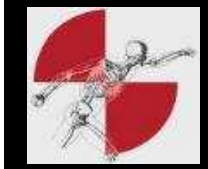

GTR 7 Informal Working Group
June 10, 2011
Washington DC

GTR7-07-06

NHTSA
www.nhtsa.gov

Injury Criteria Analysis Plan

Kevin Moorhouse, Ph.D.
NHTSA

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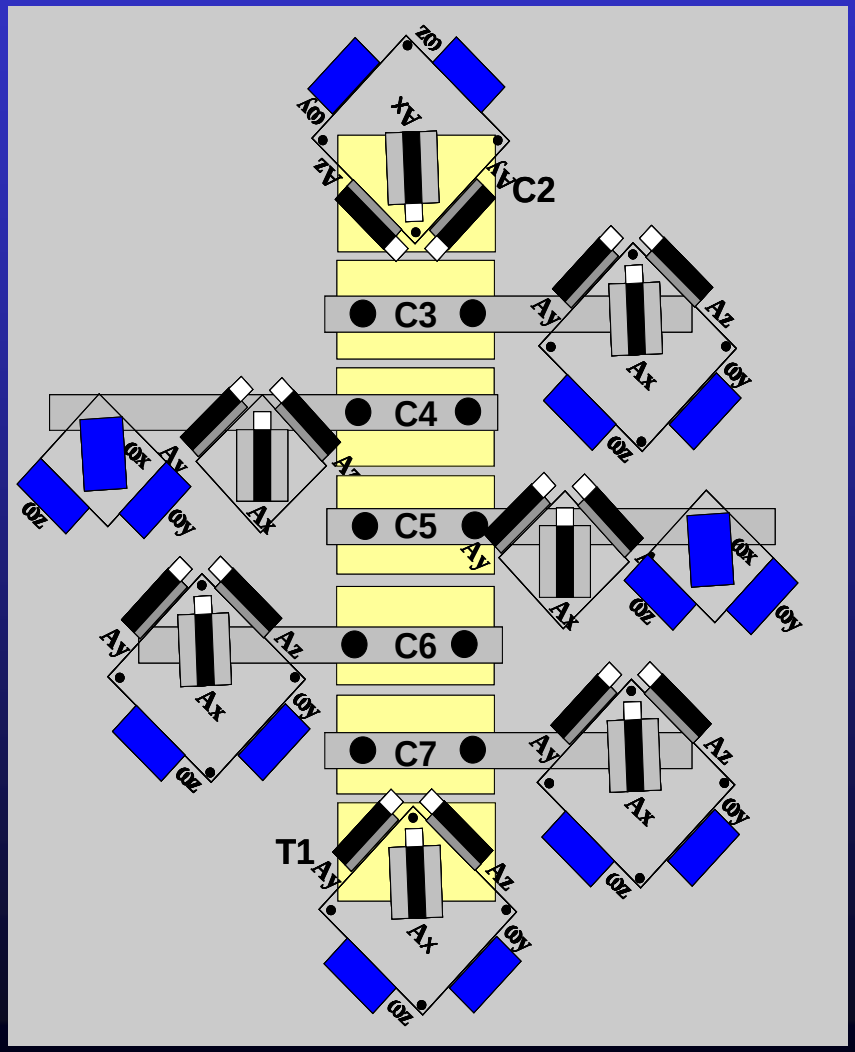
Rear Impact Research Objectives

- **Evaluate biofidelity of available RIDs (BioRID, RID3D, HyIII)**
  - Choose biofidelity test condition
  - Develop experimental seat for rear impact sled testing
  - Conduct sled tests
    - PMHS (Post-Mortem Human Subjects)
    - Dummies (BioRID II, RID3D, Hybrid III)
  - Assess biofidelity and repeatability of dummies
- **Investigate the mechanism of injury**
  - Develop and validate 3-D cervical spine kinematic instrumentation
  - Identify injurious kinematics
- **Choose appropriate injury criterion**
  - Assess efficacy of various ICs

