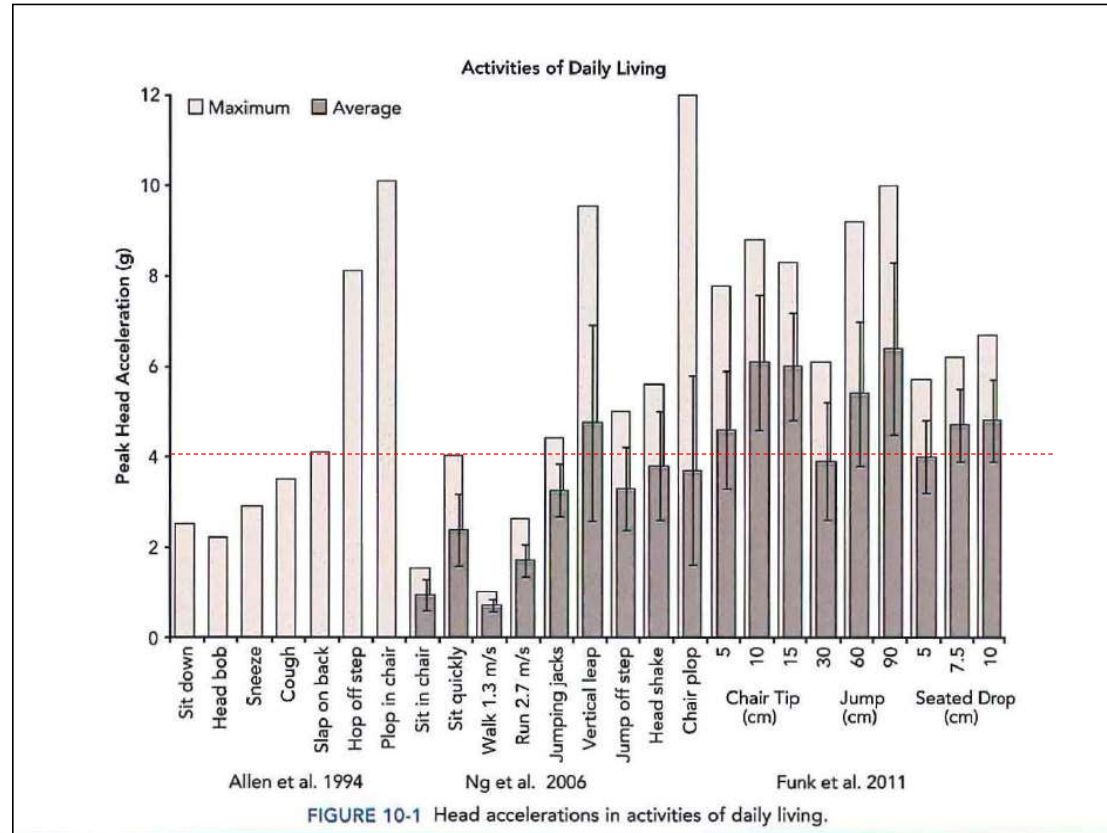
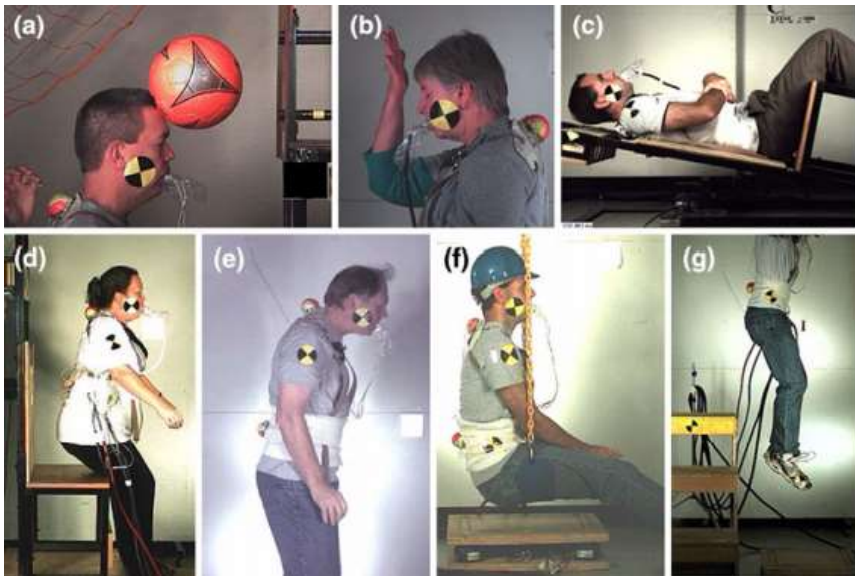


FIGURE 10-1 Head accelerations in activities of daily living.

Injury Biomechanist vs. Medical Doctor

Injury Biomechanist:

- + Premises Liability, Slip/Trip and Fall Incidents
 - Coefficient of Friction (COF), Slip Resistance
 - Stairways, escalators, moving walkways, etc.

 - Is the fall mechanics (body motions, loading magnitude, direction and duration) consistent with traumatic injuries? **Exposure vs. Tolerance**

 - Restaurants, shopping centers, hospitals, amusements parks, residential complexes, etc.

- + Industrial Accidents, Workplace Injuries, Falling Objects, Sports/Recreational Incidents, etc.



