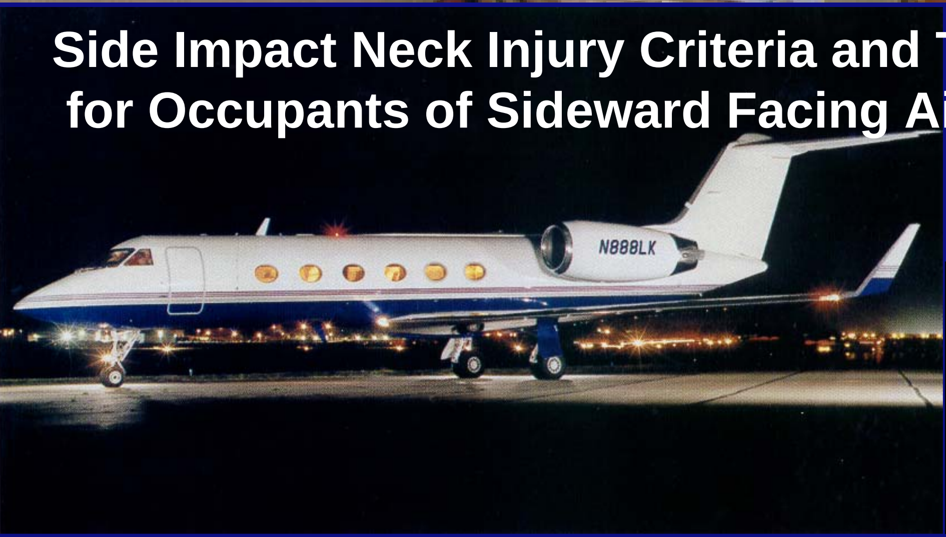
Side Impact Neck Injury Criteria and Tolerances for Occupants of Sideward Facing Aircraft Seats



Authors:

Mat Philippens, Jac Wismans, Justyna Mordaka

Narayan Yoganandan, Frank Pintar

Stephen Soltis

Rick deWeese

CAMI

FAA

TNO | Knowledge for business

Presentation overview

- Initial FAA Studies
- Project Methodology
- Neck injury criteria literature
- Test matrix
- Method
- Subject responses
    - injury specification
    - dynamics
- Injury Criteria - Tolerances
- Conclusions
- Discussion
- References

Initial FAA Research Studies

Objective: Develop certification standards for sideward facing seats that provide a level of safety and impact protection equivalent to that afforded for occupants of forward or aft facing seats.

Example Business Jet Cabin Interior

The Problem

Project Methodology

Literature Review
Injury Criteria and Tolerances

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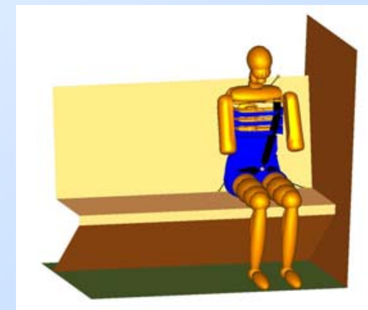
Computer Simulations with Human Models and EuroSID-2 ATD



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Post Mortem Human Subjects (PMHS) Lateral Impact Sled Tests

↓

Validate Test and Certification Procedures

Additional Sled Tests, Simulations, and Analyses to Establish Lateral Impact Tolerance Levels and Test Procedures

Literature

Injury criteria and tolerances for lateral bending

Criteria	Tolerance range for neck		
	AIS 1	AIS 2	Soltis
Impact velocity	<40 km/h	30-60 km/h	
Impact acceleration	5-10 G	10-14.7 G	
Head angle	50-70 degrees	57-75 degrees	60 degrees
Head angular velocity	8-30 rad/s	32-39 rad/s	
Head angular acceleration	680-1460 rad/s2	1588-2601 rad/s2	2600 rad/s2
Head linear acceleration	13-32 G	12.5-18 G	36 G
Neck bending moment	22.6-40.7 Nm	40.7-60 Nm	60 Nm
Tension	?	4170 N	4170 N
Compression	?	4000 N	4000 N
Shear force	240 N	>900 N	

AIS	Spine injury
1	Acute strain (no fracture)
2	Minor fracture, no cord involvement
3	Disc rupture, nerve root damage
4	Incomplete spinal cord, cord syndrom
5	Quadriplegia

