AAL Task Order 2 GOAL: To facilitate a safe environment for the new small and pregnant female aircrew population

MOTIVATION: Until recent years, aircrew in the military have been predominantly 50th and 95th percentile males. The design of the aircraft occupant compartment, seats, and catapult thrust, helmets, HMDs, NVGs, etc. has focused on the safety of that population.

My ROLE: To address the prevention and mitigation of female aircrew injury.

MY FOCUS:

1. To identify spinal injury patterns and mechanisms due to the ejection loading
2. To explore physical and virtual testing as tools to evaluate the effects of seats and catapult thrust, helmets, HMDs, NVGs, etc. on spinal injury potential
3. To evaluate and update the criteria used to assess spinal injury potential in the ejection environment

Ejection Catapult Thrust Phase

Occupants experience > 9 G's multi-axial loading

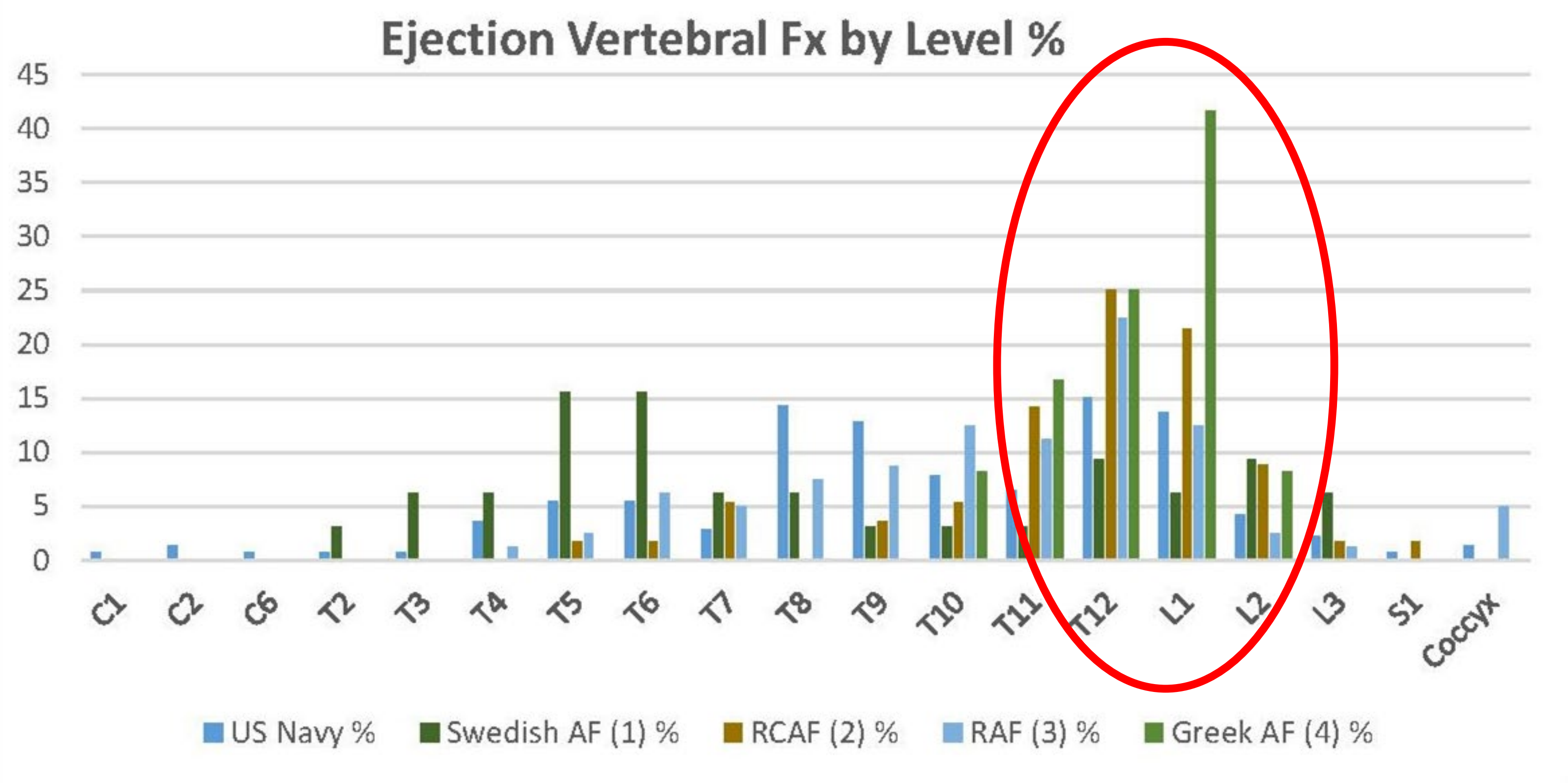
Injury Patterns: Lower neck and thoracolumbar

- Compression, burst, and wedge fractures
- Bilateral facet dislocation
- Lateral bending and compression-extension injury

We rarely see upper neck injury

Nonfatal Vertebral Ejection Fracture Levels 1958-1969

Ewing, 1971



Ejection Vertebral Fracture Levels 1977-2021

Sommer et al., 2022

TABLE 2. Spine injuries of the included aircrew members

Spine Injury	No. (%)
Fracture	66
C2	3 (4.5%)
C3	1 (1.5%)
C4	1 (1.5%)
C6	2 (3.0%)
T3	2 (3.0%)
T4	1 (1.5%)
T5	2 (3.0%)
T6	2 (3.0%)
T7	2 (3.0%)
T8	7 (10.6%)
T9	2 (3.0%)
T10	5 (7.6%)
T11	9 (13.6%)
T12	12 (18.2%)
L1	12 (18.2%)
L2	1 (1.5%)
L3	2 (3.0%)
Soft-tissue injury	31
Contusion	27 (87%)
Disc protrusion	2 (6.5%)
Disc herniation	
T11–12	1 (3.25%)
L5–S1	1 (3.25%)

66 Vertebral Fxs

Neck: 11% (7)

T-Spine 67% (44)

L-Spine 23% (15)

Total aircrew = 103

1.9 fxd vertebra per crew member

Methodology

The application of loading to the spine produces predictable spinal injury patterns.

Given the injury pattern(s), the applied loading parameters can be determined.

Applied Loading ⟷ Injury Pattern

Mechanical Determinants

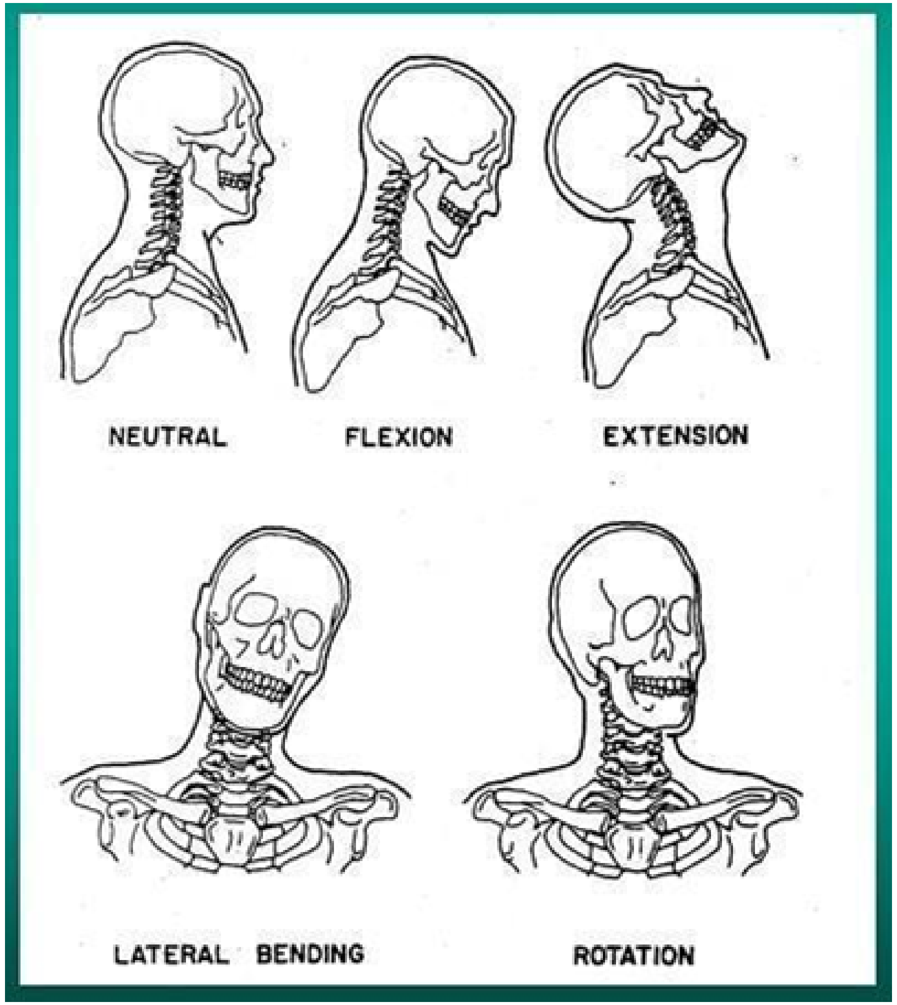
Engineers define mechanical determinants that describe the applied loading

- **anthropometry,**
- **initial body position**
- **acceleration profile (ejection)**
- **spinal curvature (e.g., pre-flexed, neutral, pre-extended) to represent the braced v. not braced occupant**
- **applied loading direction (e.g., Gx, Gy, Gz, multiaxial), location, angle, eccentricity**
- **local spinal loading (e.g., compression, tension, bending, shear, torsion), speed/frequency, magnitude**
- **musculature inactive or active**
- **seat geometry and stiffness;**
- **restraints geometry, position, mechanical properties, and initial tension**

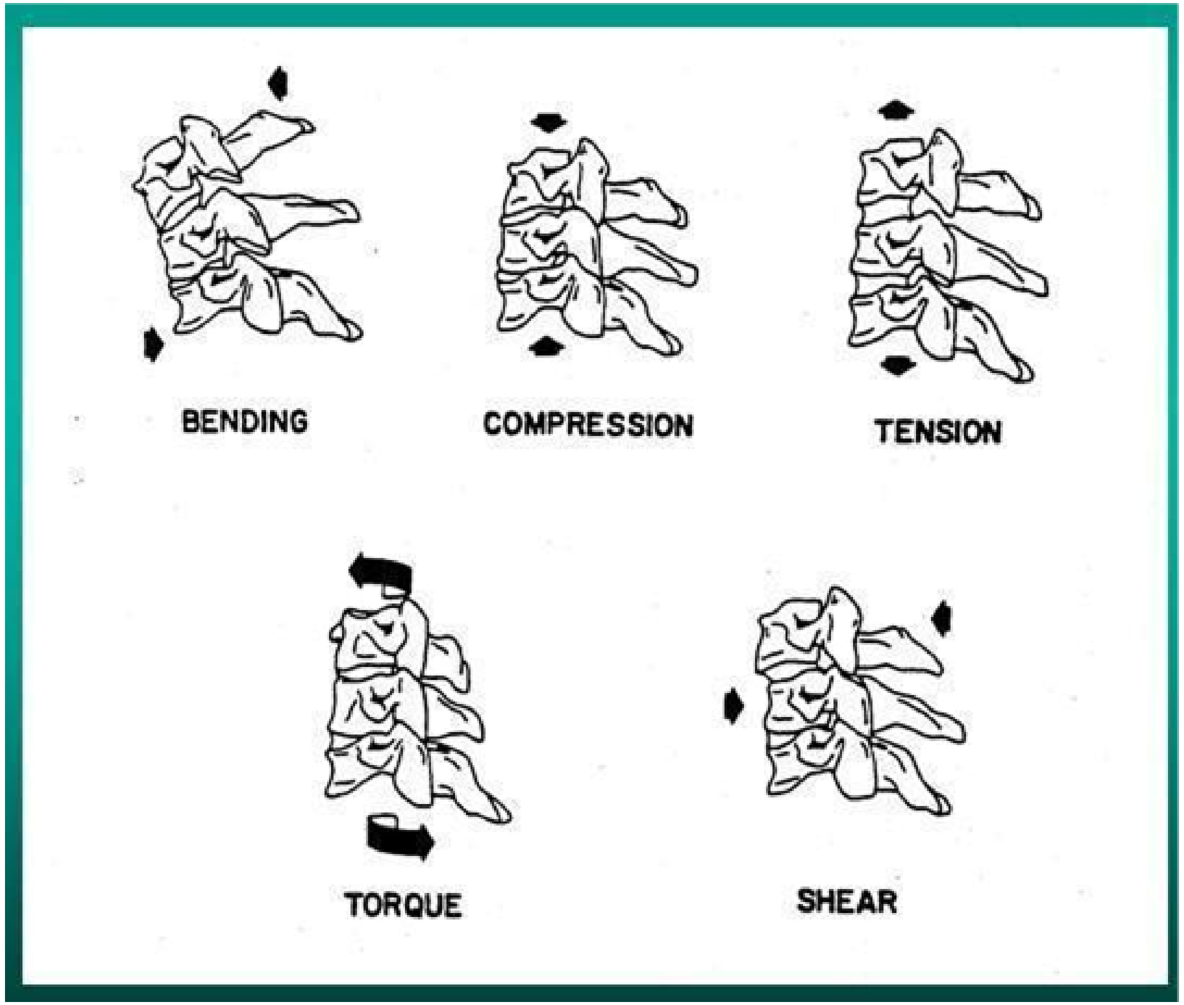
HUMAN SPINE TESTING at Duke, MCW and WPAFB (Kazarian)

- Controlled non-injurious forces were applied to provide better data for mathematical models.
- Controlled, injury-producing forces were applied to relate the applied force, displacement, torque and angle responses to the resulting injury patterns.

Head-Neck Motion



Localized Spinal Loading



Injury Patterns and Mechanisms

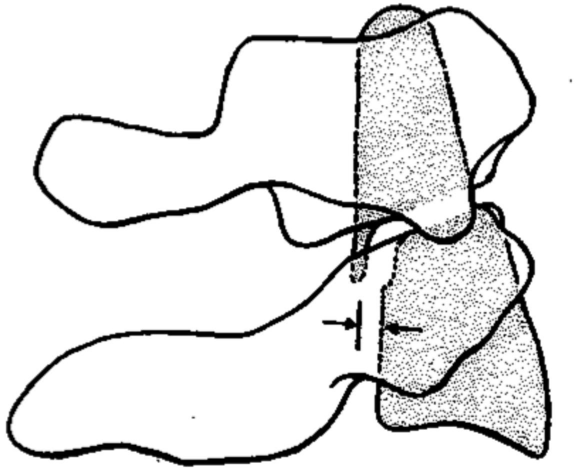
Biomechanical engineers study failure

- **Torsion** applied to a piece of chalk results in a spiral fracture pattern. Similar findings result when torsion is applied to a long bone.
- **Bending** of sufficient torque applied to a piece of chalk results in a transverse/butterfly fracture pattern. Similar findings result when bending of sufficient torque is applied to a long bone.