Injury Biomechanist vs. Medical Doctor

Medical Doctor:

+ Diagnosis of injuries

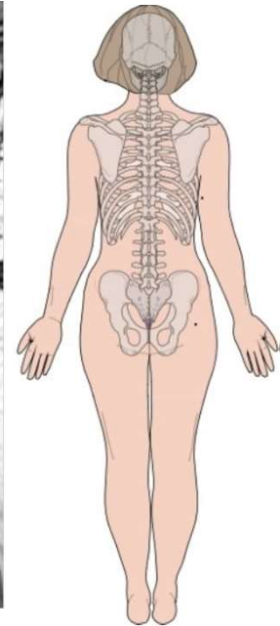
- Traumatic brain injury (TBI), Concussion
- Cervical/Lumbar disc herniation
- Cervical/Lumbar sprain/strain
- Shoulder rotator cuff tear
- Knee ACL/meniscus tear
- Ankle fracture

+ Treatment of injuries

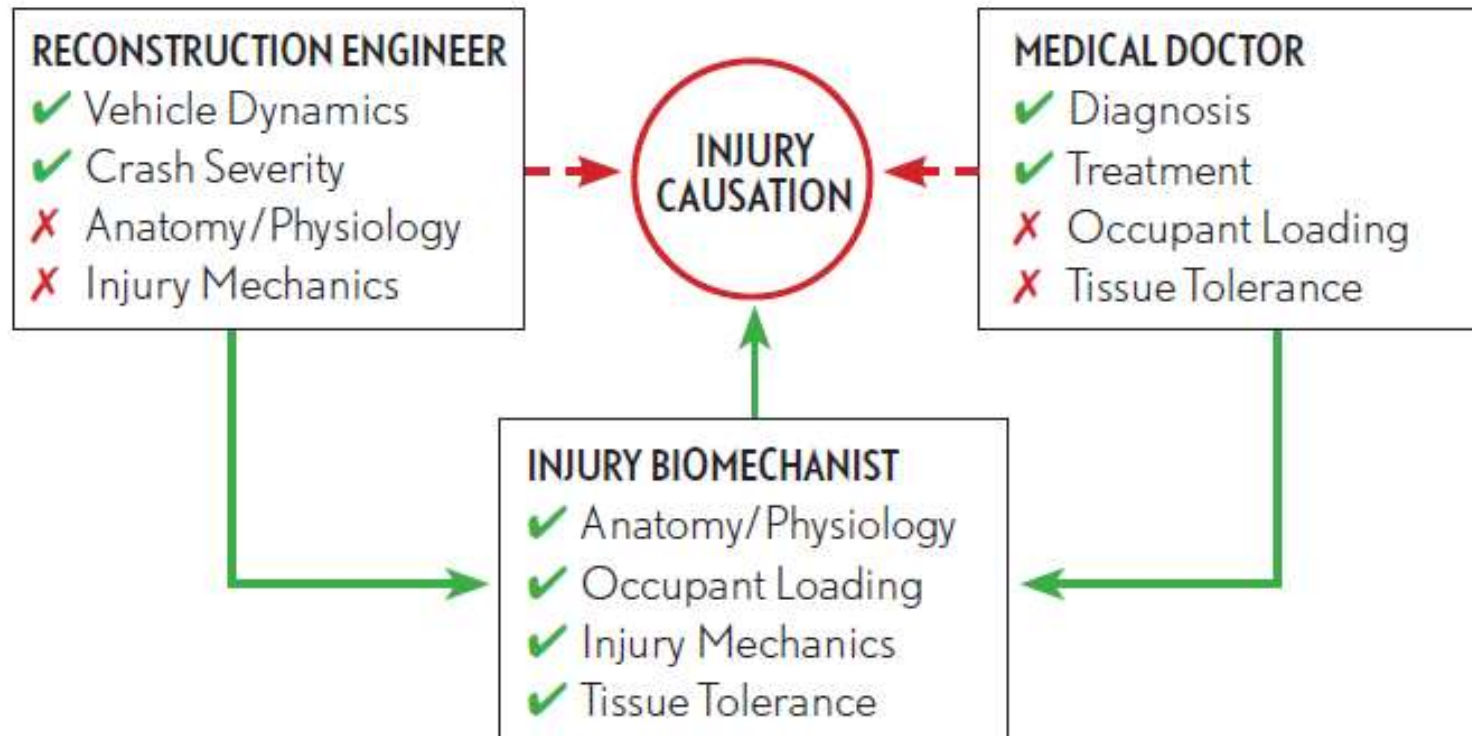
- Conservative treatment: pain medication, PT, lumbar epidural steroid injection (ESI), etc.
- Surgery: Anterior cervical discectomy and fusion (ACDF), knee/shoulder arthroscopy, etc.



"Why do I need a CAT scan? I just had a whole body scan at the airport."



Injury Biomechanist vs. Medical Doctor



(Siegmund, 2008)

Mechanisms of Injury

Mechanisms of Injury

+ Mechanism of Injury:

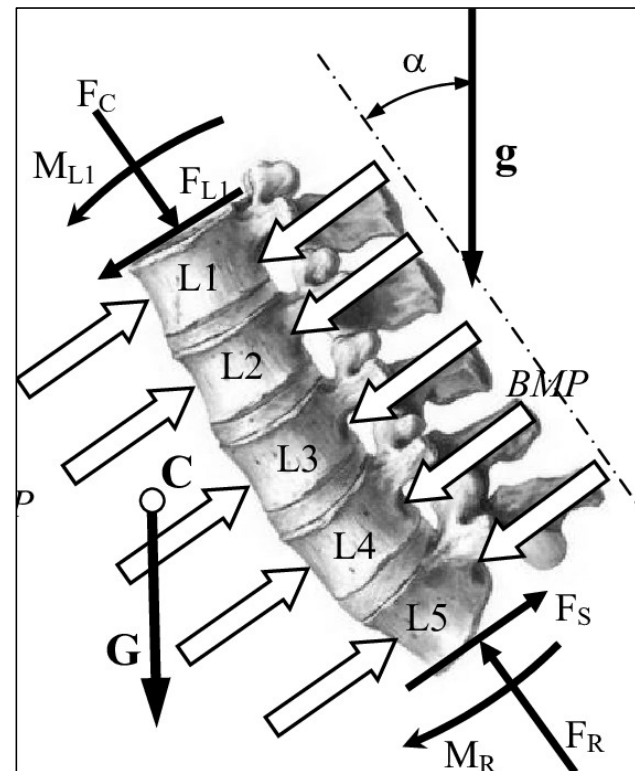
- Combination of loading (force/motion) **magnitude**, **direction** and **duration** that causes **acute** injury

+ Injury Criteria:

- Head Injury Criterion (HIC)
- Neck Injury Criterion (NIC), Neck Nij, Nkm
- Femoral axial force
- etc.