Literature since 2003

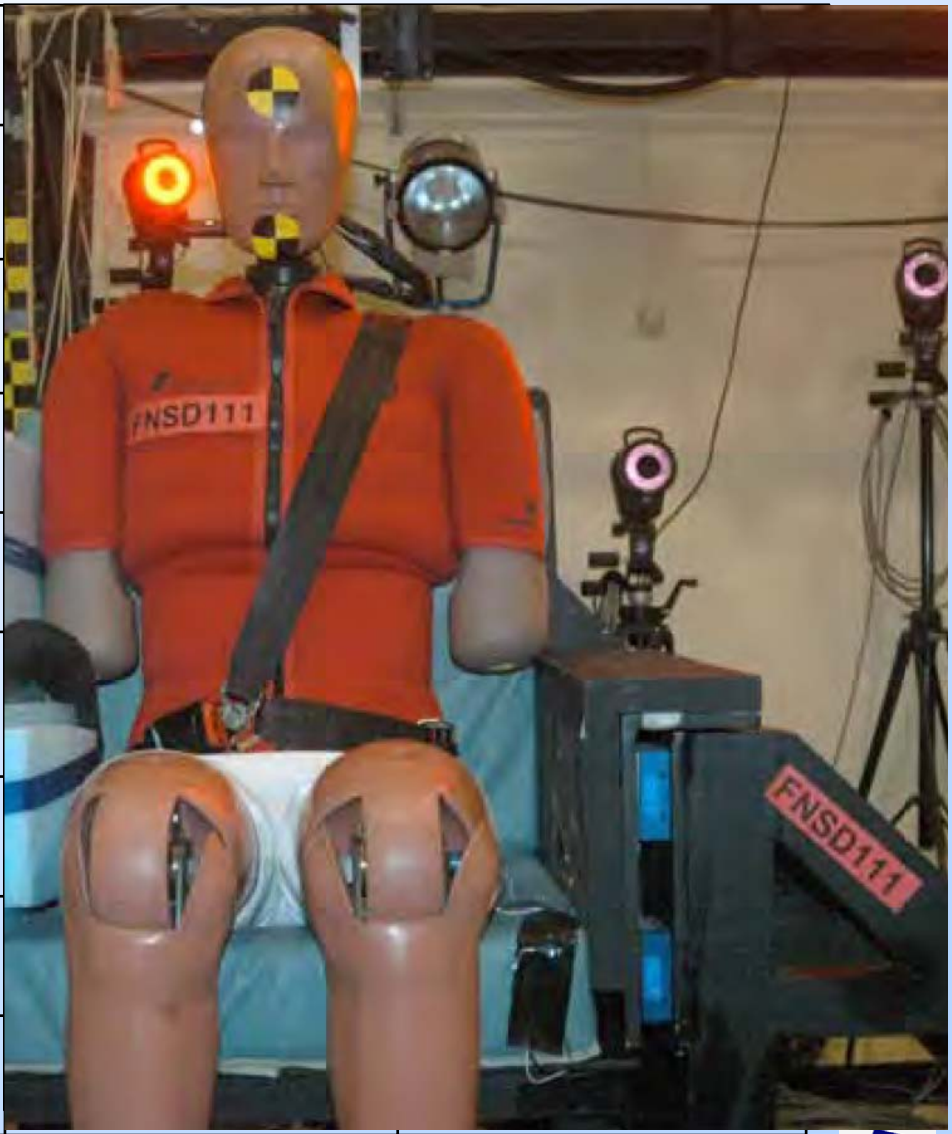
Injury criteria and tolerances for lateral bending

Upper neck	AIS 1	AIS 2
Lateral bending moment [Nm]	**132**	**180** **67** **47-60 Soltis (pre 2003)**
Tension [N]	**1500**	**2070** **4170 Soltis (pre 2003)**
Shear [N]	**1693**	**2797** **>900 (pre 2003)**
Twist [Nm]		**39**

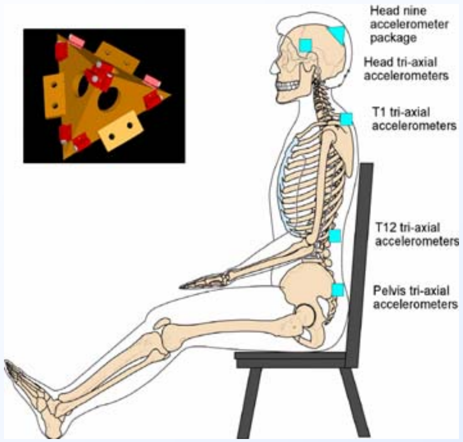
- McIntosh 2007 - **Fréchède** - Lund 2003

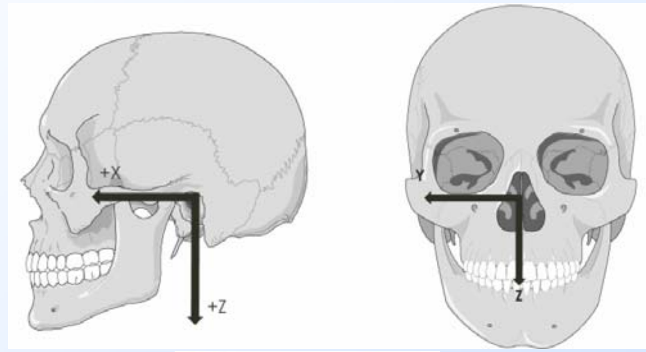
Test matrix conducted PMHS tests

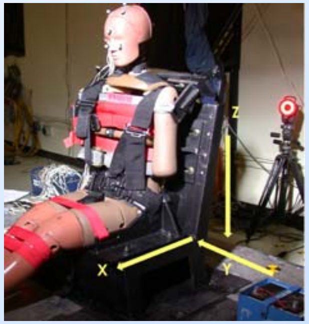
Testno	Pulse	Config
FAA23 WSU	*9 g ^ 180 ms*	*Rigid seat - Side wall up to shoulder*
FAA26 WSU	*16 g ^ 180 ms*	*Rigid seat - Side wall up to shoulder*
FNSC102 MCW	*12.5 g [] 120 ms*	*Rigid seat - Max. torso restraint*
FNSC104 MCW	*12.5 g [] 120 ms*	*Rigid Seat - Max. torso restraint*
FNSC109 MCW	*12.5 g [] 120 ms*	*Real seat with armrest*
FNSC110 MCW	*12.5 g [] 120 ms*	*Real seat with armrest*
FNSC115 MCW	*8.5 g [] 120 ms (70% ΔV)*	*Real seat with armrest*
FNSC116 MCW	*8.5 g [] 120 ms (70% Δ V)*	*Real seat with armrest*