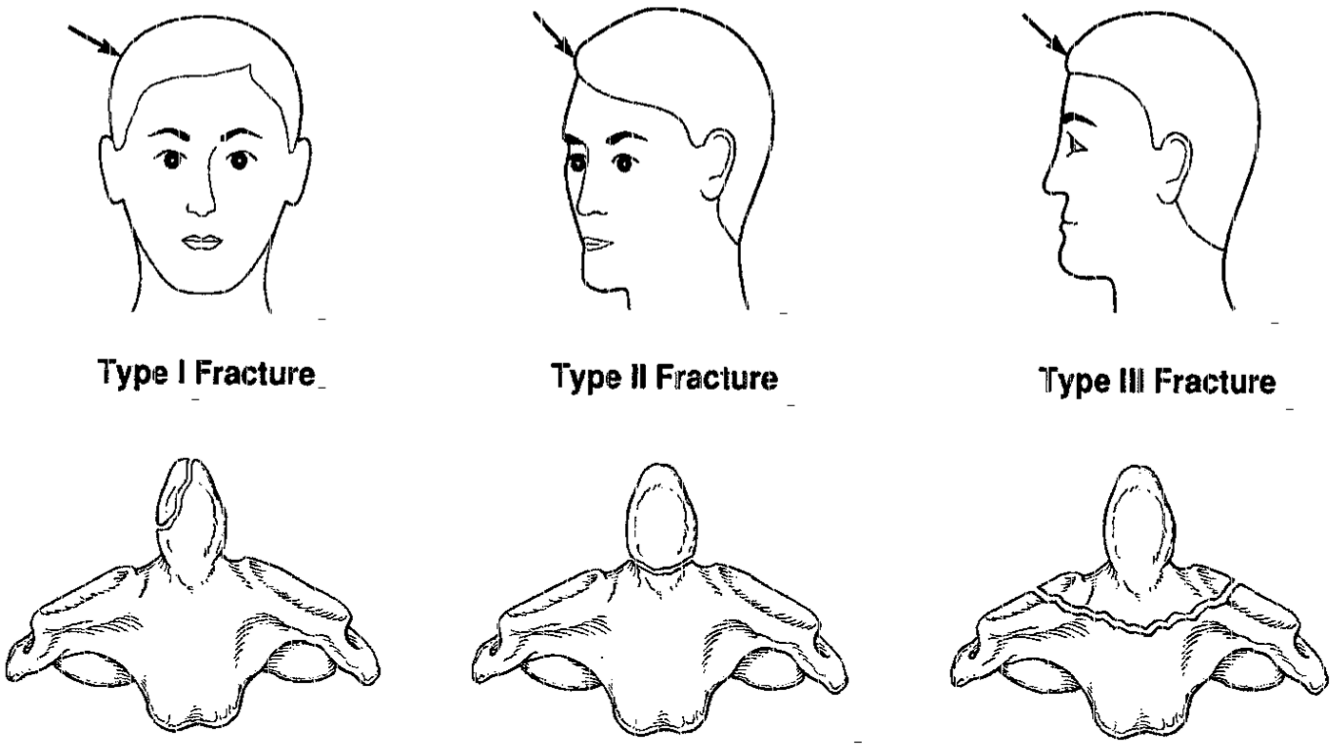
Spinal injury research reveals how applied forces relate to the resulting spinal injury patterns

- If you fall from a height onto your buttocks, the spine is **compressed**, and the bony vertebral body fractures before the disc is damaged.
- If a person bends their spine rearward in **extension** beyond a person's ROM, disc damage occurs with damage to the anterior longitudinal ligament that holds the front of the spine together, and spinous process fracture can occur.
- In **compression and forward bending** beyond a person's ROM, anterior vertebral body compression fracture and disc damage occurs with damage to the posterior ligaments.
- In **twisting**, the upper cervical spine fails before the lower cervical spine, and disc damage occurs with compromise of the facet joints.

C2 Dens Fracture with Displacement



Horizontal Shear and Vertical Compression Loading on Head and Critical Velocities to Produce Different Types of Odontoid Fractures



Type I Fracture	Type II Fracture	Type III Fracture
Approx. Impact Velocity* = 8.6 ft/sec	Approx. Impact Velocity* = 7.7 ft/sec	Approx. Impact Velocity* = 6.6 ft/sec

*Based on average test energy and 185 lb. person.

Reference: Althoff, B., Fracture of the Odontoid Process. *ACTA Orthopaedica Scandinavica Suppl.* 177, 1979.

02009.b

Human v. Hybrid III Cervical Spines in Bending

The Hybrid III ATD neck is far stiffer than the human neck

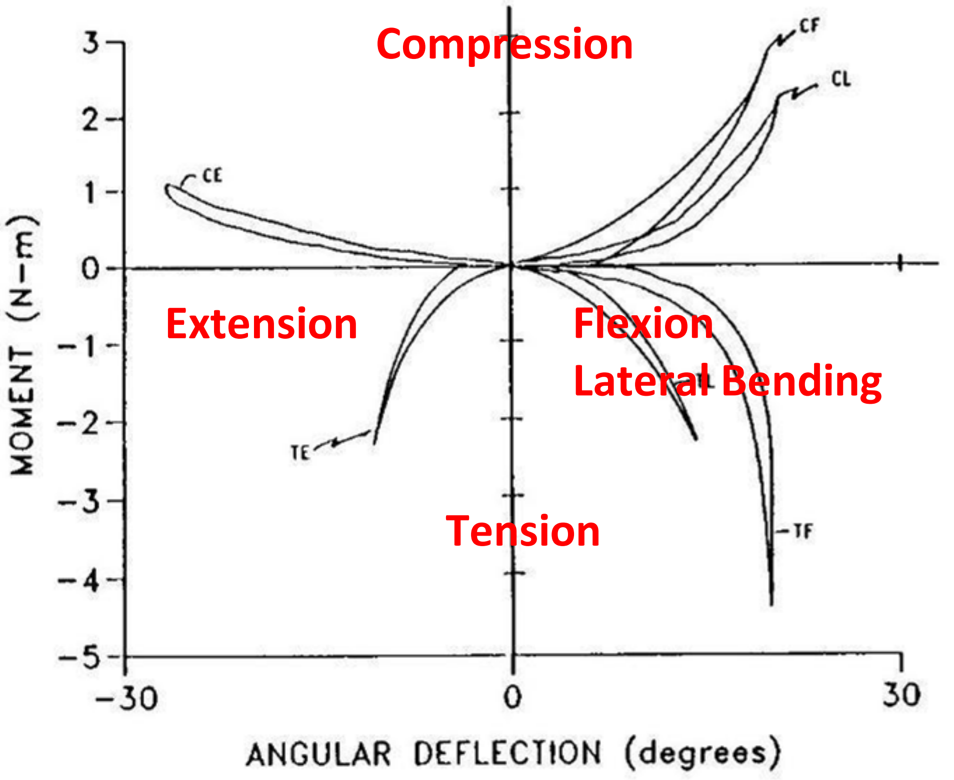


Figure 8: Typical Bending Responses of Human Cervical Spine

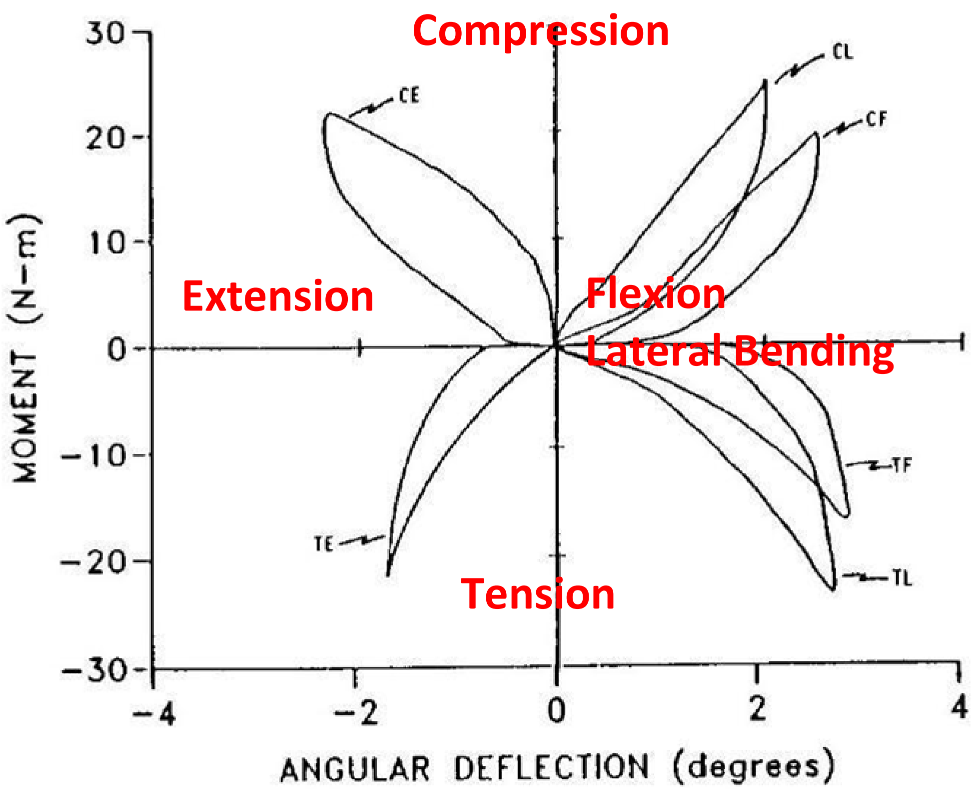
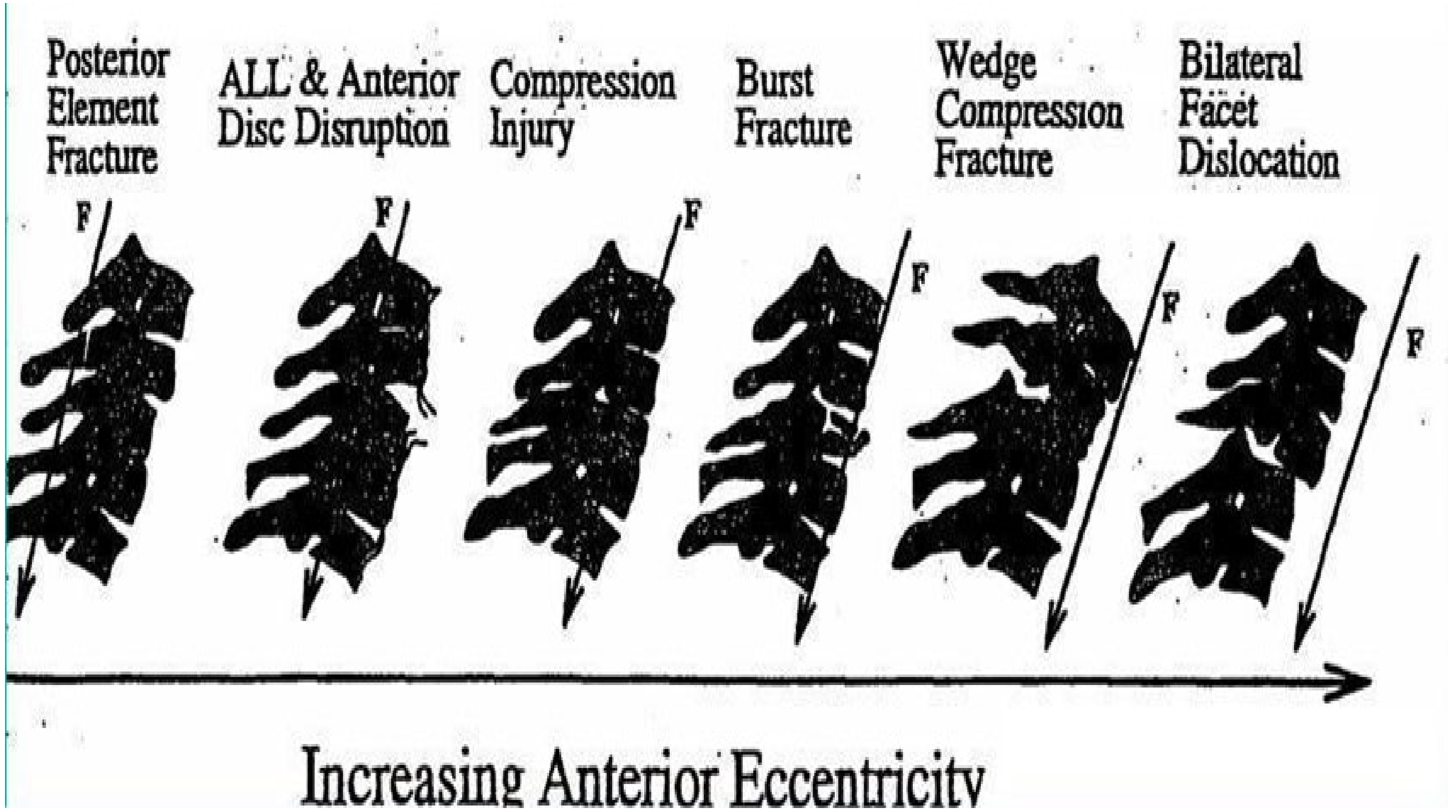