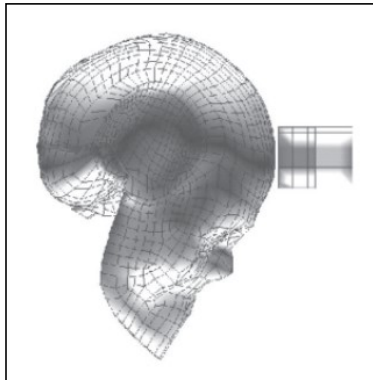
+ Injury Mechanisms:

- Head: TBI/Concussion
- Cervical Spine: Whiplash
- Shoulder: Rotator Cuff Tears
- Knee: Patella, ACL, Meniscus

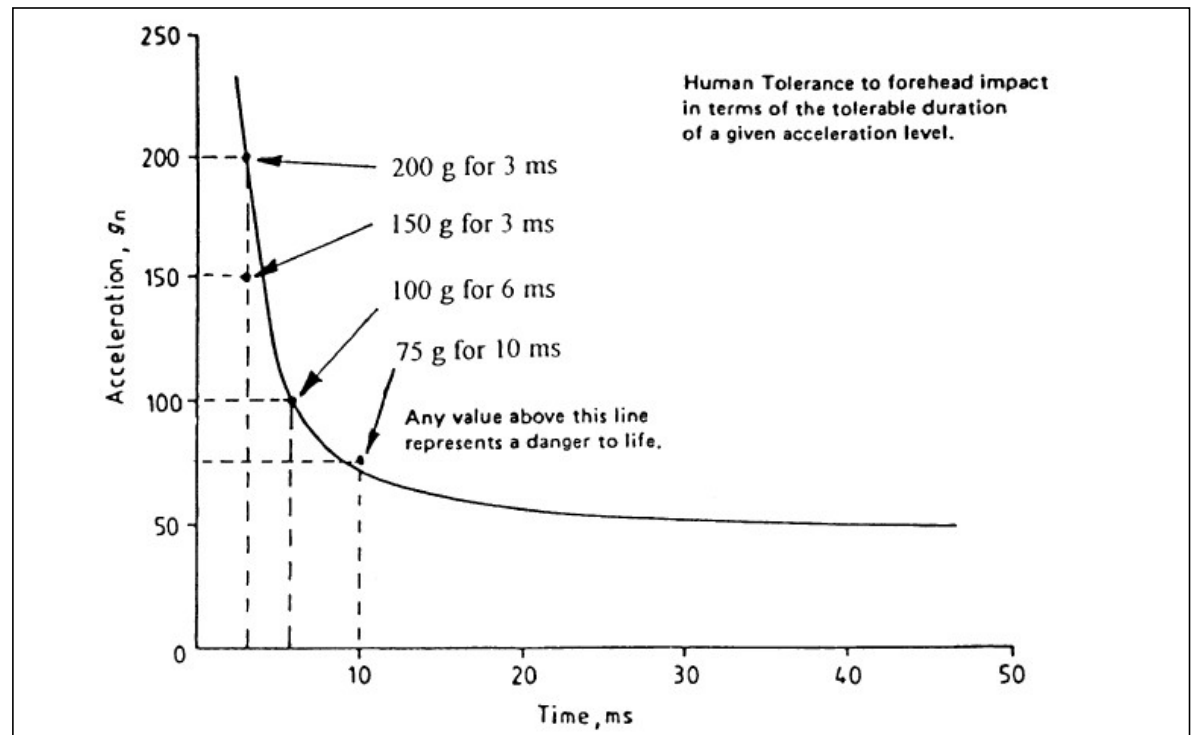


Mechanisms of Injury

+ Head Injuries: TBI, Concussion