Experimental method







$$F_{OCx} = ma_{CGx} \quad (1)$$

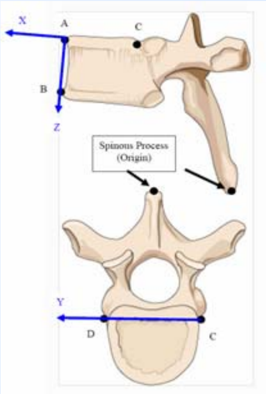
$$F_{OCy} = ma_{CGz} \quad (2)$$

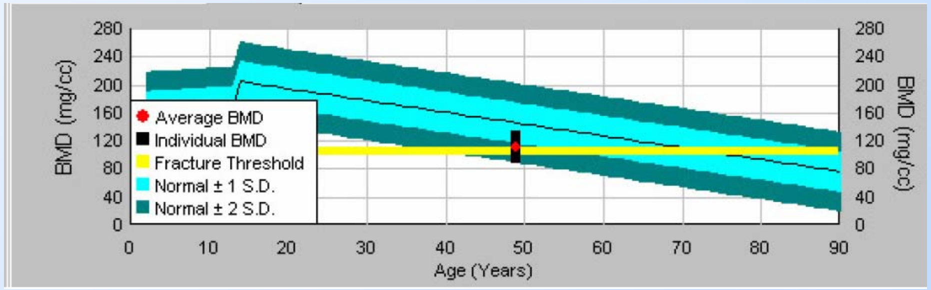
$$F_{OCz} = ma_{CGz} \quad (3)$$

$$M_{OCx} = I_{Anatomicx}\alpha_x - r_{OC} \times F_{OC} \quad (4)$$

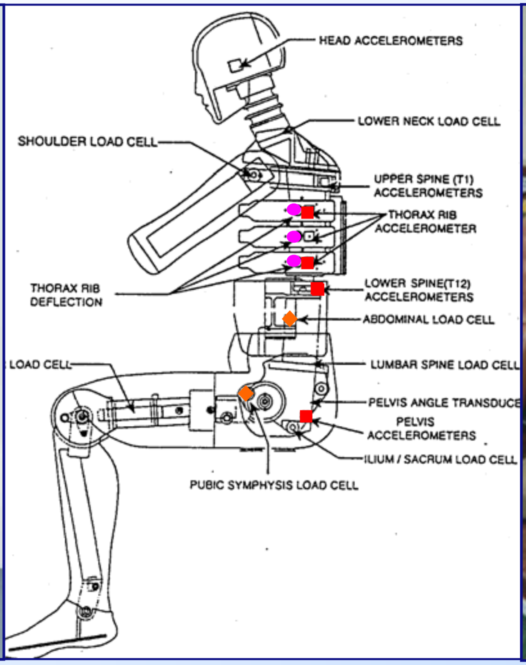
$$M_{OCy} = I_{Anatomicy}\alpha_y - r_{OC} \times F_{OC} \quad (5)$$

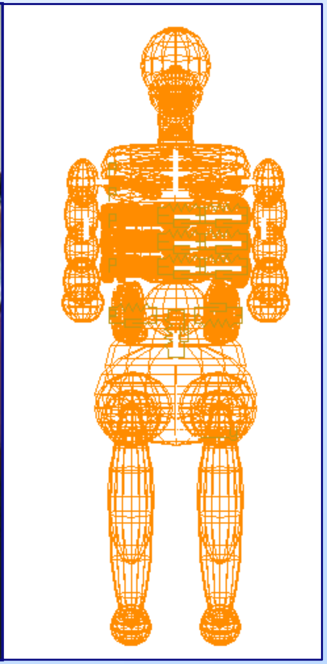
$$M_{OCz} = I_{Anatomicz}\alpha_z - r_{OC} \times F_{OC} \quad (6)$$





EuroSID and Instrumentation

Accelerometers at(■)

- Upper Rib
- Lower Rib
- Lower Spine
- Pelvis

Potentiometers at (●)

- Upper Rib
- Middle Rib
- Lower Rib

Load Cell at (◆)

- Pubic
- Lateral Abdomen

Test Condition

Test ID	% ΔV	Restraint	Seat
26 (WSU)	100	4-point	Rigid-wall
102	100	Full	Rigid
104	100	Full	Rigid
109	100	realistic	FAA
110	100	realistic	FAA
115	70	realistic	FAA
116	70	realistic	FAA

Specimen Data

Test ID	Age (years)	Height (m)	Weight (kg)
102	55	1.88	86
104	49	1.85	70
109	59	1.68	64
110	55	1.84	76
115	57	1.82	81
116	47	1.75	80

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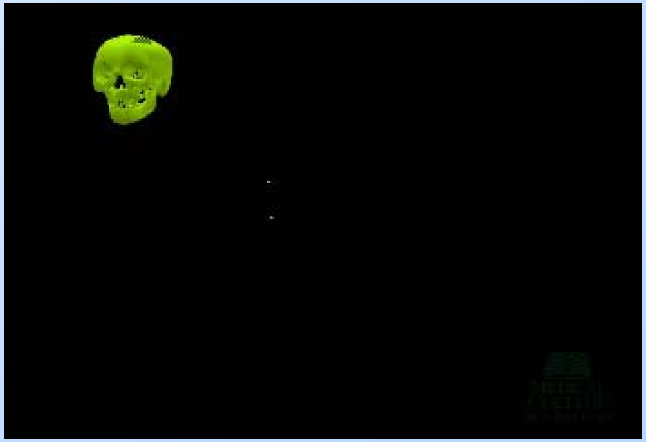
Subject Responses



MCW Injury Analysis

- Biomechanical engineering
- Clinical dx – palpation, etc.
- X-ray, CT, cryomicrotomy
- Pathological assessment
- Clinical interpretation
  - Pathologist, spine surgeon, …
- Scoring and mechanism

Pre-test X-rays FNSC102

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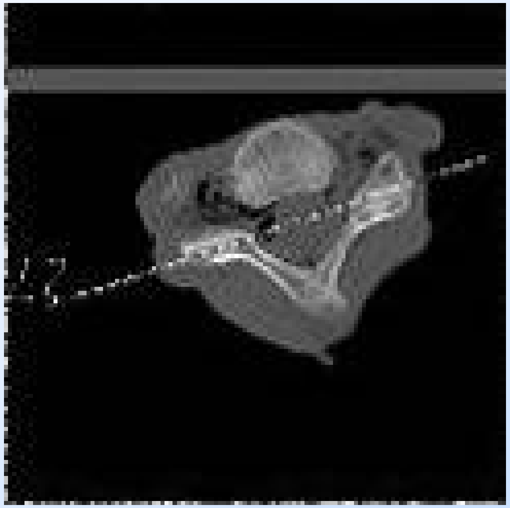
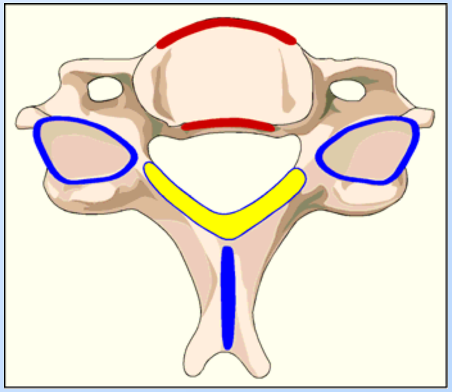
FNSC 102, rigid restraint