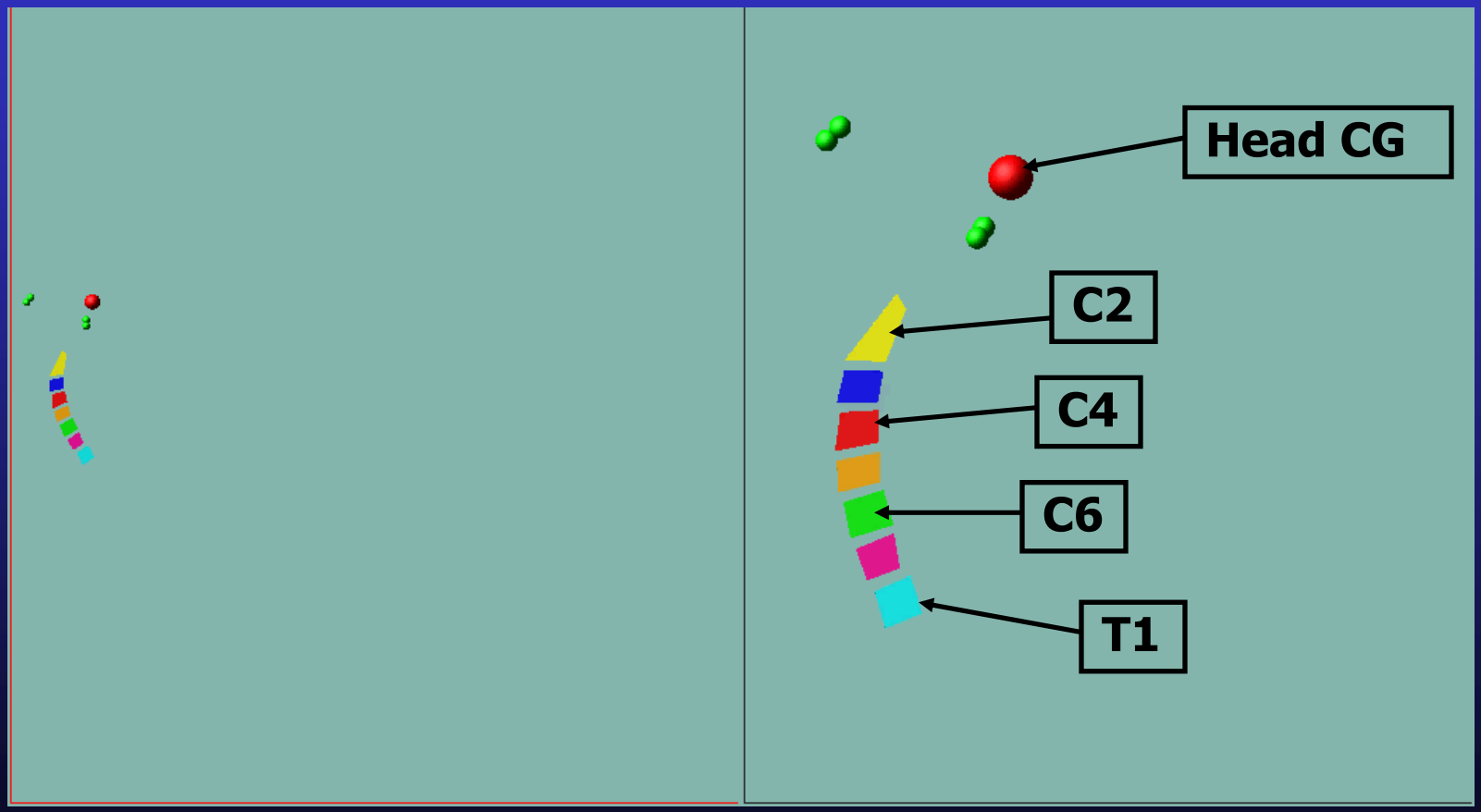
Rear Impact Injury Mechanism



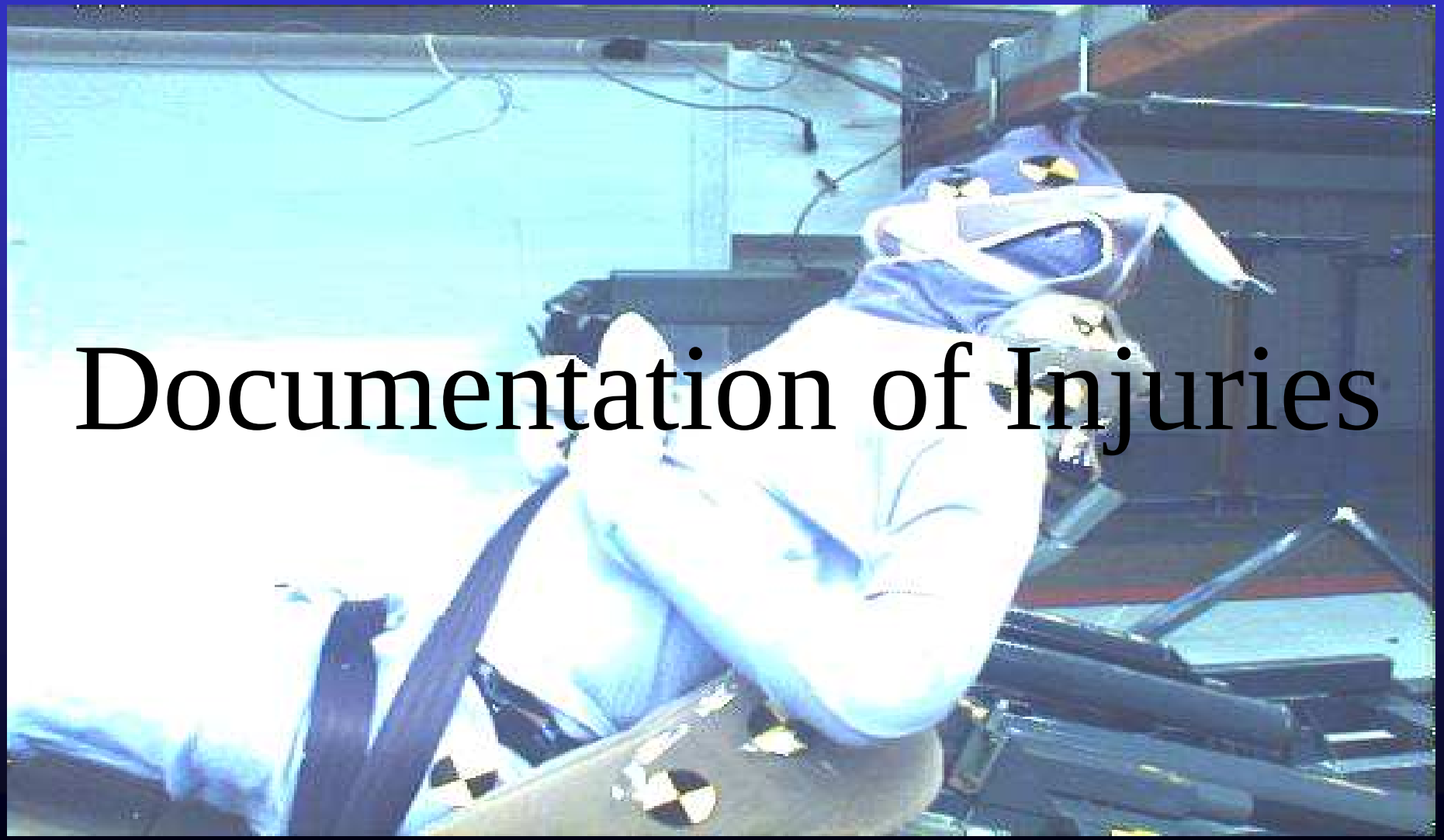