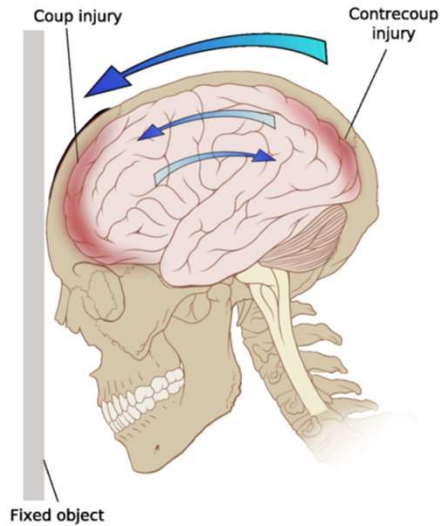


Wayne State Tolerance Curve

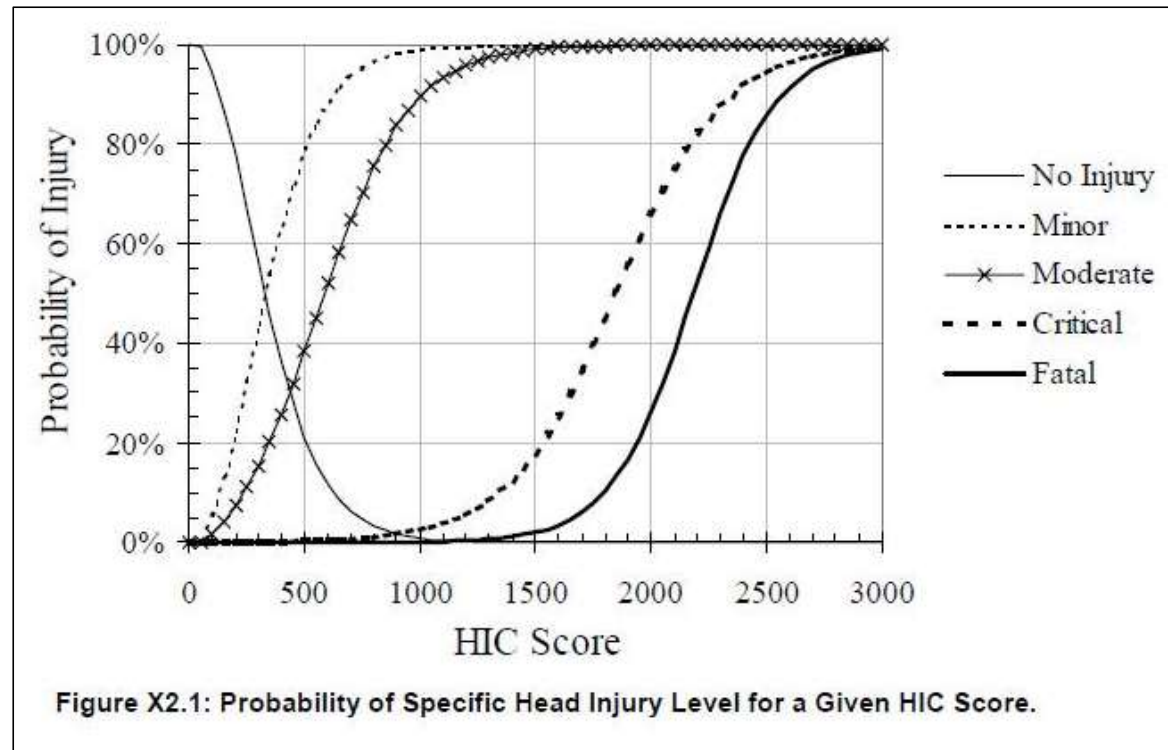


Mechanisms of Injury

+ Head Injuries: TBI, Concussion



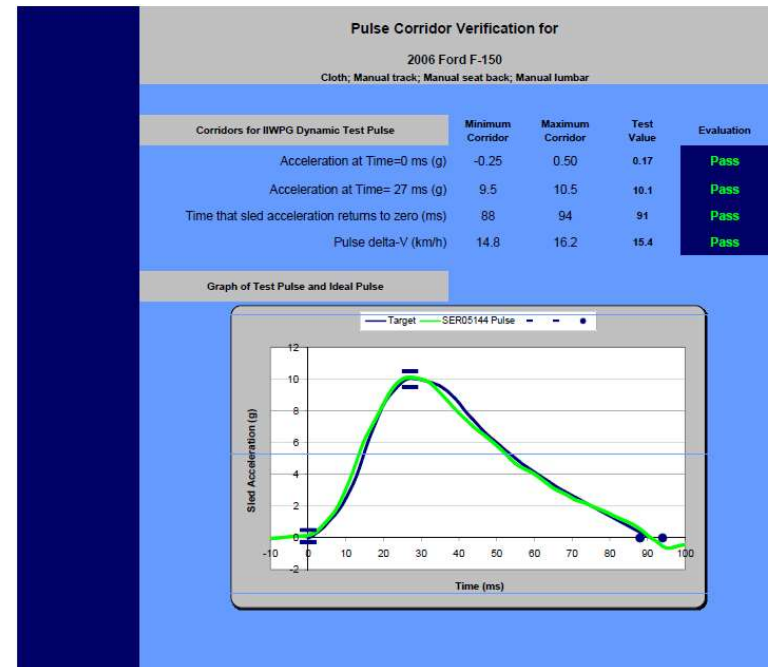
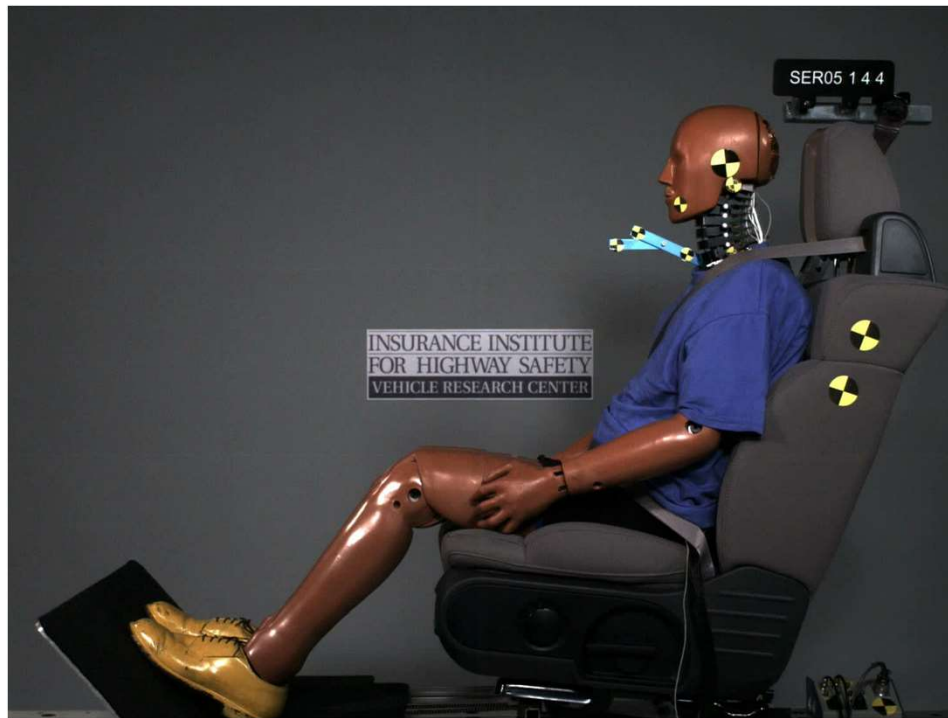
Head Injury Criterion (HIC)