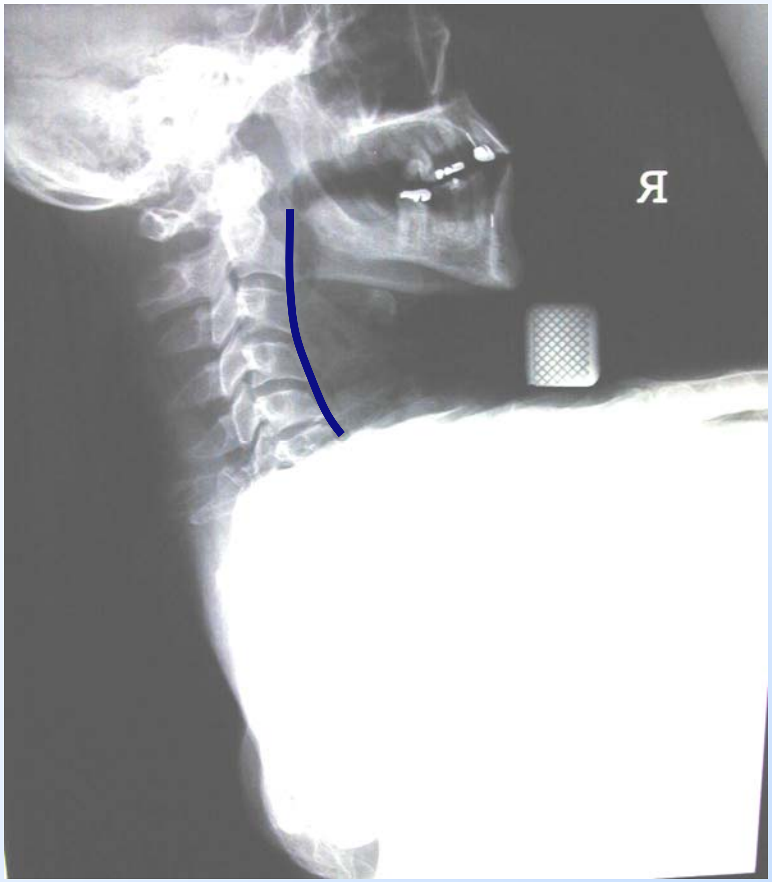
Widening facet joints below C4



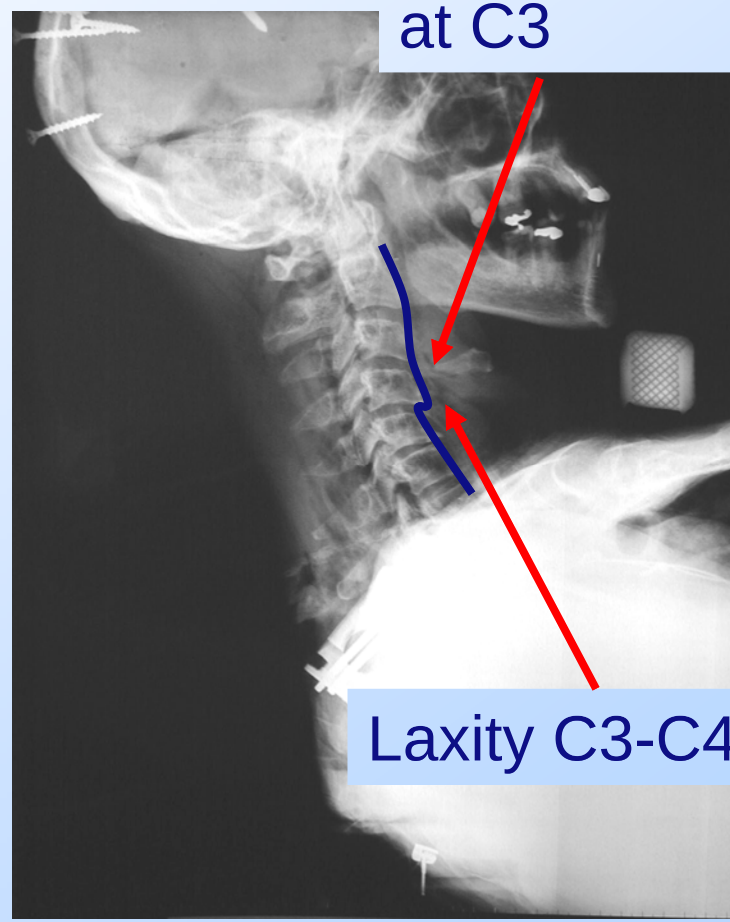


FNSC 104 rigid restraint

Pre

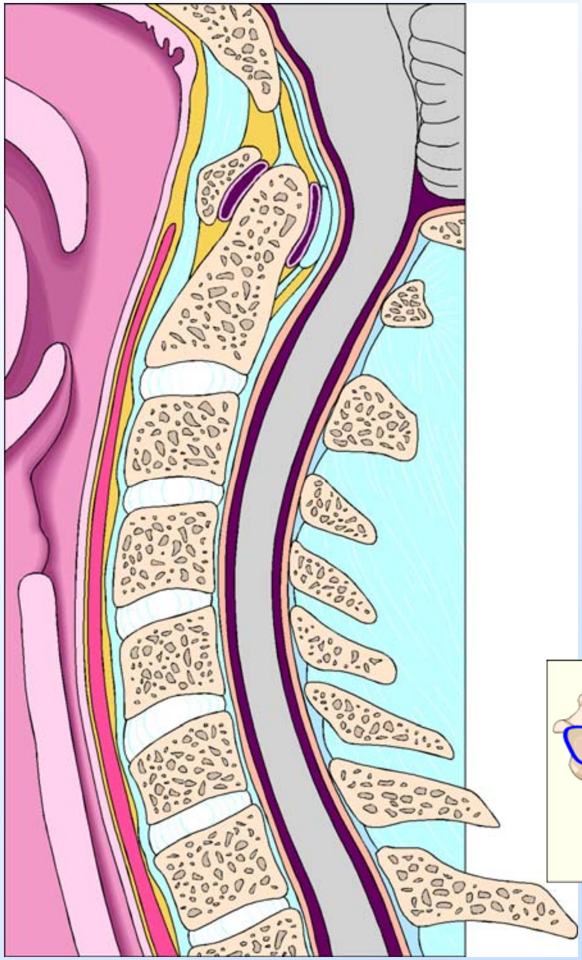


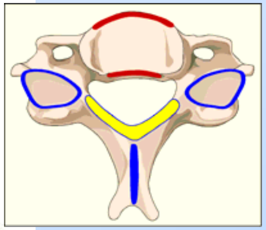