Figure 9: Typical Bending Responses of Hybrid III Neckform

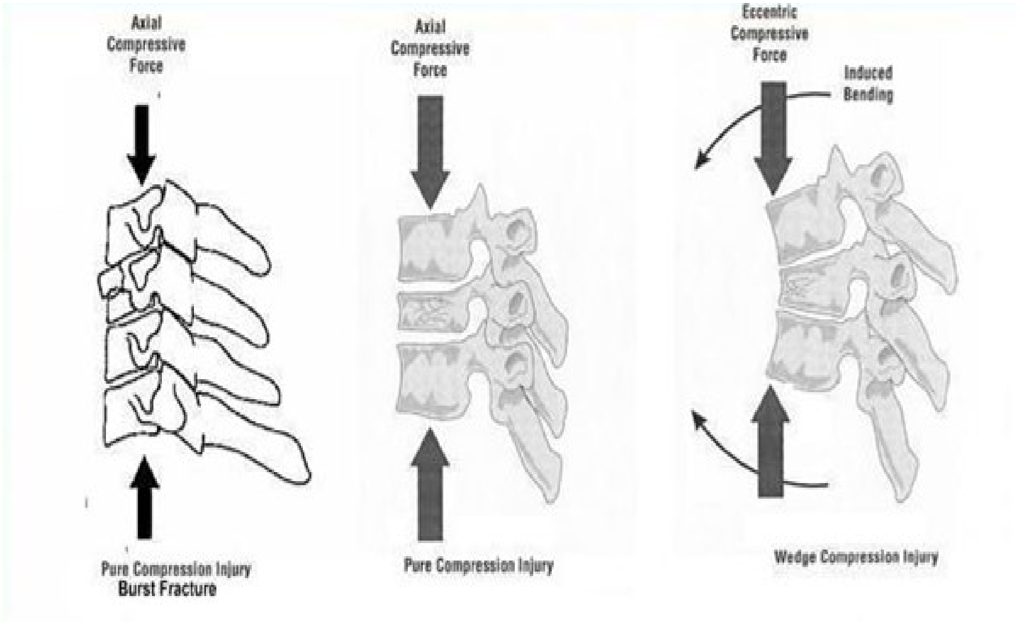
Effect of Eccentricity on Injury Patterns

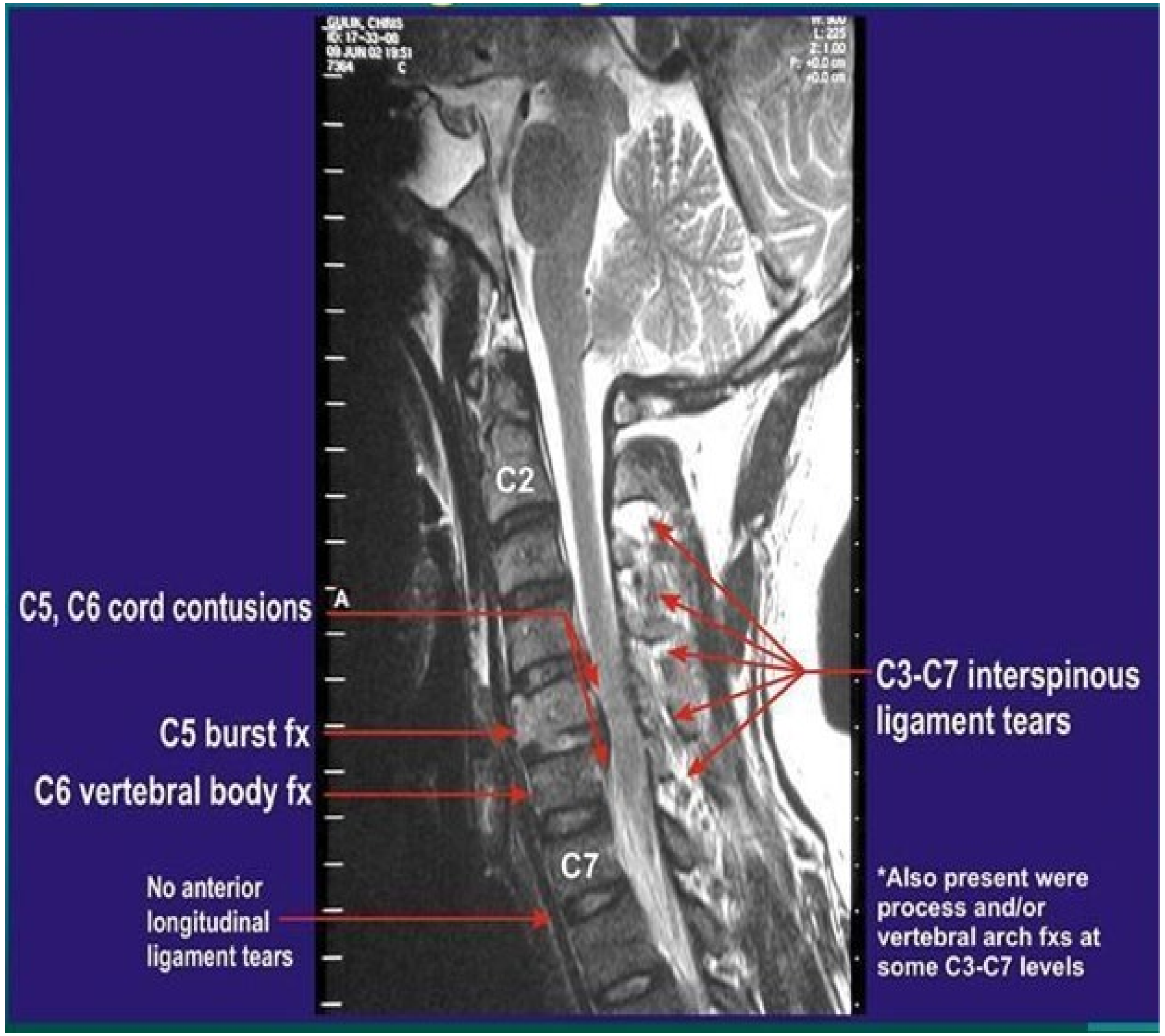
Eccentricity is the Perpendicular distance from the sagittal plane resultant force to the spine



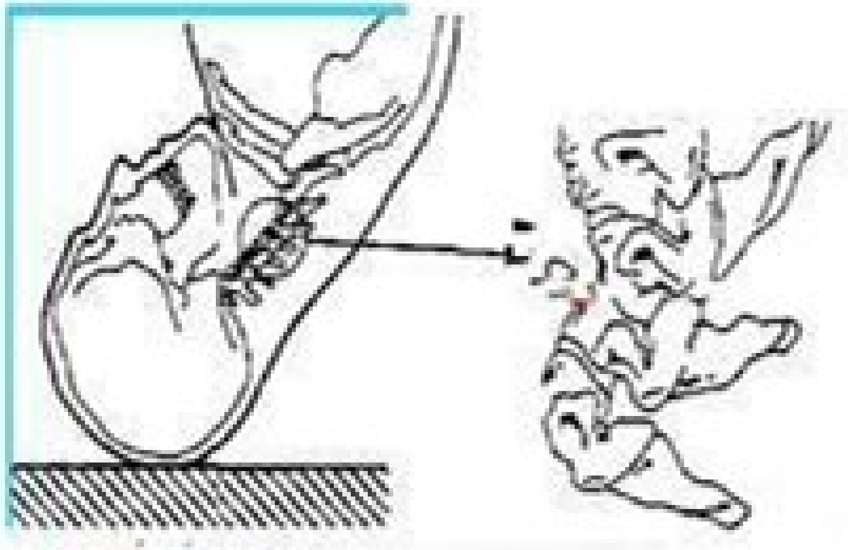
Increasing the eccentricity of the applied force from posterior to anterior changes the injury mechanism from Posterior Element Failure to Bilateral Facet Dislocation, when located most anteriorly.