Mechanisms of Injury

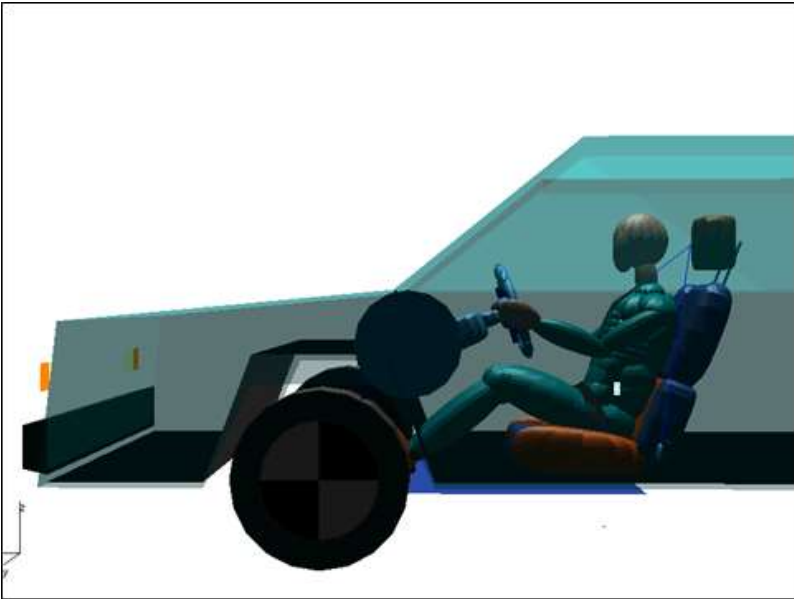
+ Cervical Spine Injuries: Whiplash

IIHS Rear Impact Testing



Mechanisms of Injury

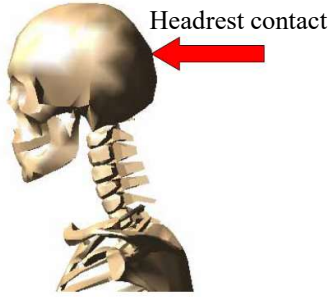
+ Cervical Spine Injuries: Whiplash



Protraction



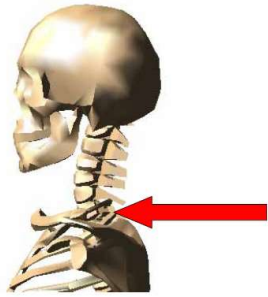
Rebound



Extension



Retraction



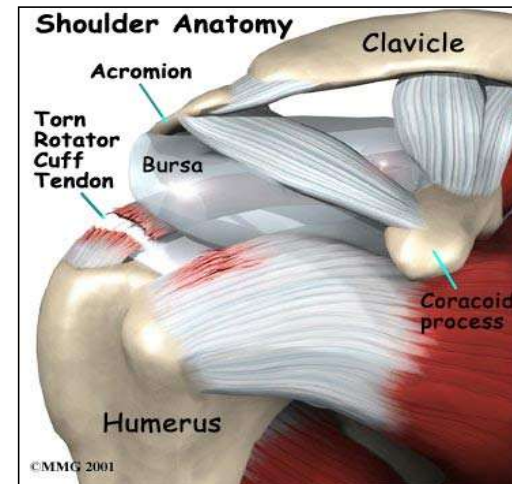
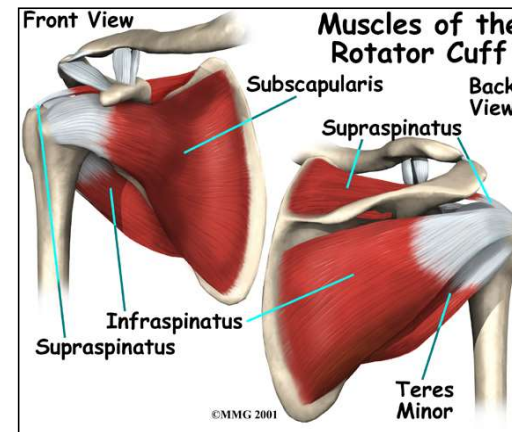
Mechanisms of Injury

+ Cervical Spine Injuries: Whiplash

Test ID		SER05144																															
HR Position - Height		Up Rearward																															
HR Position - Tilt		Up Rearward																															
BioRID Build Level		II g																															
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Test Date		10/3/2005 11:53																															
HPG Protocol File No.		3003																															
Seat Serial Number		05164																															
Test ID	Year/Make/Model	Head Max Accel (g)	Upper Neck Max Fx (N)	Upper Neck Min Fx (N)	Upper Neck Tension Max Fz (N)	Upper Neck Comp'n Min Fz (N)	Upper Neck Max My (Nm)	Upper Neck Min My (Nm)	Lower Neck Max Fx (N)	Lower Neck Min Fx (N)	Lower Neck Tension Max Fz (N)	Lower Neck Comp'n Min Fz (N)	Lower Neck Max My (Nm)	Lower Neck Min My (Nm)	Neck Max T1X (g)	Head Contact Begin (ms)	Head Contact End (ms)	Sled Acceleration Max (g)	Sled Acceleration Delta v (km/h)	Sled Acceleration Avg (g)	Sled Acceleration Max (g)	Sled Acceleration Delta v (km/h)	Sled Acceleration Avg (g)	Hpoint Position Horiz (mm)	Hpoint Position Vert (mm)	Pelvis Angle (Degrees)	Torso Angle (Degrees)	Pre Seatback Angle (Degrees)	Post Seatback Angle (Degrees)	BioRID Head Restraint Tested Backset (mm)	BioRID Head Restraint Tested Position Height (mm)	HRMD Head Restraint Tested Backset (mm)	HRMD Head Restraint Tested Position Height (mm)
SER05144	2006 Ford F-150	21.42	202.56	-17.56	828.37	-140.38	27.24	-4.66	552.55	-19.01	445.48	-92.11	1.27	-19.98	10.07	88.70	173.10	10.12	15.44	4.81	10.12	15.44	4.81	293.96	-458.46	27.30	65.30	5.00	12.00	58.02	33.00	46.41	35.52
	Time (ms)	124.2	120	73.5	109.9	60.1	124.6	160.9	111.2	56.4	110.6	127.5	59.4	126.6	118.4			27			27												

Mechanisms of Injury

- + Shoulder Injuries:
 - Superior Labrum Anterior and Posterior (SLAP) Tear
 - Rotator Cuff Tear
- + Rotator Cuff Tears:
 - Separation of their attachment
 - Most commonly involved tendon: Supraspinatus tendon
- Causes:
 - o MVC
 - o Repetitive loading (Overuse)
 - o Excessive force in external rotation (FOOSH)