Post



FNSC 104 rigid restraint

No malignment





Cryomicrotome: ligament thinning

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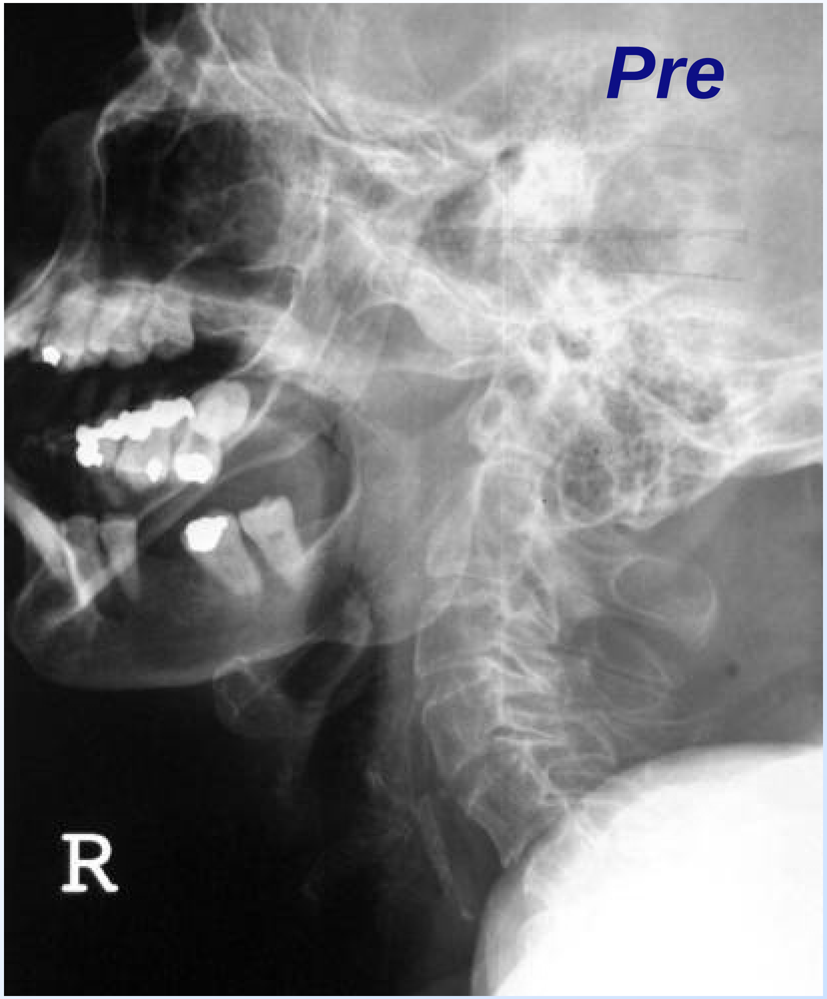
FNSC 109 3-point armrest