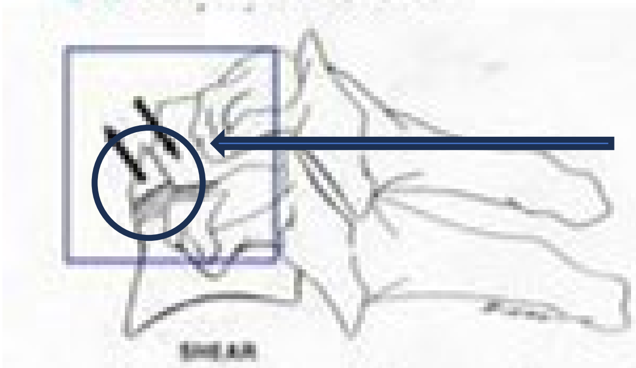
Compression v. Compression-Flexion



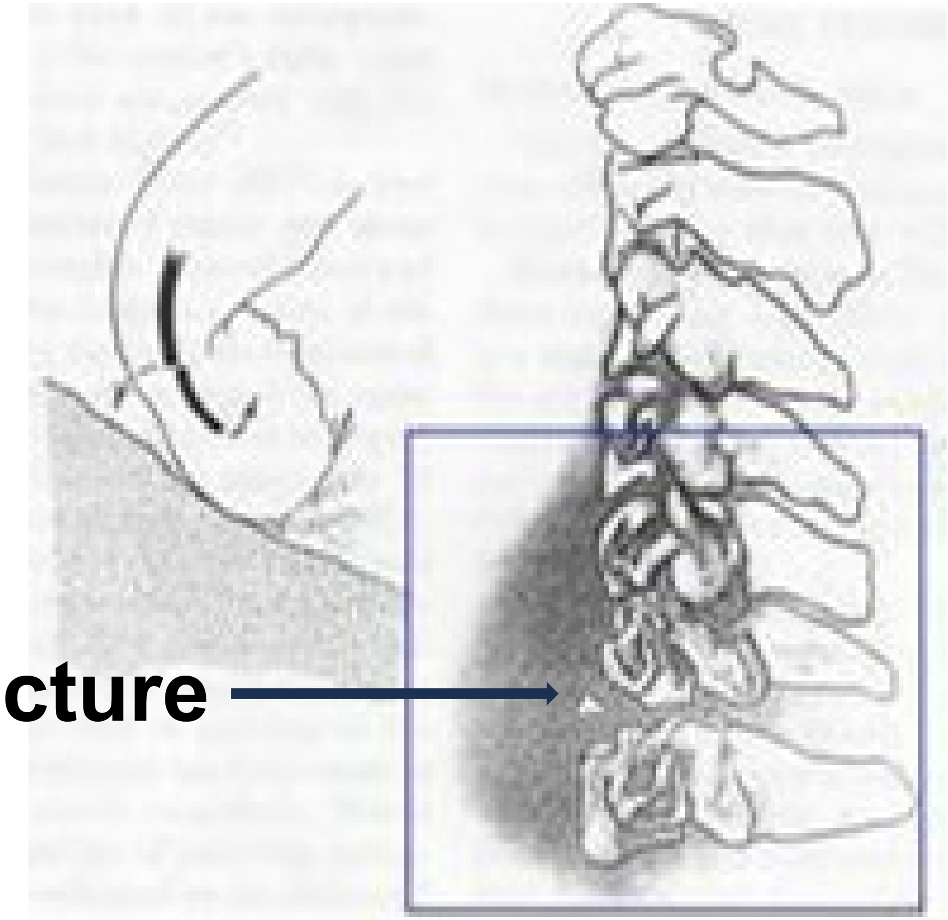


Flexion Fracture

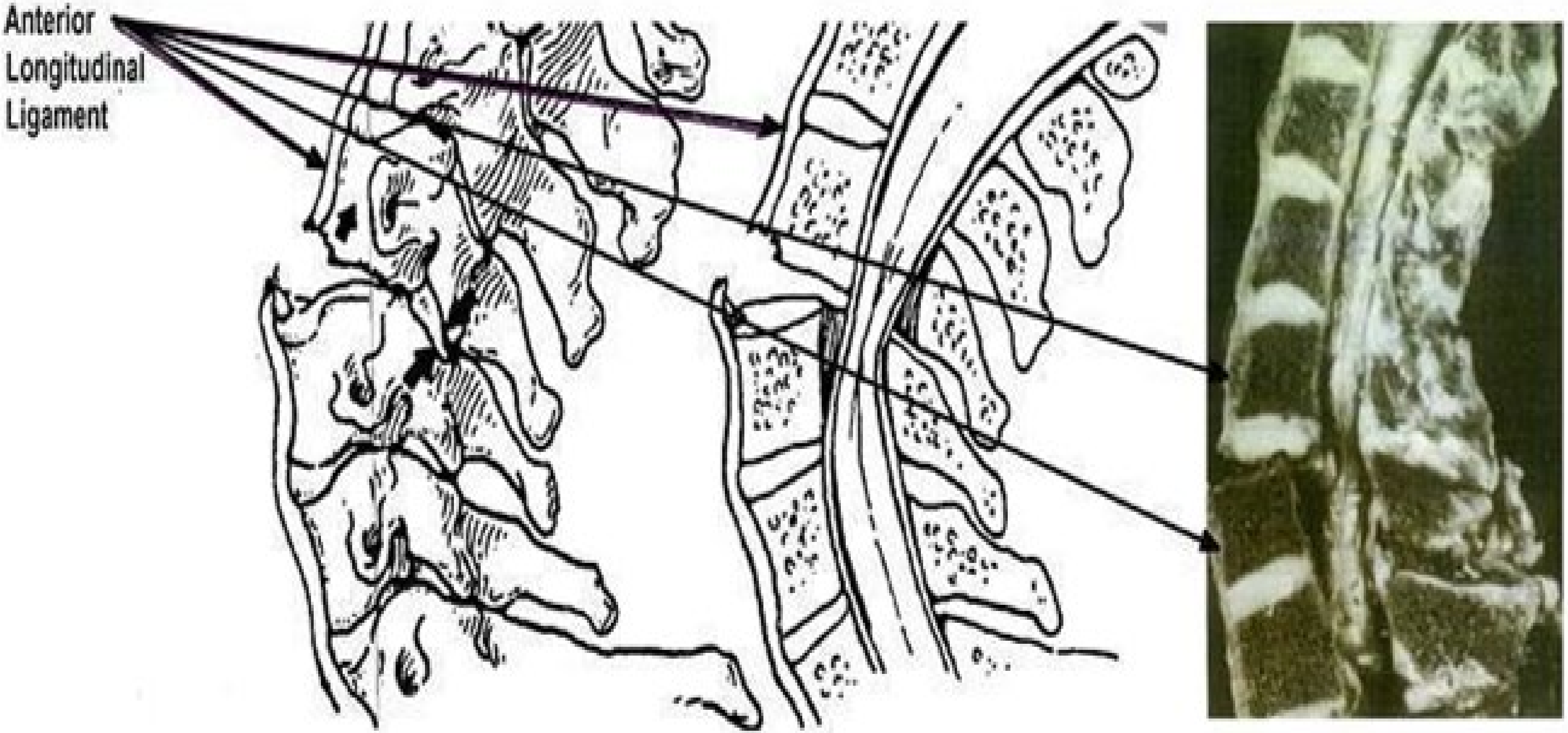




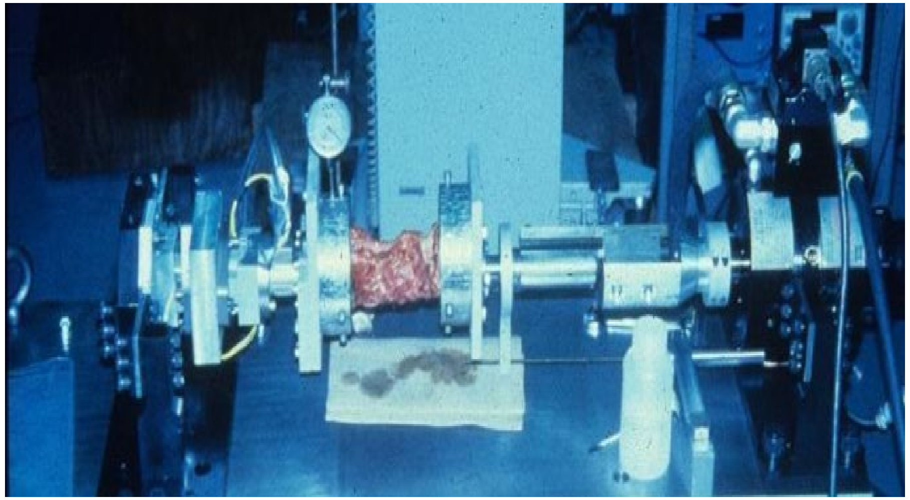
Teardrop Fracture

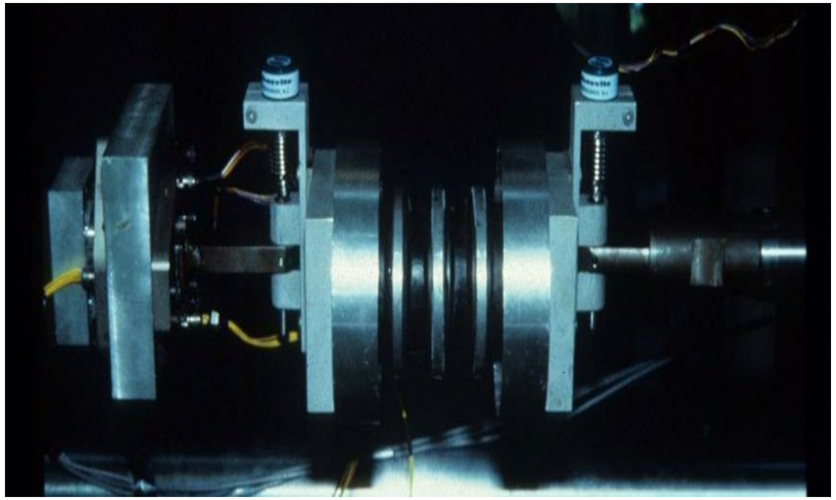


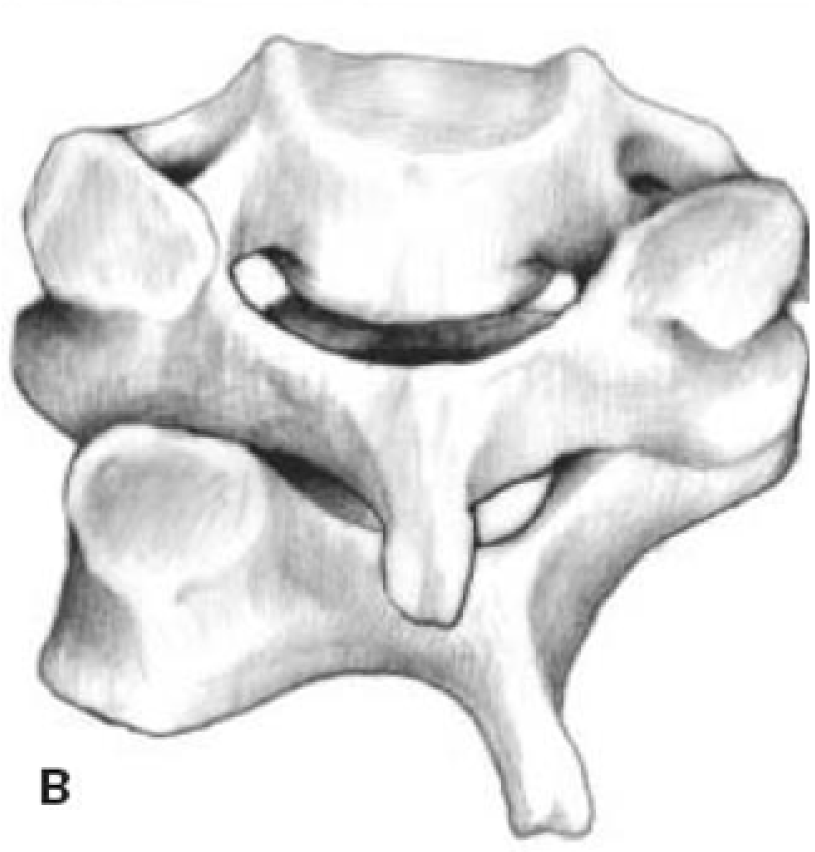
Hyperextension Injury



Human v. Hybrid III Cervical Spines in Torsion







The human upper neck fails before the lower neck fails.
The ATD neck is much stiffer than the human neck.

Physical v. Virtual Testing

to Evaluate Ejection Seats, Helmets, HMDs or NVGs, Anthropometry, etc.

Physical Testing is important, but often limited in scope due to

- **cost of test equipment, personnel, instrumentation and ATD maintenance and calibration**
- **ATDs like ADAM are up to 30 years old and degradation is a huge problem due to age or excessive loading**
- **A recent lab visit revealed that Humanetics is not making LOIS or LARD dummies or replacement parts. JASTI is another option.**

Virtual Testing allows parametric studies to be performed without test limitations varying:

- **occupant anthropometry**
- **seat and restraint parameters**
- **helmet, HMD, NVG weight, cg, and moment of inertia**
- **input pulses including multiaxial loading**
- **occupant positioning and ATD setup**

RED FLAGS

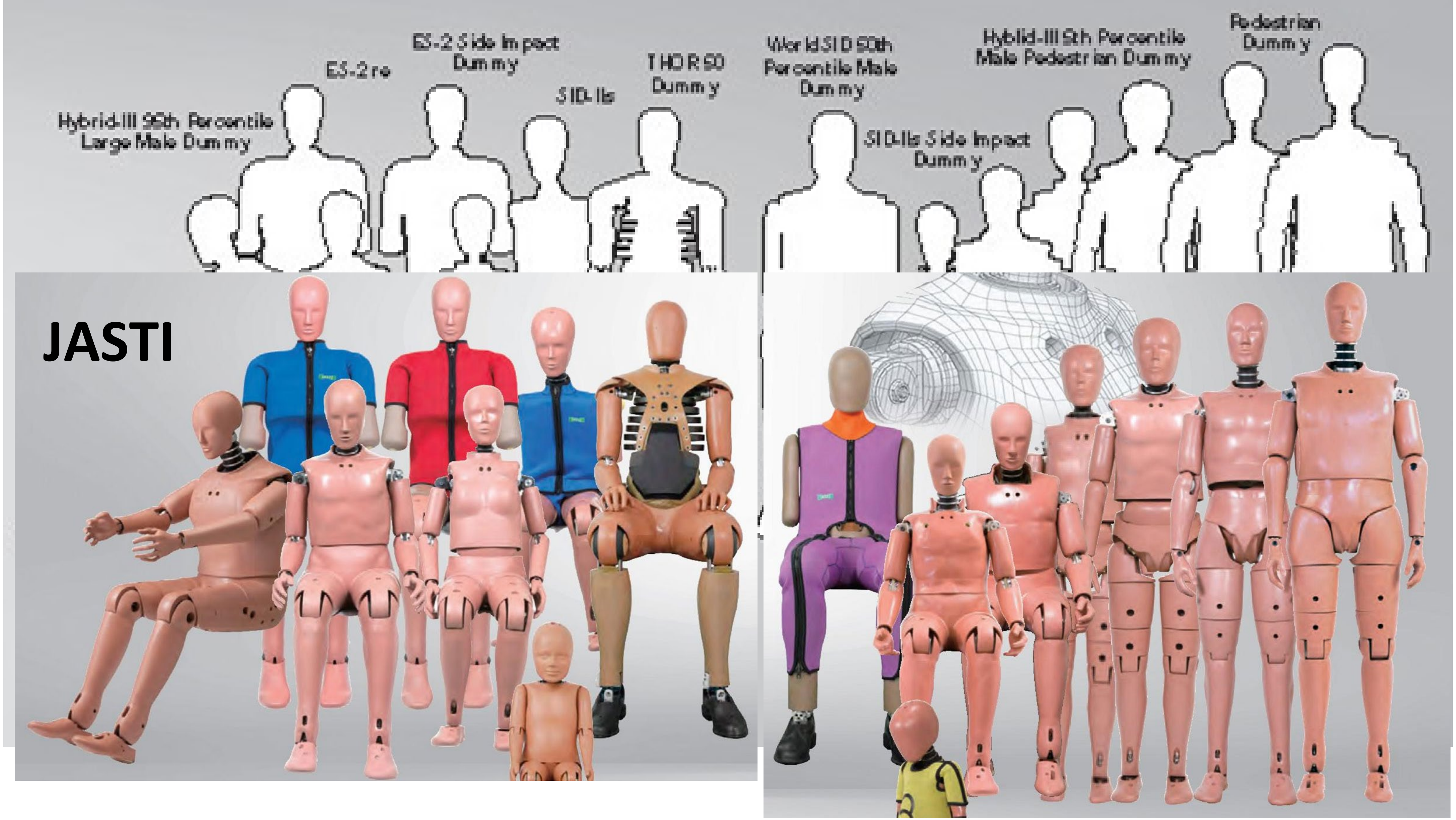
- About 5 years ago, I was consulted regarding test data that implied that neck loads with a heavy helmet, HMD and/or NVG were LESS THAN unhelmeted neck loads.
- Review of methodology showed:
  - Changes in body parts (e.g., 2 LARD heads, steel v. aluminum chest box, bronze v. aluminum knees, straight v. curved lumbar spines), 50^{th} feet instead of 95^{th} feet in LARD
  - Changes in ATD setup (e.g., lower neck angle bracket changes to account for bracing)
  - LOIS and LARD and likely Hybrid III Users Manuals are outdated
  - ATD calibration occurs when visual problems are identified, not regularly
  - ATD storage affects spine and pelvis response over time
  - Lack of standardized positioning procedures for the ATD in the seat, helmet placement and strap tension, restraint pretensioning, filtering, instrumentation, and criteria calculations
- Another observation was that the lab utilizes pass/fail criteria based ONLY on upper neck load cell data when historically it is known that ejection spinal fractures occur mostly in the thoracolumbar spine at T9-L3.

SUGGESTIONS

- **Update LOIS, LARD, and Hybrid III Users Manuals and set up regular static calibration checks.**
- **Establish ATD positioning procedures.**
- **Improve documentation of changes in ATDs and test parameters and procedures for the lab techs and between the labs and the equipment selection teams.**
- **Incorporate lower neck and lumbar spine criteria in the evaluation of effects of seats and devices.**
- **Create special task forces to achieve harmonization of ATDs and methodology within labs and between labs (e.g., Holloman, WPAFB and ejection seat manufacturers)**

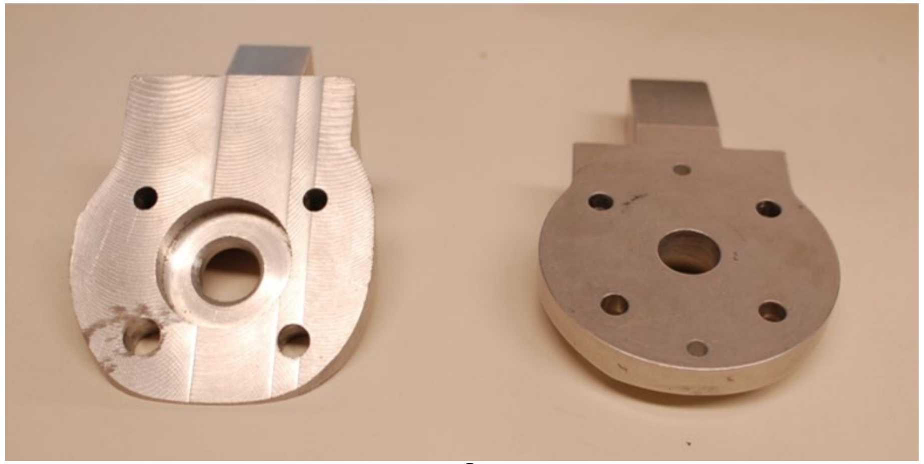
Aircrew and Surrogates

- Human Volunteer
- Human Cadaver (PMHS)
- Frontal ATD (FAA, NHTSA Hybrid II, III, THOR)
- Side Impact ATD (SID, Eurosid, WorldSid, Biosid)
- Rear Impact ATD (RID, RID2, Biorid)
- Air Force ATD (Adam, Lois, Lard)
- Navy Blast ATD (Wiaman)

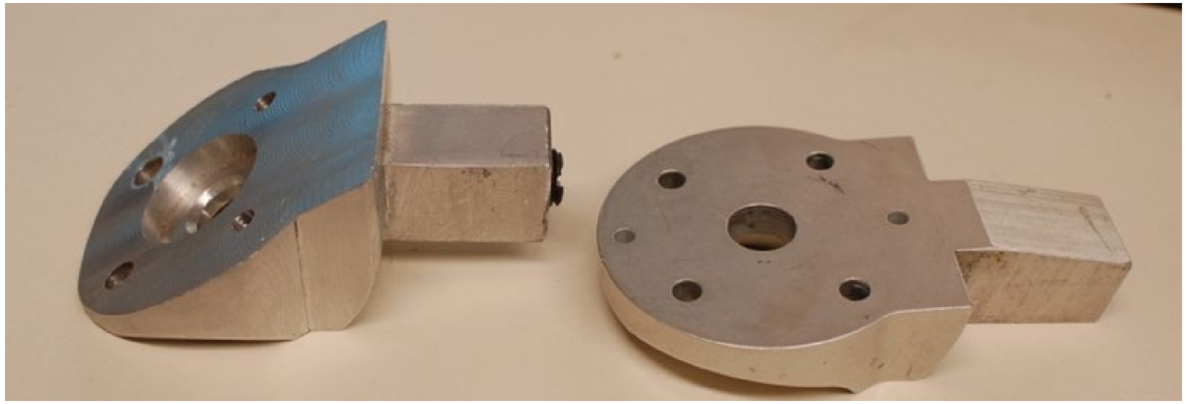


Hybrid-III 95th Percentile Large Male Dummy
ES-2re
ES-2 Side Impact Dummy
SID-IIs
THOR 50 Dummy
WorldSID 50th Percentile Male Dummy
SID-IIs Side Impact Dummy
Hyblid-III 5th Percentile Male Pedestrian Dummy
Pedestrian Dummy
JASTI