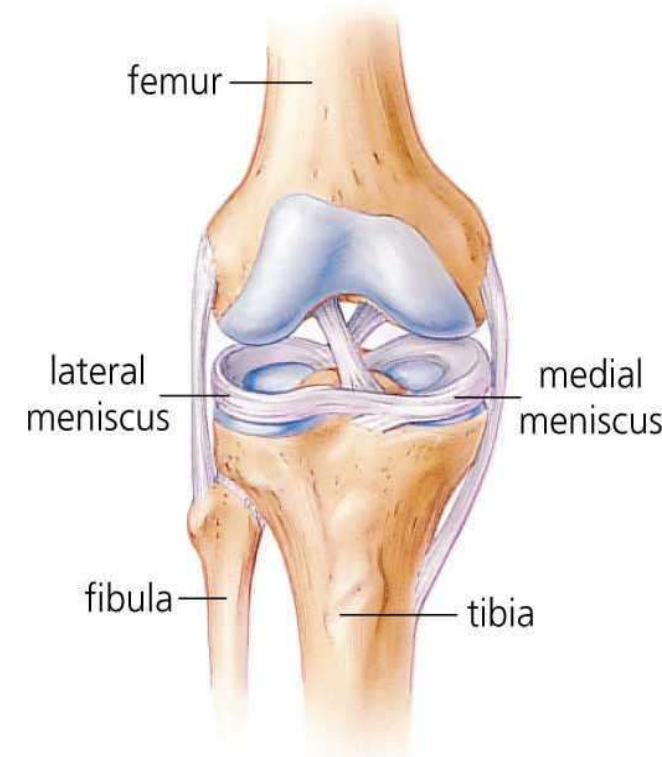
Mechanisms of Injury

- + Shoulder Injuries in Rear End Collisions:
 - Forward rebound motion
 - Acromioclavicular (AC) and Coracoclavicular (CC) ligaments
- + Delta-Vs of 3.9, 6.5, 8.9 and 12.2 mph:
 - Relative motion between the clavicle and shoulder due to belt loading
 - Compression of the humerus into the Glenoid Fossa due to locked arms on the steering wheel.
 - AC and CC Ligament forces for Scenarios 1 and 2:
 - Range: 38 – 90 N and 71 – 462 N.
- + Forces less than reported force at failure



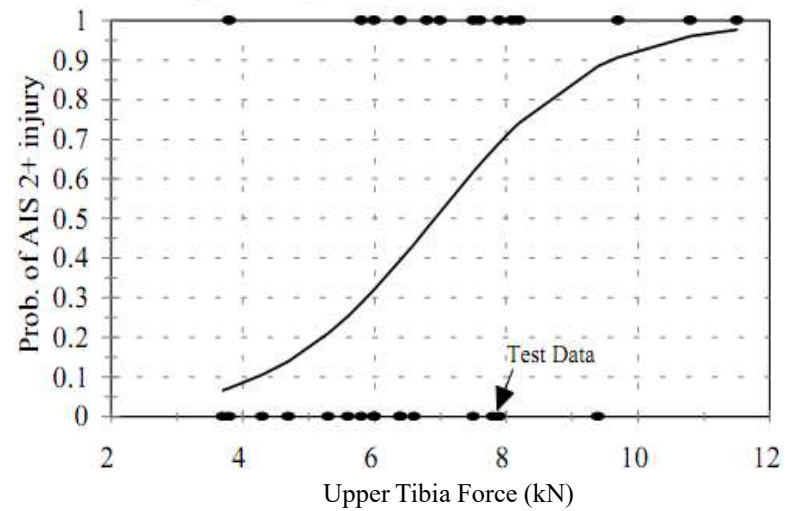
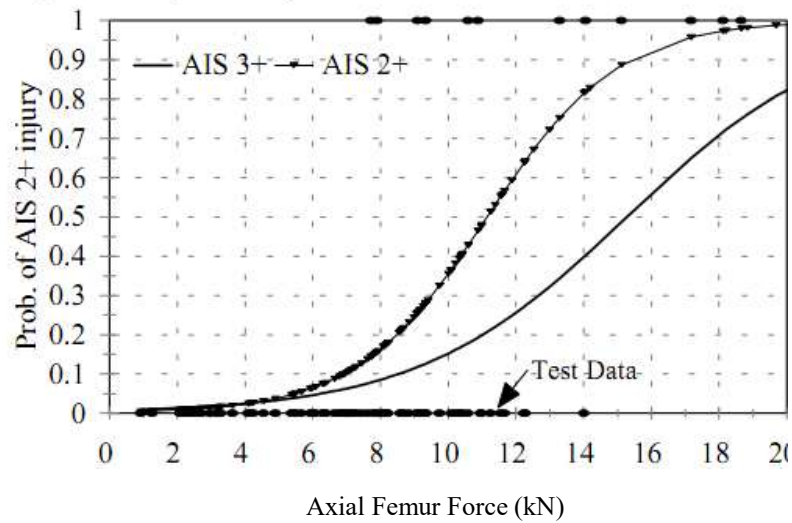
Mechanisms of Injury

- + Knee Injuries: Patella, ACL, Meniscus
 - Secondary impact with dashboard (rear-end collisions)
- + Position of the seat with relative to the dashboard
- + Distance from the knee to dashboard
 - Knee Displacement
 - Knee Velocity
 - Impact Force



Mechanisms of Injury

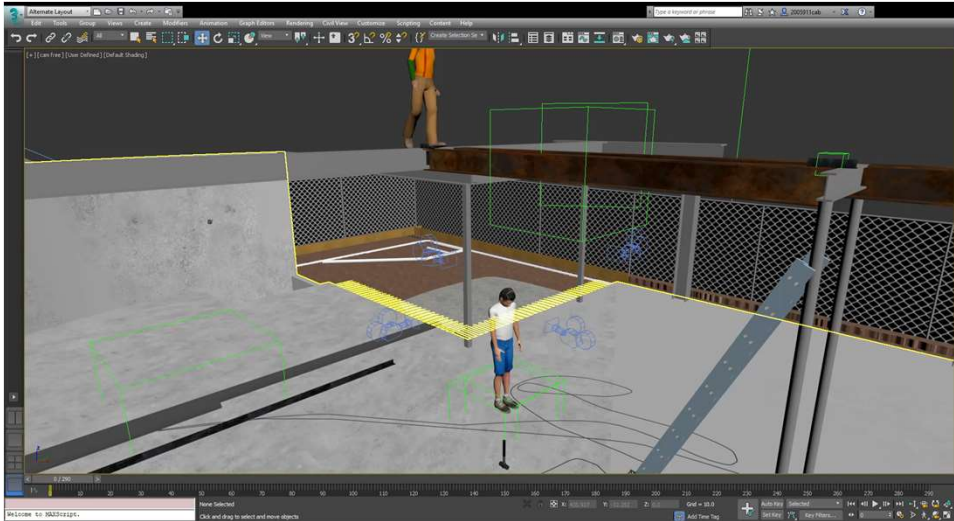
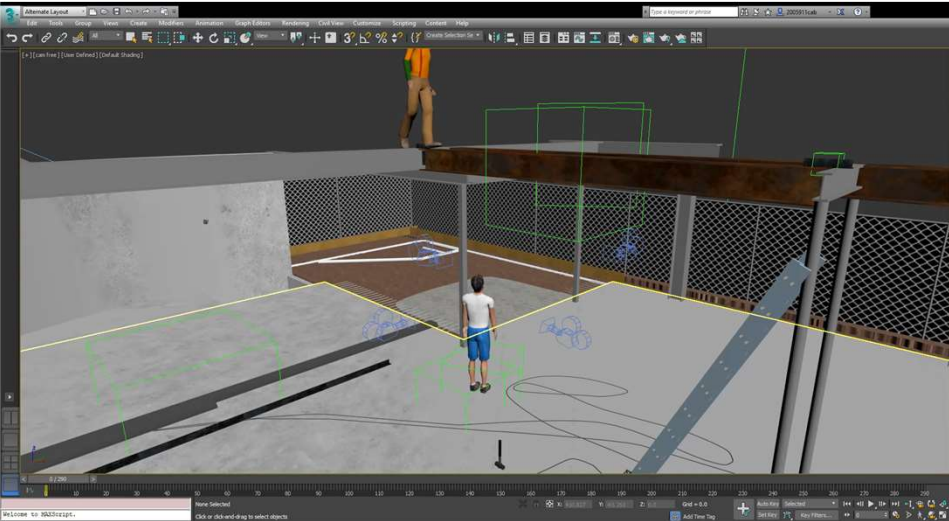
+ Knee Injuries:



Case Studies

Case Studies

Case Study 1: Beam Accident in Construction Site



Case Studies

Case Study 2: Bench Failure



Case Studies

Case Study 3: Side Impact



Case Studies

Case Study 4: Low-Speed Rear-End Collision

- + Cervical Sprain/Strain
 - + Lumbar disc herniation
 - + Shoulder rotator cuff tear
 - + Knee ACL tear
-
- + Delta-V = 2-3 mph (vs. bumper car impacts: 6.5 mph)
 - + Vehicle Accelerations = 0.7-1.2 g
 - + PDOF = 6 o'clock
-
- + Head Accelerations: 1-2 g
 - + Lumbar loads < normal lifting of objects
 - + Shoulder: very low rebound velocity/force
 - + Knee: rebound velocity << walking speed

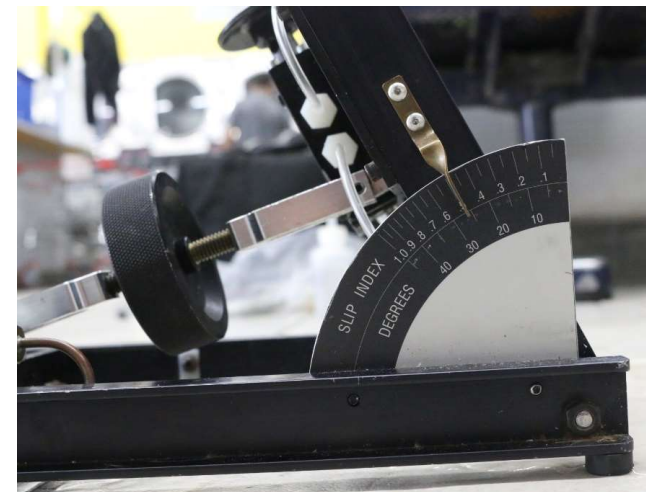


Case Studies

Case Study 5: Slip and Fall Incident in Laundry

- + Fell backwards and left
- + Did not see the water beforehand

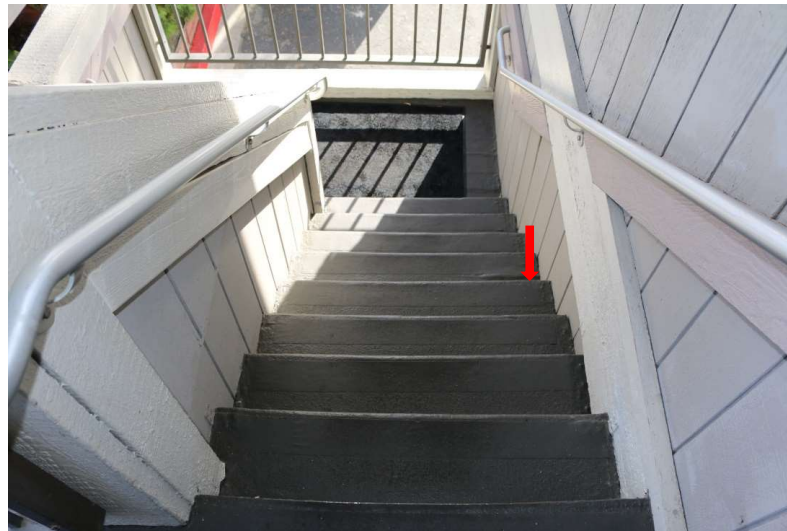
- + Medical Records (MRI)
 - Slap tear in the left shoulder
 - Tri-compartmental arthritis in both knees
 - Torn meniscus in both knees
 - Degenerative joint disease in cervical and lumbar spine



Case Studies

Case Study 6: Trip and Fall on Stairway

- + Raised portion on stairway
 - + Walking down the stairs
 - + Foot stuck on the raised portion
 - + Ankle Ligament Tear
-
- + Stairway Dimensions: width, rise, run, handrails, etc → meets UBC
 - + Lighting
 - + Slip Resistance
-
- + Foot clearance/placement during stair descent
 - + Anterior talo-fibular ligament (ATFL) tear



Case Studies

Case Study 7: Revolving door incident



Case Studies

Case Study 8: Falling off water tower

- + Body was 32 feet away from the bottom of water tower
- + Question: Fall or Jump?