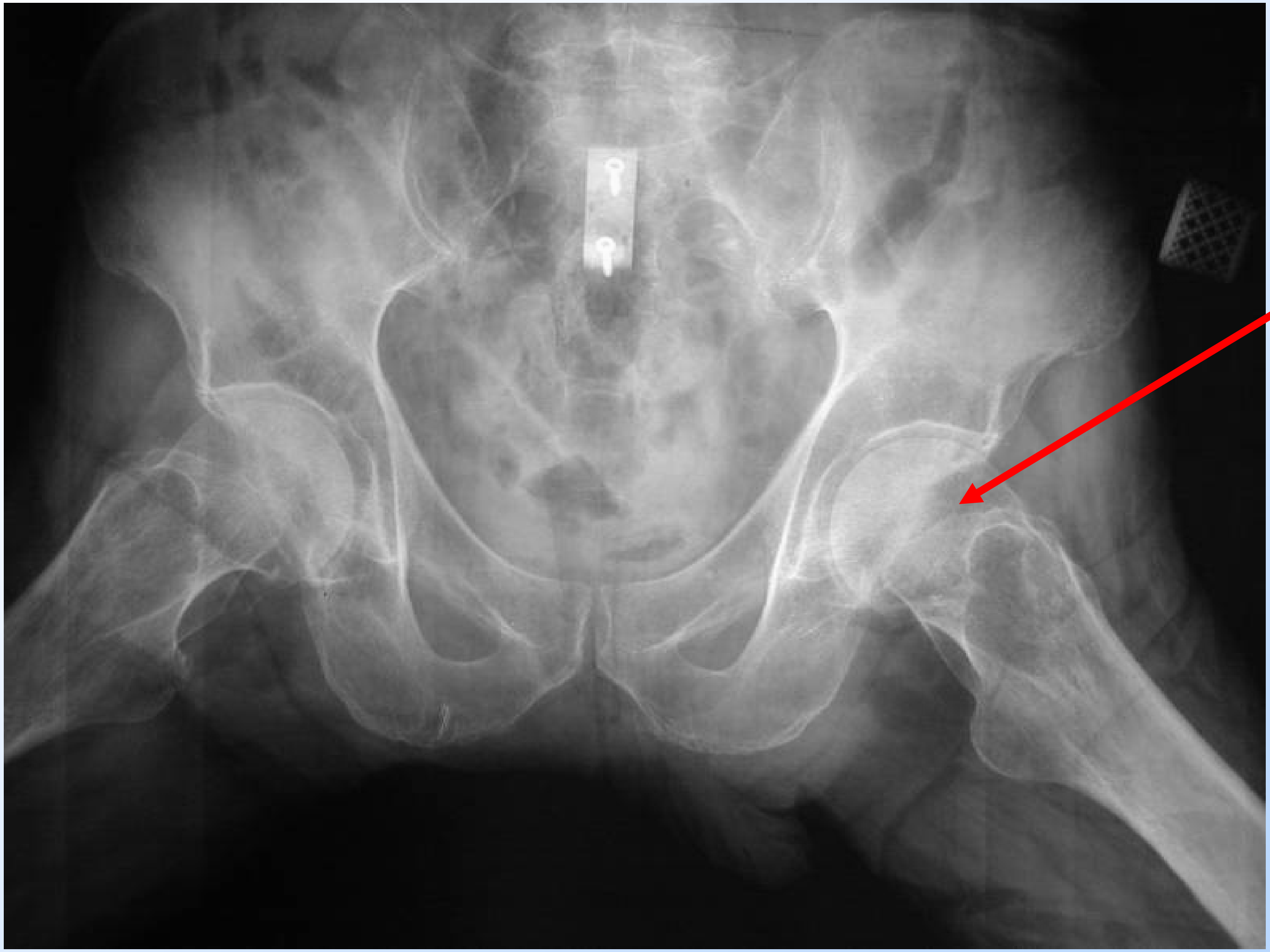


C1 pulled away
Anatomically AIS 3
Clinically AIS 5

C6-C7 dislocation AIS 3

Clinical AIS 4-5 due to instability

FNSC 109 3 point armrest Injuries other body parts



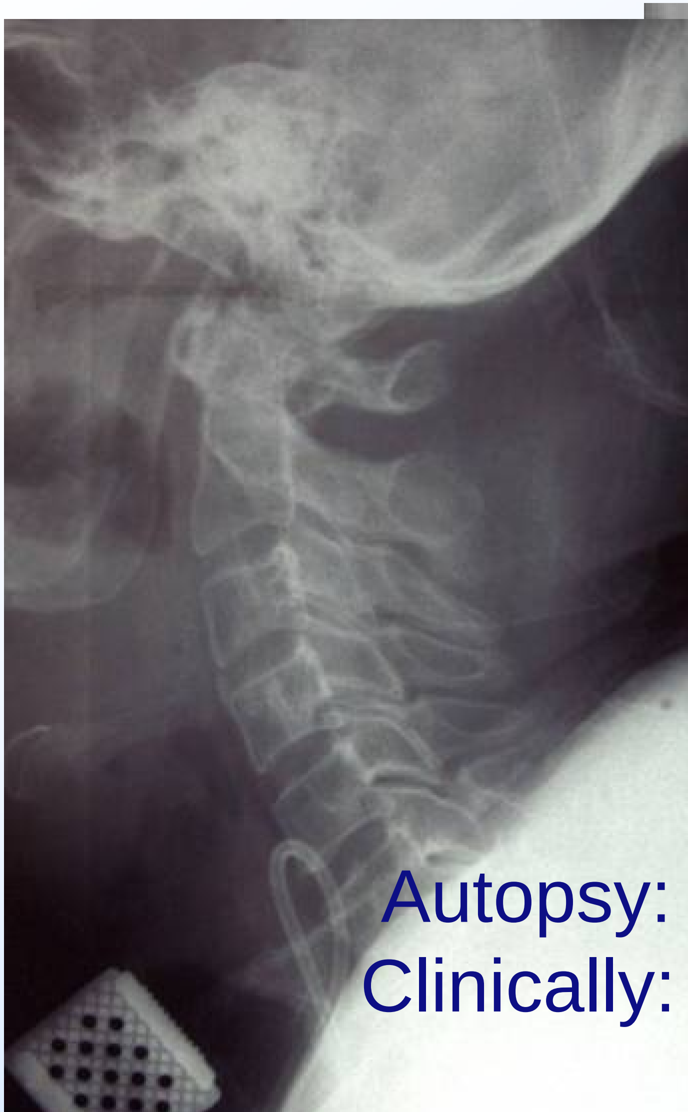
Femur fracture

&

carotid artery injury

AIS 3

FNSC 110 3 point arm rest

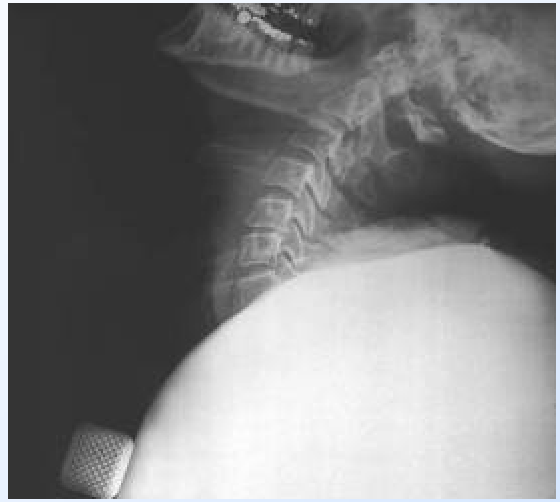


Autopsy: T1-T2 dislocated AIS 3,
Clinically: possible cord involvement, AIS 5

FNSC 110 3 point arm rest
Other body parts

- left distal (near knee) fracture,
  (AIS 3, clinical 3)
- clavicle fracture
  (AIS 2, clinical 2)
- flail chest
  (AIS 3, clinical 4)
- left shoulder dislocation
  - (AIS clinical 2).