Lower Neck Load Cell Bracket Changes



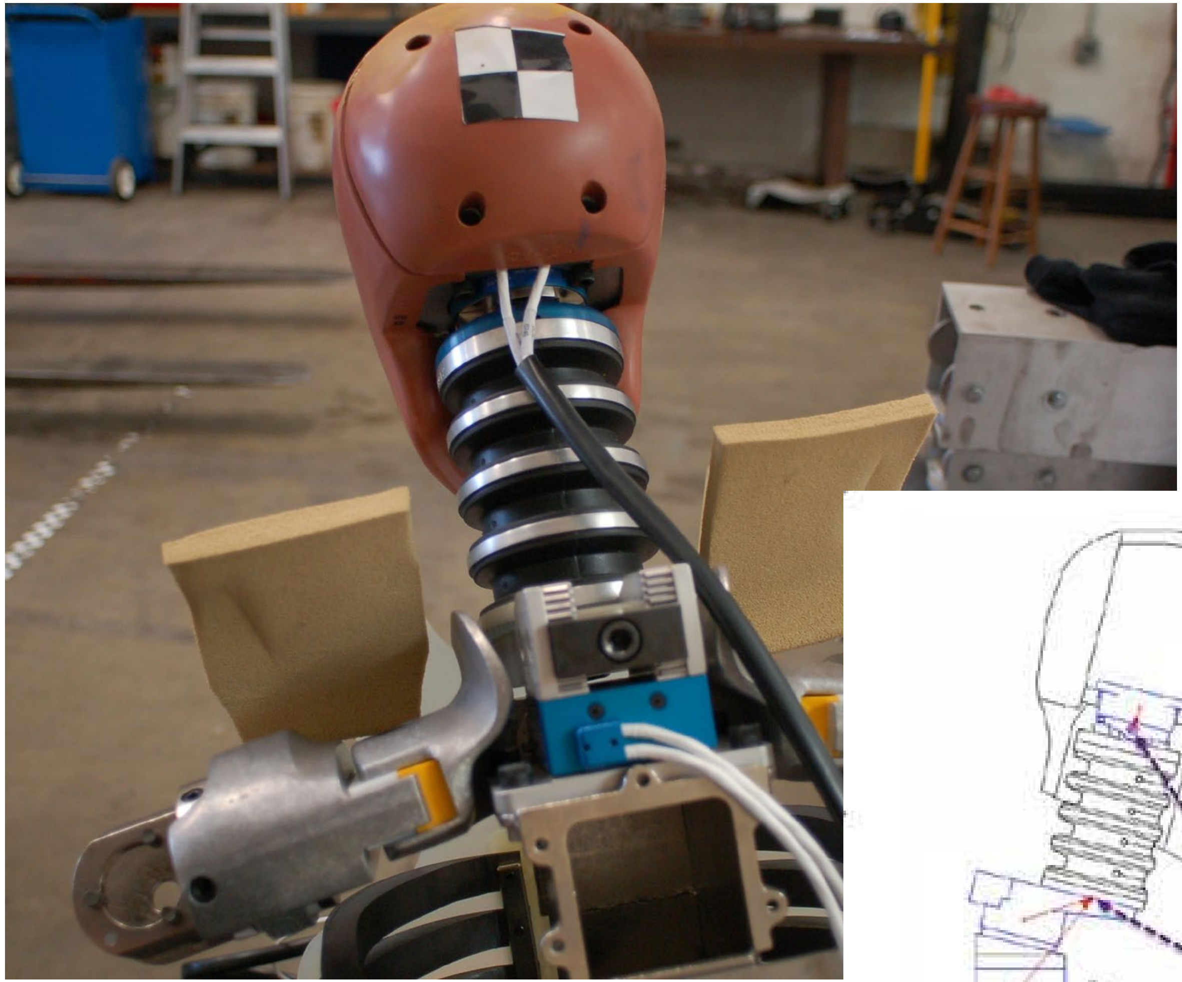
Fixed

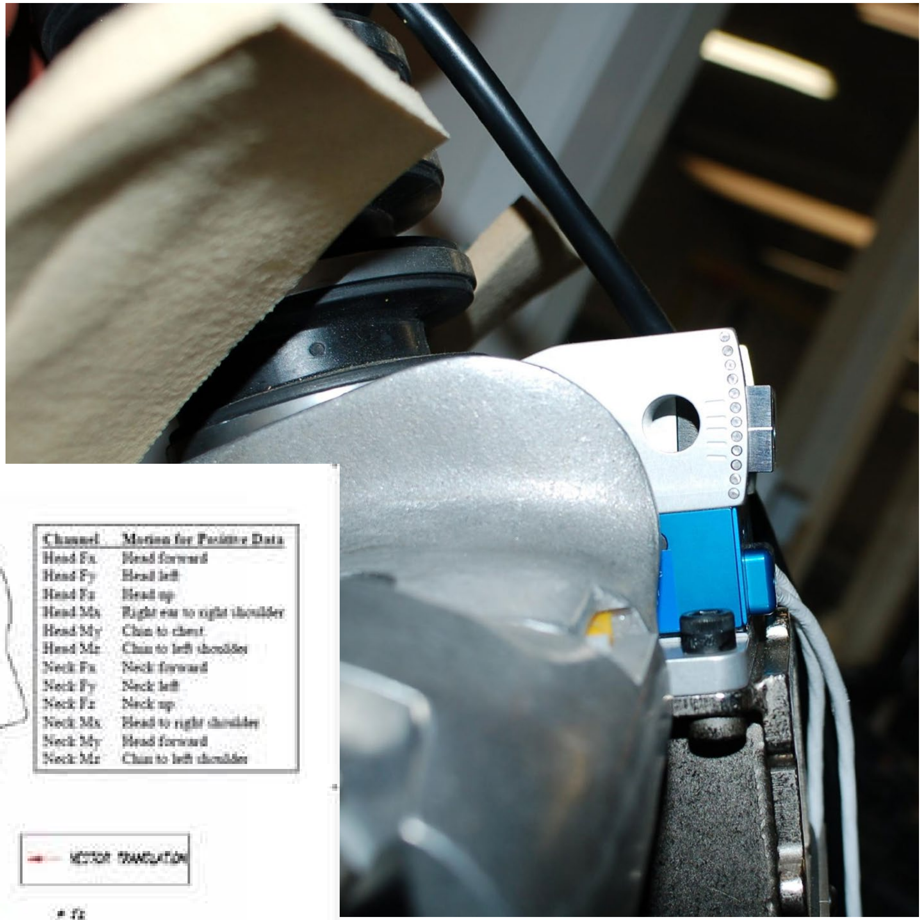


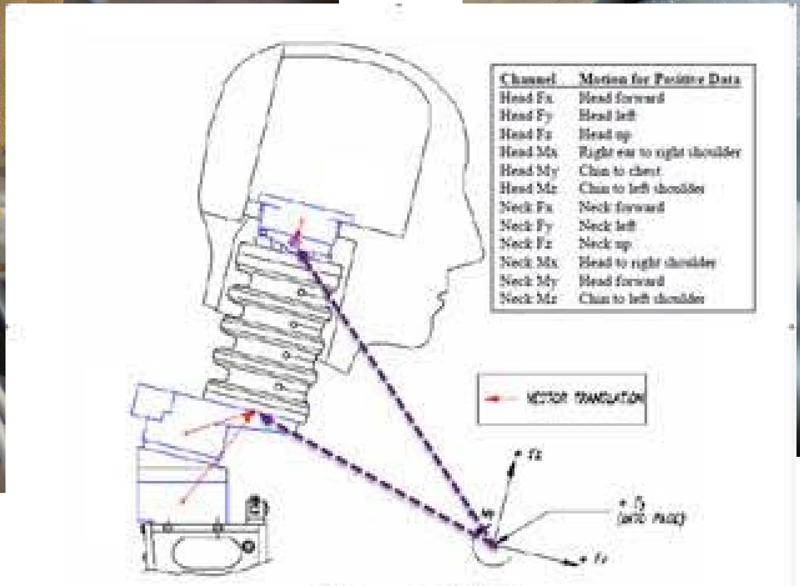
Adjustable

IT MEASURES
4.8 DEGREES
DOWNWARD ANGLE

THIS IS WHERE WE
SET IT FOR TESTING



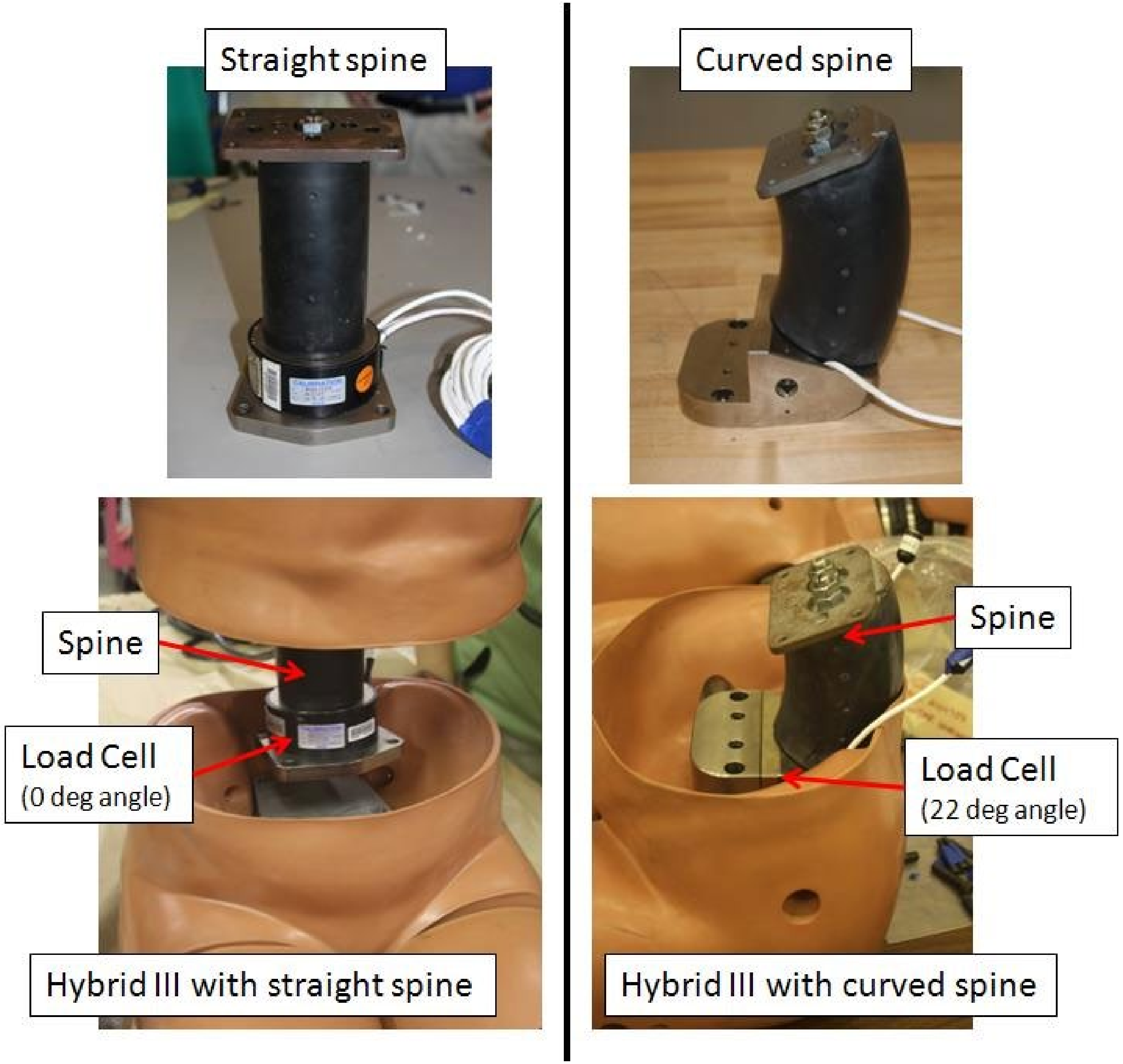




Channel	Motion for Positive Data
Head Fx	Head forward
Head Fy	Head left
Head Fz	Head up
Head Mx	Right ear to right shoulder
Head My	Chin to chest
Head Mz	Chin to left shoulder
Neck Fx	Neck forward
Neck Fy	Neck left
Neck Fz	Neck up
Neck Mx	Head to right shoulder
Neck My	Head forward
Neck Mz	Chin to left shoulder

Figure 3.1.2-1

FAA and Hybrid III Straight and Curved Lumbar Spines



Established Occupant Positioning Procedures

- **FAA**
- **NHTSA and SAE Hybrid II and III, THOR, WorldSid**
- **Navy Wiaman**

The Air Force does NOT have established occupant positioning procedures for Adam, Lois, or Lard

Air Force Injury Criteria

AFLCMC, MIL-HDBK-516C and Congress

specify

5% risk of AIS >= 2 Spinal Injury

NECK INJURY METRICS

- **Multi-Axial Upper Neck Injury Criteria MANIC (WPAFB)**
- **Normalized Upper Neck Injury Criteria Nij (NHTSA)**
- **Lower Neck Beam Criteria BC (Bass, 2006)**
- **Upper and Lower Neck Injury Criteria NIC (Nichols, 2006)**
- **Interaction-Based Force/Moment Lower Neck Injury Criteria LNij and LNic (MCW)**

Neck Injury Metrics

	Neck Injury Risk for AIS	Risk Function	Multi-Axial?	ATD sizes	Upper or Lower Neck	Validated for HSM
MANIC	5% for AIS>=2	Yes	Axial load, shear, bending, and torsion	5^{th}, 50^{th}, 95^{th}	Upper Neck	YES
NIC	10% for AIS>=3	Yes	Axial load, shear, bending, and torsion	5^{th}, 50^{th}, 95^{th}	Upper and Lower Neck	YES
Nij (NHTSA)	22% for AIS>=2	Yes	Axial load and flexion-extension	5^{th}, 50^{th}, 95^{th}	Upper Neck	NO
Beam Criterion BC	50% for AIS>=2	Yes	Axial load and flexion-extension	50^{th}	Lower Neck	YES
LNic	50% for AIS>1	Yes	Axial load and flexion-extension	5^{th}, 50^{th}, 95^{th}	Lower Neck	N/A
Knox Box	NO	NO	N/A	N/A	N/A	YES