- + Testing using ATDs
- + Rest location not compatible with slipping off the top of water tower
- + Initial horizontal take-off speed: 13-15 ft/sec
 - Fast walking/jogging towards the edge of water tower



Case Studies

Case Study 9: Public Transport Bus Incident

- + Passenger on walker
- + Bus steps (not ramp) were provided for transport
- + Comminuted, displaced femur fractures (bilateral)

- + 2.1 times the kinetic energy of a fall on level ground
 - Fall from the **second** step of the bus



Conclusions

Best Practice

- + Biomechanics is the application of mechanical engineering principles to the human body
- + Injury Biomechanists and Medical Doctors provide two distinct and complementary perspectives on injury:
 - Injuries Biomechanist: **Forces, motions and injury tolerance**, injury mechanisms, **exposure vs. tolerance**, traumatic vs. degenerative conditions, comparison to ADL loads
 - Medical Doctor: **Diagnosis** (medical examination, radiological assessment, etc.) and **treatment** (surgery, non-surgery, conservative treatments, etc.)
- + Injury Mechanisms: Loading **magnitude, direction (PDOF)**, and **duration** to cause traumatic injury
- + Cases: **Similar concepts** apply to automotive collisions, industrial accidents, workplace injuries, premises liability, slip/trip and falls, sport/recreation accidents, etc.

Services

VEHICULAR

- ATV accidents
- Bicycle accidents
- Bus accidents
- Low speed MVA
- Motorcycles
- Occupant dynamics
- Off-road vehicles
- Paratransit vehicles
- Pedestrian accidents
- Protective helmets & equipment
- Railroad accidents
- Restraint systems
- Trucking equipment
- Vehicle access systems

OCCUPATIONAL AND PREMISES

- Automatic doors
- Bathtub accidents
- Bus & train doors
- Construction accidents
- Elevator doors
- Ergonomics
- Fall protection
- Flexible doors
- Guardrails
- Hard hats
- Industrial accidents
- Industrial equipment
- Lifting injuries
- Machine guarding
- Protective equipment
- Railroad equipment accidents
- Retail displays
- Slip, trip & fall accidents
- Stair & handrail
- Walking surfaces
- Wood & metal working tools

SPORTS AND RECREATION

- Amusement rides
- Athletic footwear
- Bicycle accidents
- Exercise equipment
- Gymnasium equipment
- Playground accidents
- Playground equipment
- Protective equipment
- Roller skating
- Scooters
- Sports fields & flooring surface
- Sports related injuries
- Swimming pools
- Trampolines

MEDICAL DEVICES

- Biomedical devices
- Cryotherapy devices
- Hospital gurneys
- Laparoscopic tools
- Orthopedic appliances (braces)
- Orthopedic prostheses
- Surgical tools

CRIMINAL

- Biomechanical reconstruction
- Mechanism of injury
- Vehicle occupant position

Witness Questions List

Accident: Who/what/when/where?

1. Precise location of accident?
2. Which direction were you going?
3. What time was the accident?
 - a. What were the lighting and weather conditions?
4. Where were you driving from?
5. Where were you driving to?
6. How many lanes were there?
7. When did you first see the other vehicle (answer can be in time/distance/car lengths)
8. Anything blocking your view in this incident?
9. What was the posted speed limit?
10. What was your speed
 - a. Generally as proceeding along the roadway?
 - b. Just prior to the accident?
 - c. At impact? (This will be different from "just prior to the accident if they took their foot off the accelerator and/or applied the brakes.)
 - d. How do you know?
11. Did you steer and/or brake before the collision?
 - i. How much? Gradual, moderate, hard (skidded or felt pedal pulsing from ABS)
12. Where were your hands on the steering wheel? (Position i.e. "10 and 2 o'clock position")
13. Were you on a cell phone?
14. Did you observe the other driver to be on a cell phone?
15. How long had you been driving?
16. Passengers?
 - a. Names
 - b. Location in the vehicle
 - c. Ages, heights and weight (approximate)
17. Did the other party/ies have passengers?
18. What were the rest positions of all vehicles after the accident?
 - a. Ask for positions relative to fixed reference points such as:
 - i. Crosswalks
 - ii. Limit lines
 - iii. Curbs
 - iv. Light posts, traffic signals
 - v. Buildings (gas station, house, etc.)
19. What color was the other vehicle?
20. Describe the damage to both vehicles involved
 - a. Did you see any paint or rubber transfer from the other vehicle on your car?
 - b. Did you vehicle hit any fixed object (curb, pole, guardrail)?
 21. Was there any physical evidence (i.e. – tire marks, debris, fluid)?

Witness Questions List

Witnesses/observers

22. Were there any witness statements or potential witnesses that can be contacted?
23. Were any photos taken at the scene that you are aware of? (cell phone photos or video?)
24. As far as you know, would there be any surveillance cameras in the area where the accident occurred?

Vehicle

25. Do you own the vehicle or who is the registered owner?
26. Year make and model of your vehicle. When acquired?
27. Color.
28. License plate number
29. VIN number
30. Was there any damage to the vehicle prior to this event? (Type and location)
31. Has the vehicle been repaired since the accident?
 - a. Do you have a repair estimate or invoice?
 - b. Do you have photos of the damaged vehicle? (cell phone photos?)
32. What type of headrest?
33. How was headrest positioned relative to your head?
 - a. Was the top of the headrest at the back or base of their head?
34. Was there any damage to the seat or seat back? (Seat back collapse or twist?)

Witness Questions List

Injury

35. Were you the driver or passenger?
36. Type of Collision? (Rear, frontal, side)
37. Were you wearing a seatbelt?
38. Did your airbag deploy?
39. What were the areas of impact?
 - a. What direction did your body move
 - b. Which part of the body contacted what?
 - c. What are the injuries claimed as a result of the accident?
40. Photographs of any bruises, lacerations, any physical evidence of injury
41. Prior to the accident, were you aware of the collision. If yes, how did you respond?
 - a. Arm position at the time of the impact? (Was it on or off the wheel)
 - b. Foot position at the time of the impact?
42. Do you have any medical records
 - a. Prior degeneration, previous injuries, prior surgeries, or any other medical disorders
43. When did you first experience any pain?
 - a. What part(s) of your body?
 - b. Intensity (1 to 10 scale)?
 - c. How long did pain last?
 - d. What treatment (Advil/Tylenol, hot /cold pack) did you employ?
 - e. Any change(s) in pain intensity? If so, how much and when?

Injuries?



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Biomechanics Podcast: <https://lnkd.in/eQ7Gsss>

Questions?