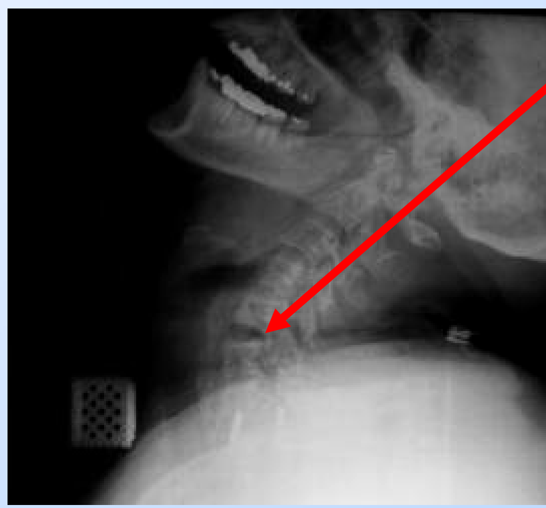
FNSC 115 3 point arm rest, 70 % pulse



Pre

subluxation C4 -C5

longitudinal ligament
and disc C5-C6 distraction



Post

AIS2 –AIS3

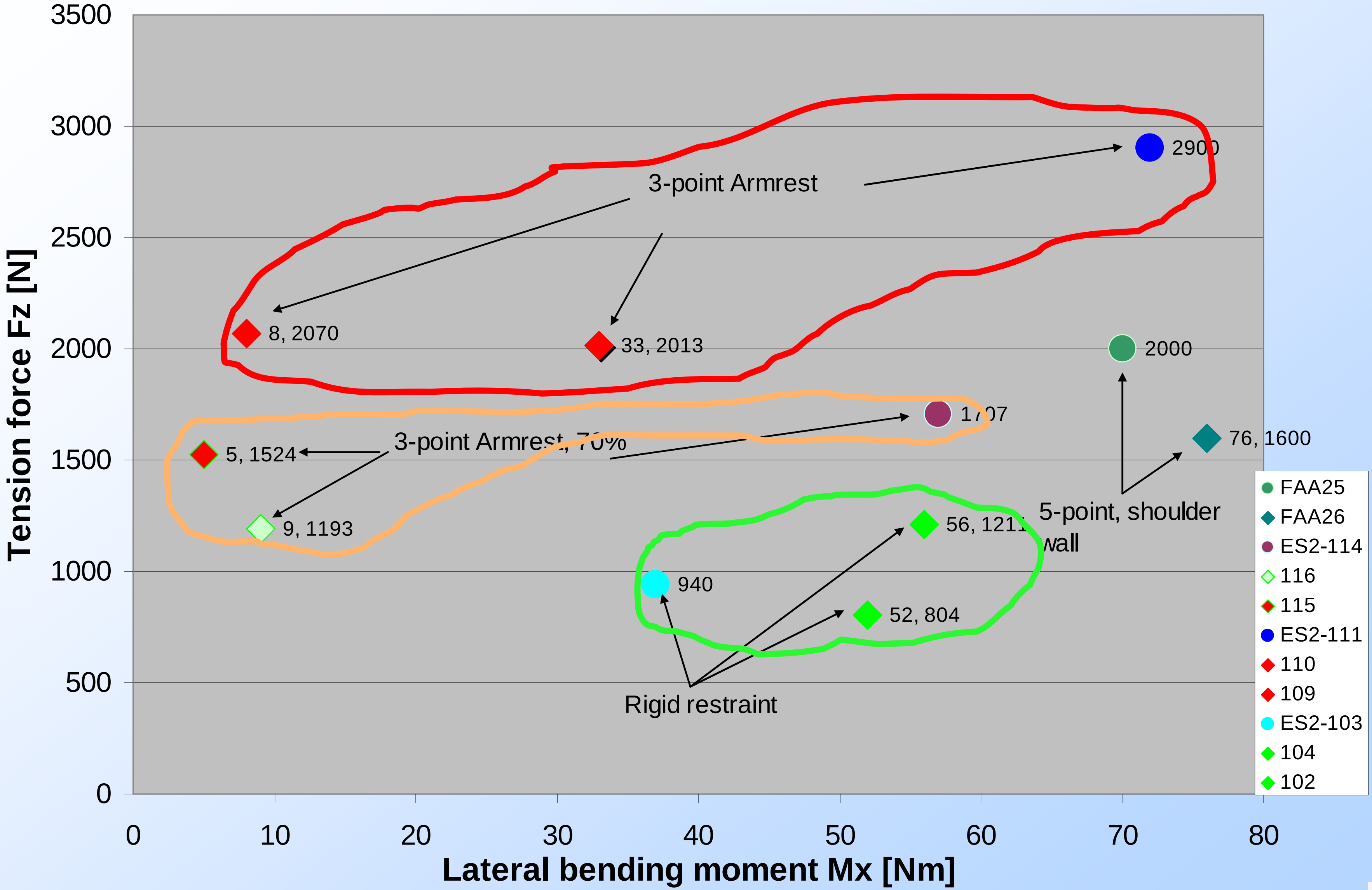
Summary injuries (1)

ID	Pathology
102	C4-T1 diastasis (widening)
103	C2-3 antreolisthesis (subluxation) C3-4 joint laxity, C6-7 ligament thinning
109	C2 fx/dislocation, C6-7 joint dislocation, carotid artery intimal tear, rib fractures, femur fracture
110	T1-2 fx/dislocation, clavicle fx, rib fractures, left shoulder dislocation, left distal femur fx
115	Ant long. ligament, disc C5-6, C4-5 subluxation
116	None