Upper Neck MANIC is the ONLY metric used to predict spinal injury in the WPAFB lab

Upper Neck MANIC

$$MANIC = \sqrt{\left(\frac{F_X}{F_{Xcrit}}\right)^2 + \left(\frac{F_Y}{F_{Ycrit}}\right)^2 + \left(\frac{F_Z}{F_{Zcrit}}\right)^2 + \left(\frac{M_Y}{M_{Ycrit}}\right)^2 + \left(\frac{M_Z}{M_{Zcrit}}\right)^2}$$

Where:
Fx = observed x direction shear loading
Fxcrit = critical intercept value for x direction shear loading
Fy = observed y direction shear loading
Fycrit = critical intercept value for y direction shear loading
Fz = observed axial loading (+*Fz* = tension, -*Fz* = compression)
Fzcrit = critical intercept value for axial loading (different for tension/compression)
Mx = observed moment about the anatomical x axis (side bending)
Mxcrit = critical intercept value for side bending
My = observed moment about the anatomical y axis (sagittal plane anterior/posterior bending, +*My* = flexion, -*My* = extension)
Mycrit = critical intercept value for sagittal plane moments (different for flexion/extension)
Mz = observed moment about the anatomical z axis (neck twisting)
Mzcrit = critical intercept value for neck twisting

Upper Neck MANIC

MANIC criteria were adopted by MIL-HDBK-516, and consistent with Congressional and AFLCMC limits for ejection systems to maintain:

Risk of AIS >= 2 Neck Injury below 5%

MANIC is the ONLY metric used to predict spinal injury in the WPAFB lab

Manikin Neck Size	Manikin Mass	Human Mass	Component	Force		Component	Moment	
	(lbs)	(lbs)		(lbs)	(N)		(in-lbs)	(N-m)
Small Female Hybrid III (for 103-135 pound manikin)	103	<114	F_{xcrit}	405	1802	M_{xcrit}	593	67
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	872	3880	M_{zcrit}		
			$+F_{zcrit}$ (tens)	964	4287	$+M_{ycrit}$ (flex)	1372	155
	125	114-130.5	F_{xcrit}	496	2206	M_{xcrit}	845	95
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1099	4889	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1214	5400	$+M_{ycrit}$ (flex)	1939	219
	136	130.5-143	F_{xcrit}	522	2322	M_{xcrit}	912	103
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1157	5147	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1278	5685	$+M_{ycrit}$ (flex)	2094	237
Mid Male Hybrid III (for 136-199 pound manikin)	150	143-161	F_{xcrit}	561	2495	M_{xcrit}	1016	115
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1243	5529	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1373	6107	$+M_{ycrit}$ (flex)	2333	264
	172	161-186	F_{xcrit}	625	2780	M_{xcrit}	1195	135
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1385	6160	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1530	6806	$+M_{ycrit}$ (flex)	2744	310
	200	186-210	F_{xcrit}	683	3038	M_{xcrit}	1364	154
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1513	6730	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1671	7433	$+M_{ycrit}$ (flex)	3133	354
Large Male Hybrid III (for 200-245 pound manikin)	220	210-232.5	F_{xcrit}	777	3456	M_{xcrit}	1584	179
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1673	7440	M_{zcrit}		
			$+F_{zcrit}$ (tens)	1847	8216	$+M_{ycrit}$ (flex)	3673	415
	245	232.5+	F_{xcrit}	836	3719	M_{xcrit}	1850	209
			F_{ycrit}			$-M_{ycrit}$ (extens)		
			$-F_{zcrit}$ (comp)	1853	8243	M_{zcrit}		
			$+F_{zcrit}$ (tens)	2047	9106	$+M_{ycrit}$ (flex)	4248	480

Nij

The Normalized Neck Injury Criterion Nij considers 4 combinations of axial forces and sagittal plane A-P bending moments

- NTE (tension-extension) and NTF (tension-flexion),
- NCE (compression-extension) and NCF (compression-flexion)

where the "ij" subscripts of the Nij:

- T and C represent the axial tension and compression force index, respectively
- F and E represent the sagittal plane flexion and extension bending moment index, respectively.

The Nij is the sum of the normalized loads and moments. :

$$Nij = \frac{F_z}{F_{zc}} + \frac{M_{OCy}}{M_{yc}}$$

where:

F_z	axial force at the OC
M_{OCy}	flexion-extension bending moment at the OC
F_{zc}	Critical axial force intercept value used for normalization
M_{yc}	Critical flexion-extension bending moment intercept value used for normalization.

The current Nij "performance limit" is set at 1.0. A test where Nij>1 fails the criterion.

Lower Neck BEAM Theory Criterion BC

$$BC = \frac{F_Z}{F_{ZC}} + \frac{M_Y}{M_{YC}}$$

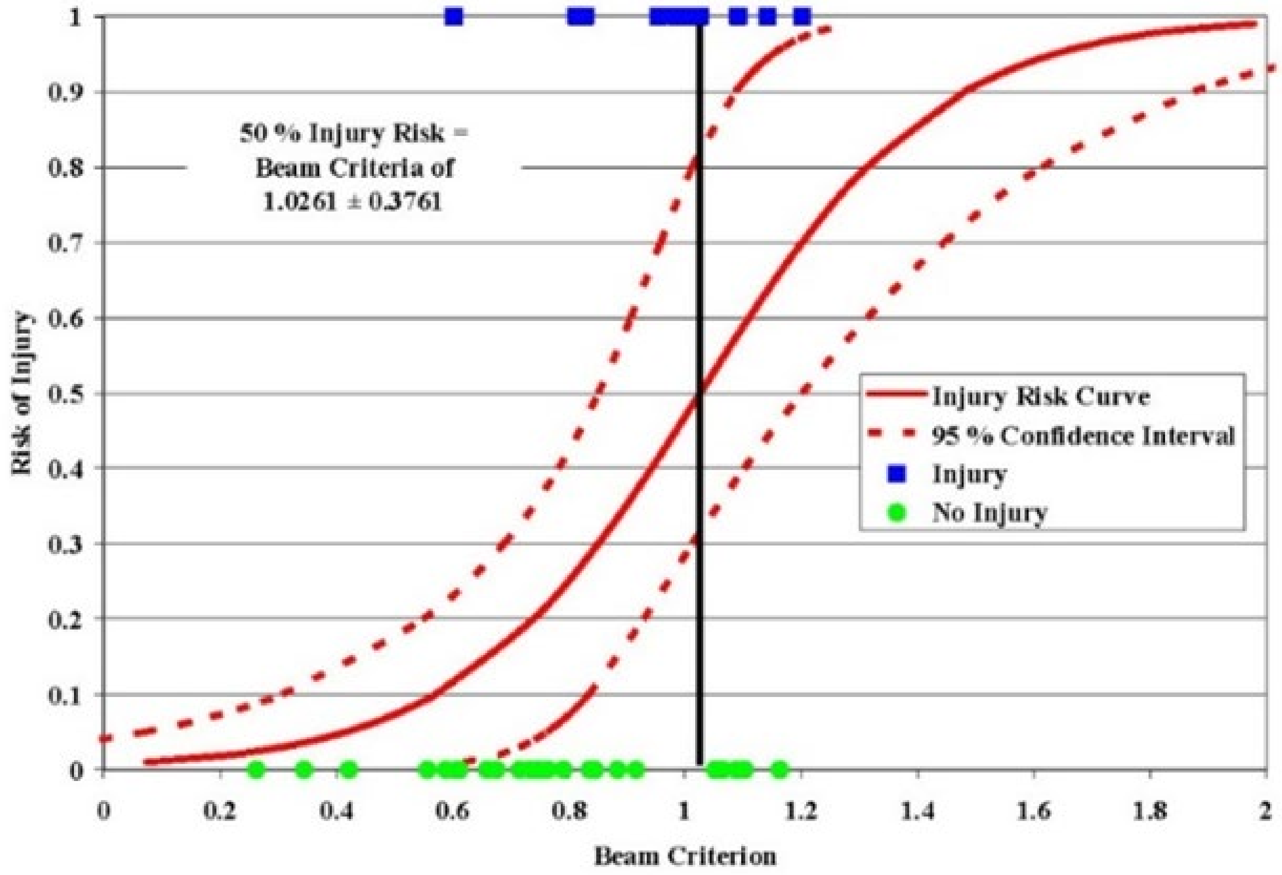
where:

- ***F_z*** **is the axial compression-tension neck force at the C7-T1 intervertebral disc**
- ***M_Y*** **is the A-P flexion-extension moment in the sagittal plane at the C7-T1 intervertebral disc**
- ***F_{ZC}*** **is critical axial force**
- ***M_{YC}*** **is the critical moment**

Lower Neck
Beam Criterion

Optimized IARC (mean BC =1 .0 and SD= 0.38)
Corresponds to
50% risk of AIS ≥ 2 Lower Neck Injury

- ***Optimized*** F_{ZC} **= 5660 N in axial tension**
- ***Optimized*** F_{ZC} **= 5430 N in axial compression**
- ***Optimized*** M_{YC} **= 141 Nm in A-P flexion**



Lower Neck NIC

10% Risk of AIS >= 3 Injury

Table 4. NIC Summary (from Nichols, 2006)

Criteria Element	Upper Neck Limit	Lower Neck Limit
1) Tension Duration S – small (0-135 lb) M – medium (136-199 lb) L – large (200+ lb)	**S** (5 ms, 414 lbs 31 ms, 414 lbs 40 ms, 200 lbs 80 ms, 200 lbs) **M** (5 ms, 618 lbs 35 ms, 618 lbs 45 ms, 320 lbs 80 ms, 320 lbs) **L** (5 ms, 761 lbs 37 ms, 761 lbs 48 ms, 450 lbs 80 ms, 450 lbs)	Same
2) Compression Duration S – small (0-135 lb) M – medium (136-199 lb) L – large (200+ lb)	**S** (5 ms, 519 lbs 27 ms, 200 lbs 80 ms, 200 lbs) **M** (5 ms, 790 lbs 30 ms, 320 lbs 80 ms, 320 lbs) **L** (5 ms, 979 lbs 32 ms, 450 lbs 80 ms, 450 lbs)	Same
3) Shear (composite) Duration S – small (0-135 lb) M – medium (136-199 lb) L – large (200+ lb)	**S** (5 ms, 405 lbs 20 ms, 225 lbs 29 ms, 225 lbs 37 ms, 165 lbs 80 ms, 165 lbs) **M** (5 ms, 625 lbs 25 ms, 337 lbs 35 ms, 337 lbs 45 ms, 247 lbs 80 ms, 247 lbs) **L** (5 ms, 777 lbs 28 ms, 414 lbs 39 ms, 414 lbs 50 ms, 304 lbs 80 ms, 304 lbs)	**S** (5 ms, 810 lbs 20 ms, 450 lbs 29 ms, 450 lbs 37 ms, 330 lbs 80 ms, 330 lbs) **M** (5 ms, 1250 lbs 25 ms, 674 lbs 35 ms, 674 lbs 45 ms, 494 lbs 80 ms, 494 lbs) **L** (5 ms, 1554 lbs 28 ms, 828 lbs 39 ms, 828 lbs 50 ms, 608 lbs 80 ms, 608 lbs)
4) $N_{ij} = \frac{F_z}{F_{zcrit}} + \frac{M_y}{M_{ycrit}}$ (S / M / L) $+F_{zcrit}$ (lb): 964 / 1530 / 1847 $-F_{zcrit}$ (lb): 872 / 1385 / 1673 $+M_{ycrit}$ (in-lb): 1372 / 2744 / 3673 $-M_{ycrit}$ (in-lb): 593 / 1195 / 1584	Peak *Nij* < 0.5	Peak *Nij* < 1.5
5) $NMI_x = \frac{M_x}{M_{xLIM}}$ $+/-M_{xLIM}$(in-lb): 593 / 1195 / 1584	Peak $NMI_x < 0.5$	Peak $NMI_x < 1.5$
6) $NMI_z = \frac{M_z}{M_{zLIM}}$ $+/-M_{zLIM}$ (in-lb): 593 / 1195 / 1584	Peak $NMI_z < 0.5$	Peak $NMI_z < 1.0$

UNCLASSIFIED

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

REPORT NO: NAWCADPAX/TR-2004/86

CERVICAL INJURY RISK RESULTING FROM ROTARY WING IMPACT:
ASSESSMENT OF INJURY BASED UPON AVIATOR SIZE, HELMET MASS PROPERTIES, AND IMPACT SEVERITY

by

Glenn Paskoff

21 October 2004

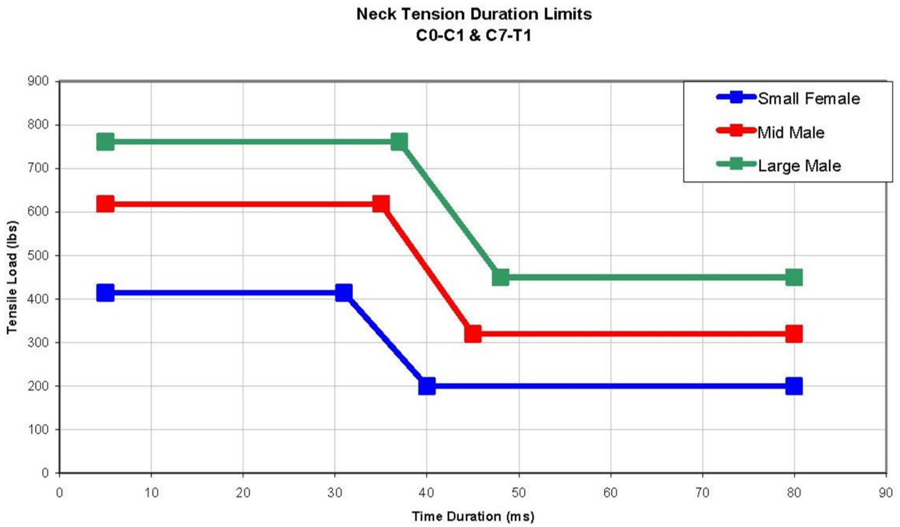


Figure G-1: Neck Tension Duration Limits (C0-C1 and C7-T1)

Crew Systems Bulletin

AFLCMC/EZFC
Bldg 28, 2145 Monhan Way
WPAFB, OH 45433-7017
Phone 937-656-9683

Number: EZFC-CSB-16-001

Date: 28 Nov 2016

Subject: USAF Revision of MIL-HDBK-516C section 9.1.1Escape system safety compatibility criteria standard; supporting data and legacy criteria.

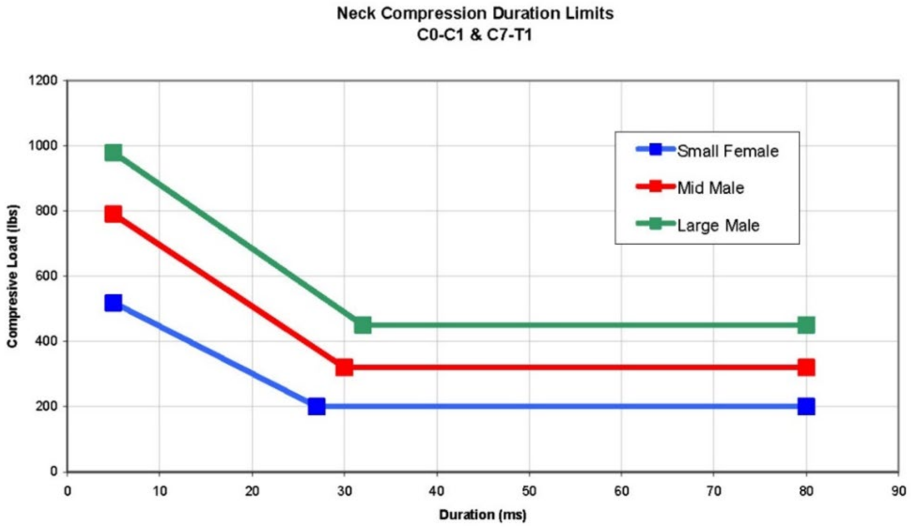


Figure G-2: Neck Compression Duration Limits (Co-C1 and C7-T1)

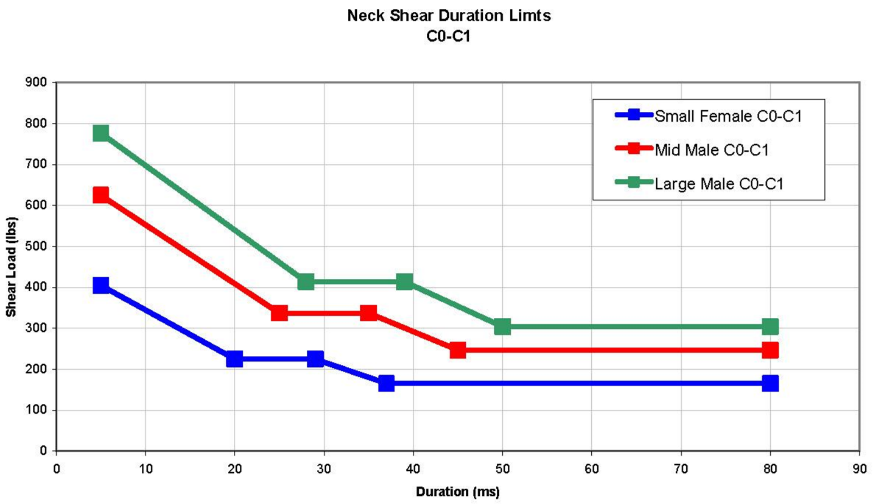


Figure G-3: Neck Shear Duration Limits (C0-C1)

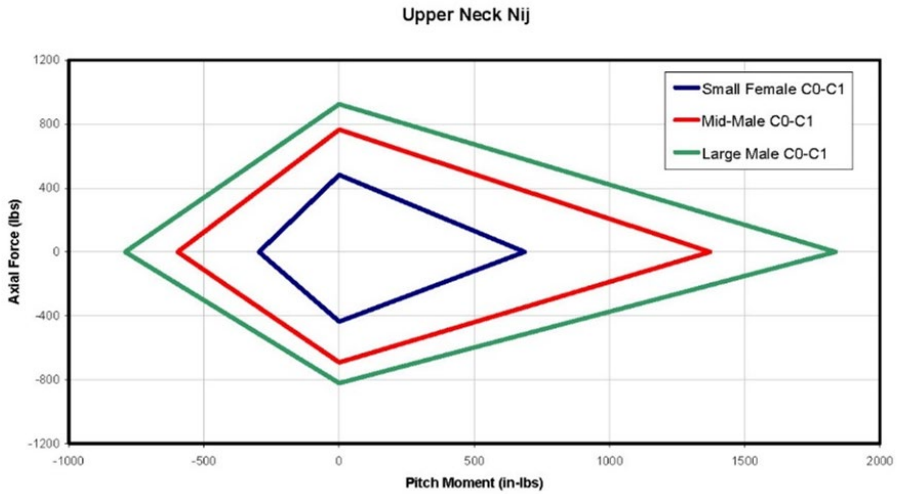


Figure G-5: Upper Neck Nij

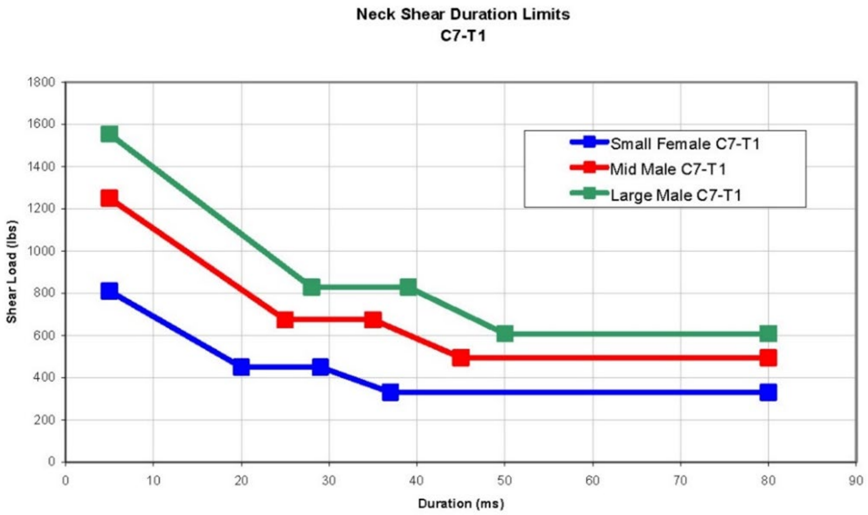


Figure G-4: Neck Shear Duration Limits (C7-T1)

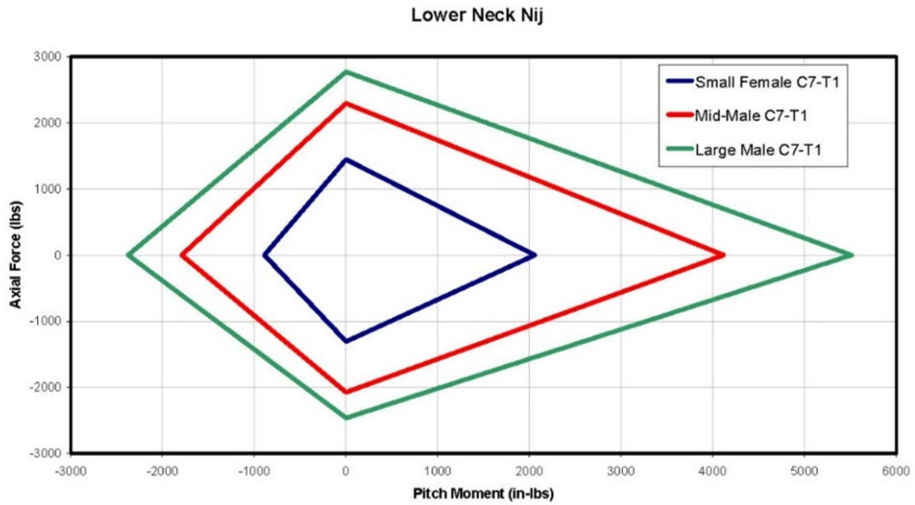


Figure G-6: Lower Neck Nij

MCW Interaction-Based Force and Moment Lower Neck Injury Criteria LNic

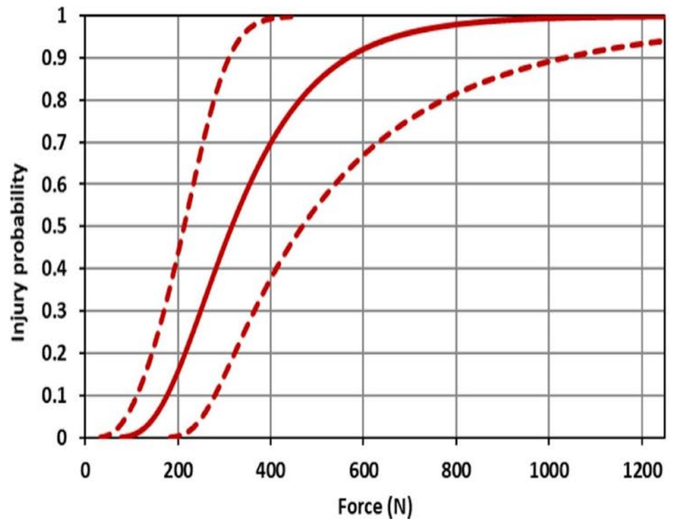
$$LN_{ic}(t) = \frac{F(t)}{F_{crit}} + \frac{M(t)}{M_{crit}}$$

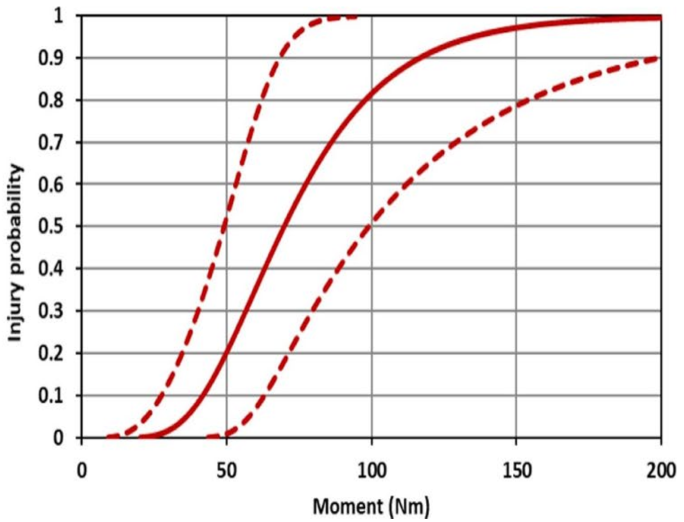
where the time-dependent parameters are:

- **F is the A-P shear force**
- **M is the sagittal plane extension bending moment,**
- **subscript "crit" represents the critical intercepts**.

AIS>1 C7-T1 Injury Risk Curves

from Matched-Pair PMHS-H3 Tests under Gx Loading



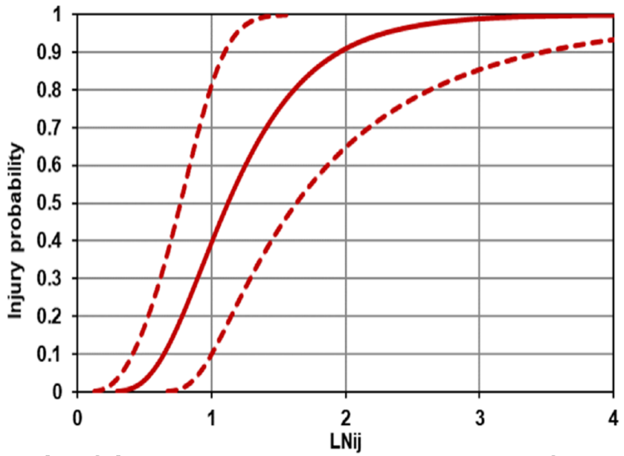


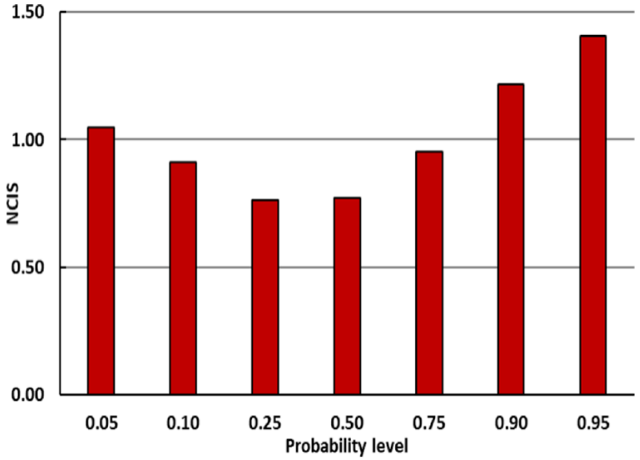
Force (left) and Moment (right) IARCs for the H3