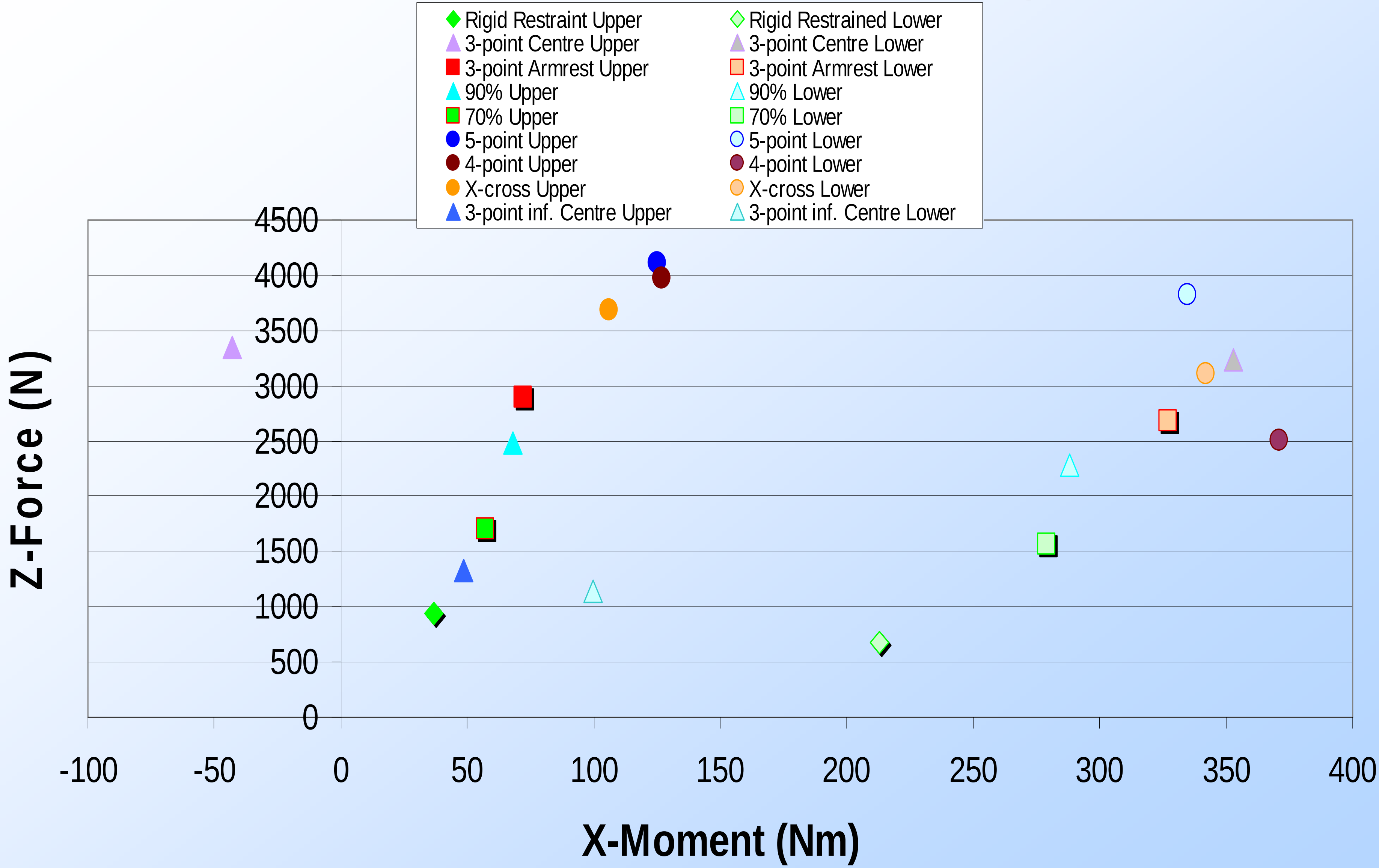
Summary injuries (2)

ID	% ΔV	AIS (neck)	Clinical (neck)	Other region	Brain (rad/s^2)
102	100	0	1	0	3230
103	100	0	1	0	-
109	100	3	5	4	2260
110	100	3	5	4	2550
115	70	2	3		1810
116	70	0			1750

OC max load Tension Lateral Bending



ES-2 Tension force - lateral bending moment



Conclusions Injury risk

- Serious neck injuries (AIS4+) are likely to happen in side facing seats under FAR25 crash pulse conditions, armrest and centre location;

- Additional injuries to be expected:
  - rib fracture
  - femur /hip fractures (armrest location)
  - cartoid intimal tear
- Near side wall locations will induce serious rib fractures but no gross neck injury

- Head angular accelerations are likely to cause up to one hour unconsciousness

Conclusions injury criteria-tolerance ES2

- Neck tension loads above 2000 N combined with a minimum lateral bending moment 20-40 Nm appears to be an AIS3+ tolerance limit in PMHS

- ES2 lower neck loads appear to be a good predictor for AIS3+ injuries, tension force ~1600-2000 N, bending moment ~ 280 Nm

- Keeping head-thorax aligned appears promising in reducing neck injury risk e.g. inflatable shoulder belt, seat integrated airbags

Discussion

- The injury patterns found in the back-to-back PMHS tests are almost identical indicating a most likely non-subject specific injury response. Although the number of specimens are statistically not significant;

- The C1-C2 injury is most unusual and seems to be caused by a different injury mechanism as the simultaneously found C6-T1 injuries;

- ES2 neck dynamics are not validated against humans, which is illustrated by the high bending moments found in ES 2 compared to the values in the PMHS;

Discussion

- Keeping head-thorax aligned appears promising in reducing neck injury risk e.g. inflatable shoulder belt, seat integrated airbags. However, timing, general application for all aircraft types etc. need to evaluated to ensure no additional injury risk induced by such systems;

- At the very moment a simulation study is done to find experimental conditions which generate a high bending moment with tension forces below ~ 1500 N to find a critical value for “bending only”


THANK YOU

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