For 50% Risk

Mean Force = 315 N

Mean Moment = 70 Nm





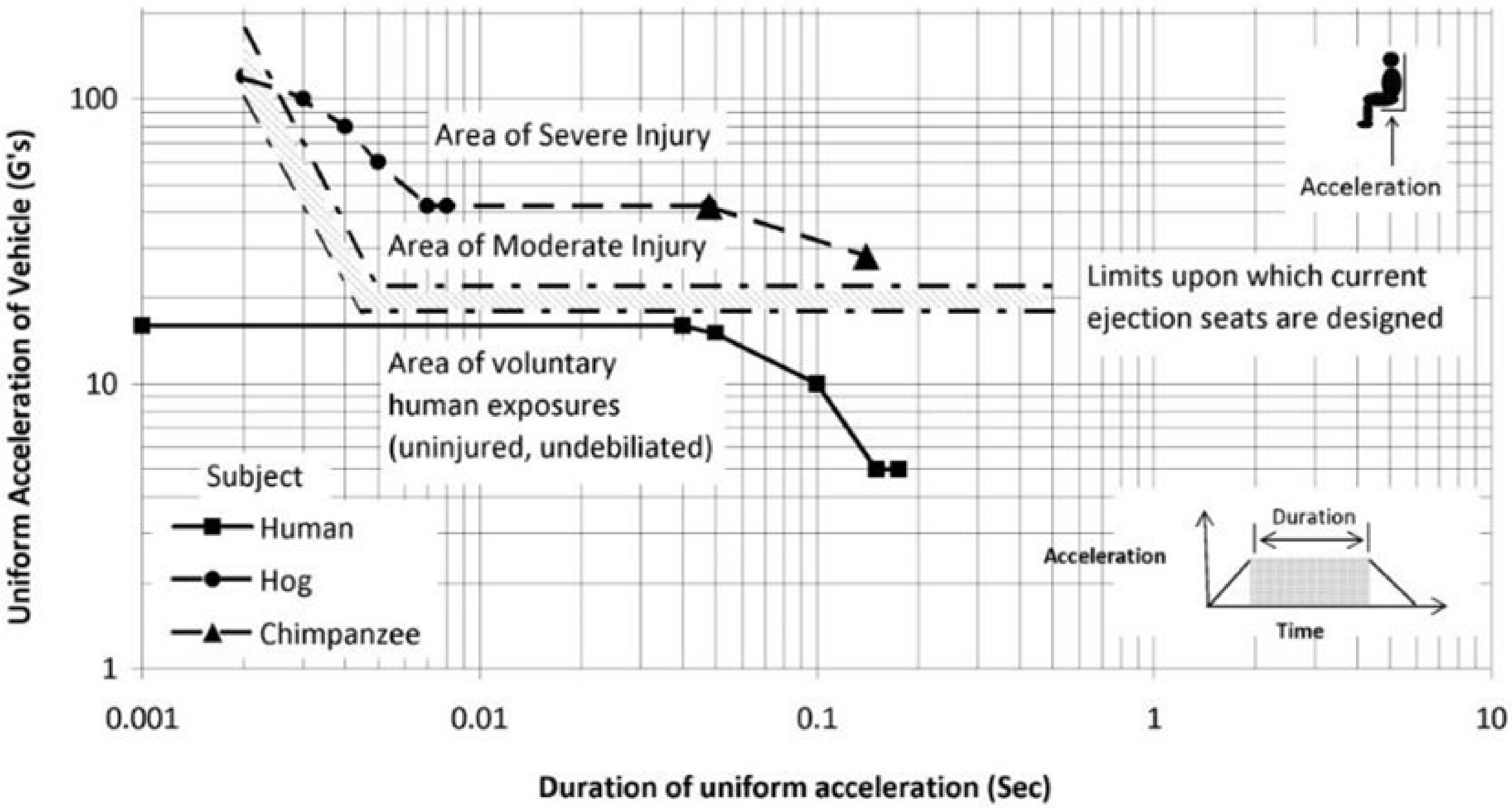
IARCs (left) and normalized confidence interval size (right) for the LNic for the H3

Historical Thoracolumbar Spine Injury Criteria

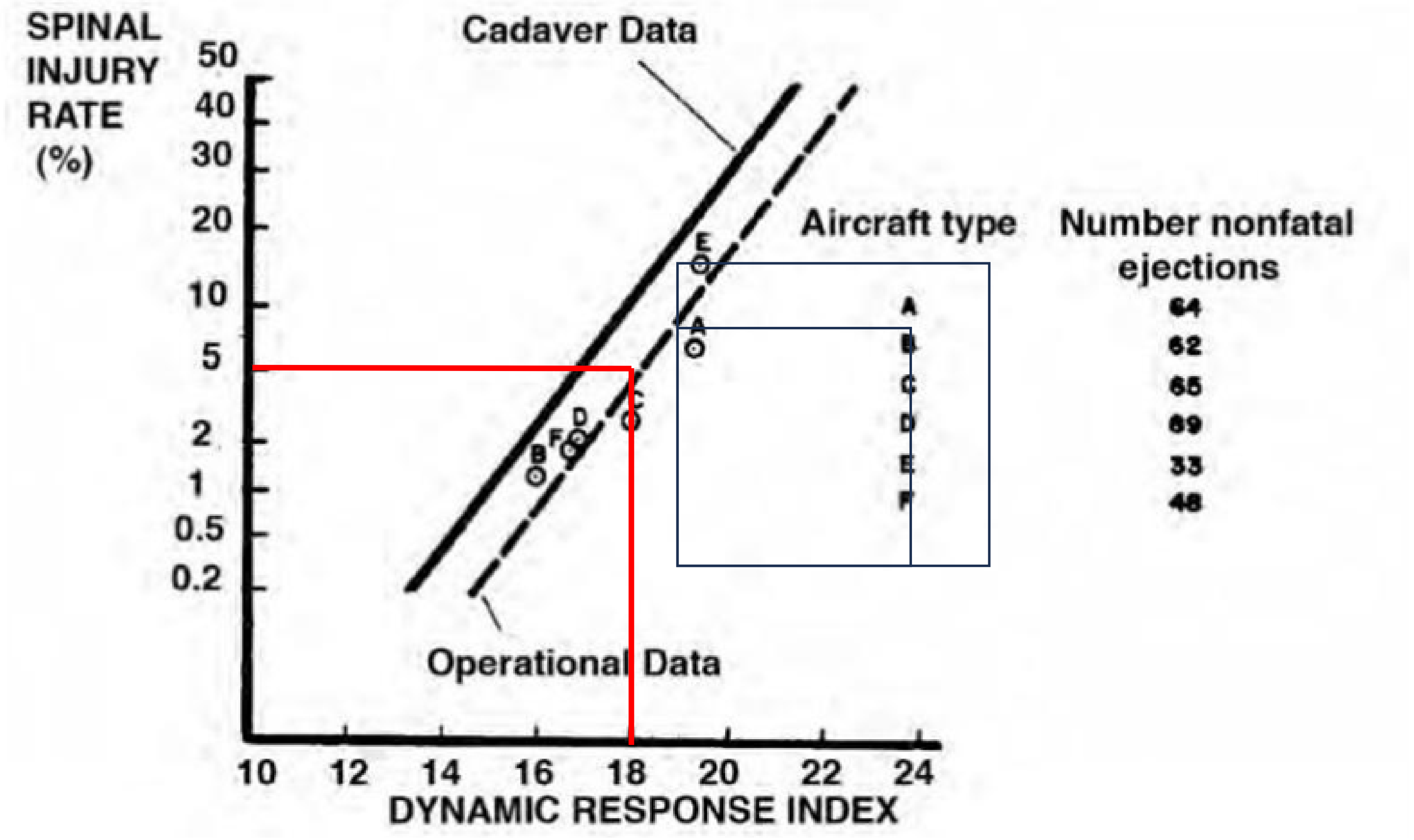
- **Eiband criteria derived from seat accelerations**
- **DRI criteria derived from seat accelerations**
- **ATD lumbar spine force and moment criteria**

WPAFB does not use thoracolumbar spine metrics in the evaluation of seats and devices.

Eiband Injury Tolerance Curve for Spineward Acceleration



Dynamic Response Index (DRI)



DRI=18 for 5% Risk of Nonfatal AIS 2+ Spinal Injuries

Current Lumbar Injury Criteria for Vertical Loading

	5% Female	5% Male	50% Male	95% Male
Early AF	NA	Eiband	Eiband	Eiband
Army Aviation G vs. ms	≤ 23 ≤ 25	≤ 23 ≤ 25	≤ 23 ≤ 25	≤ 23 ≤ 25
AF, DRI	18 nom	18 nom	18 nom	18 nom
FAA	NA	NA	1500 Lb	NA
JSSG	1281 Lb	NA	2065 Lb	2534 Lb
Army, Ground	G vs. ms, AF DRI, and FAA	G vs. ms, AF DRI, and FAA	G vs. ms, AF DRI, and FAA	G vs. ms, AF DRI, and FAA

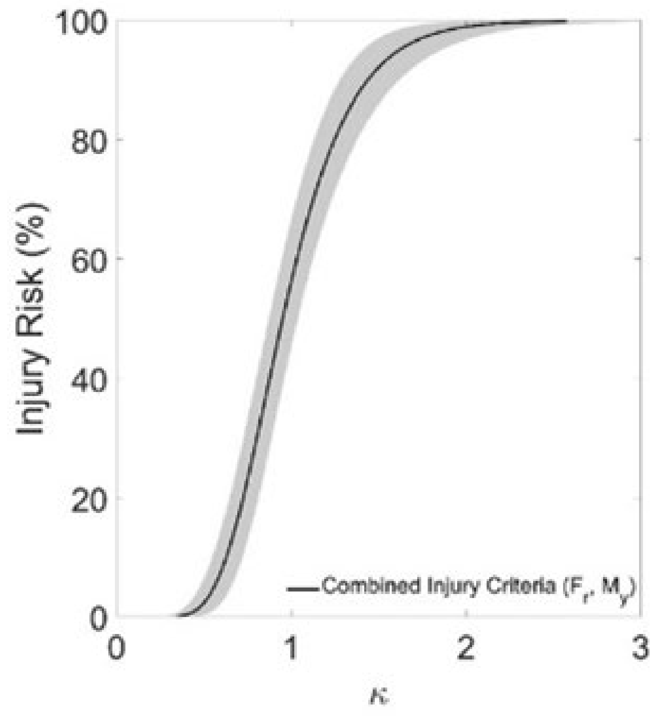
MCW PMHS Lumbar Criteria under Gz Loading

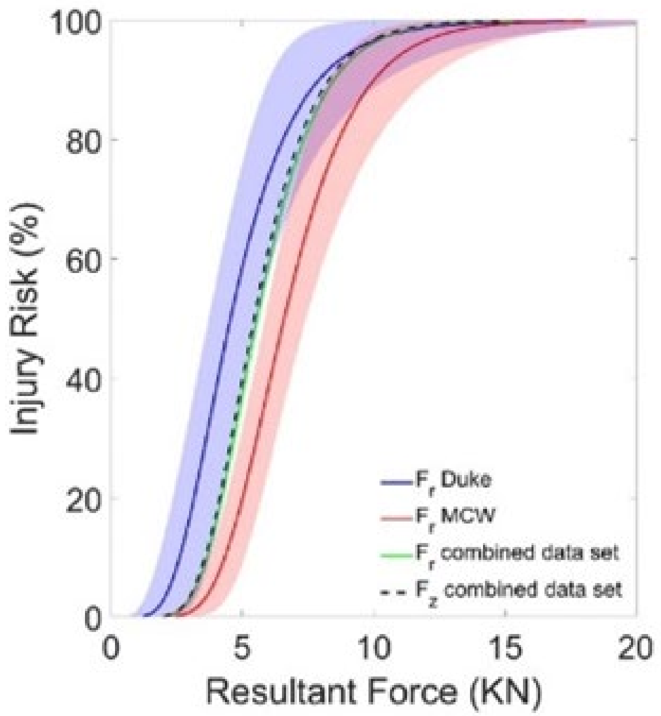
K = Fz/Fz,crit + My/My,crit Risk of T12-L1 Vertebral Body Fracture

optimized for Resultant Sagittal Force Fr,crit=1188# (5824 N) and Bending Moment My,crit= 852 ft# (1155 Nm)

Risk	Combined Metric K
5%	0.59
50%	1
95%	1.70

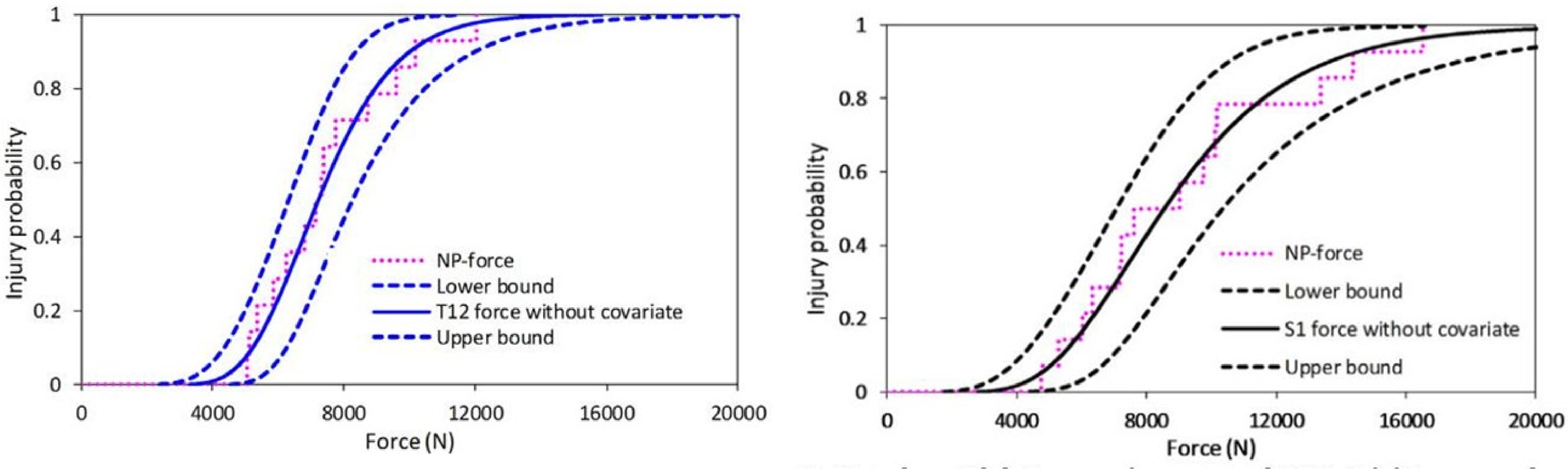
	Resultant Sagittal Force	Risk of Spinal Injury	Combined Metric K
Duke	1021# (4540 N)	50%	1
MSW	1481 (6590 N)	50%	1





MCW PMHS Lumbar Spine Compressive Injury Tolerances

Injury Risk Curves: T12-L1 (Left) and L5-S1 (Right)



Yoganandan et al. 2018	Plot	5% Risk	10% Risk	50% Risk
T12-L1 Force	Left	1068# (4750 N)	1171# (5211 N)	1624# (7223 N)
L5-S1 Force	RIght	1059# (4710 N)	1208# (5372 N)	1921# (8545 N)

CONCLUSIONS

- **Ejection spinal injury levels, patterns and mechanisms are well-documented**
- **Physical and virtual testing are valuable tools for seat, helmet, HMD, NVG evaluation given limitations**
- **Suggestions:**
  - **Update LOIS, LARD, and Hybrid III Users Manuals and set up regular static calibration checks.**
  - **Establish ATD positioning procedures.**
  - **Incorporate lower neck and lumbar spine criteria in the evaluation of effects of seats and devices.**
  - **Improve documentation and communication within and between labs and device evaluation teams**
  - **Create special task forces to achieve harmonization of ATDs and methodology within labs and between labs (e.g., Holloman, WPAFB and ejection seat manufacturers)**