Cervical Kinematics (Generic Geometry)

Including seat/sled translation

T1 Fixed

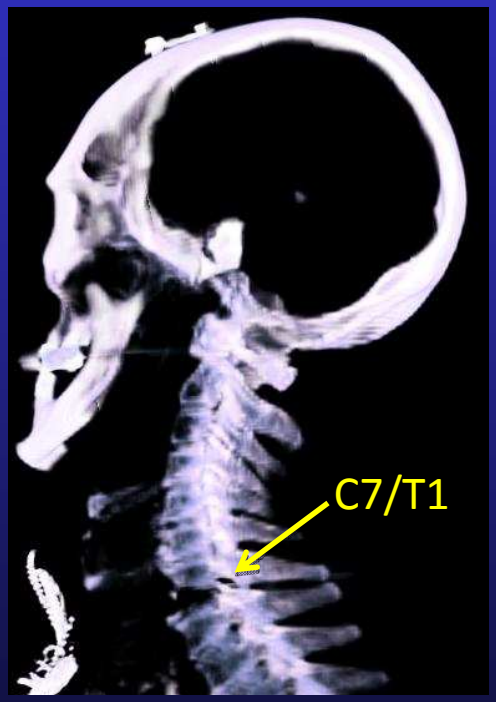


Documentation of Injuries

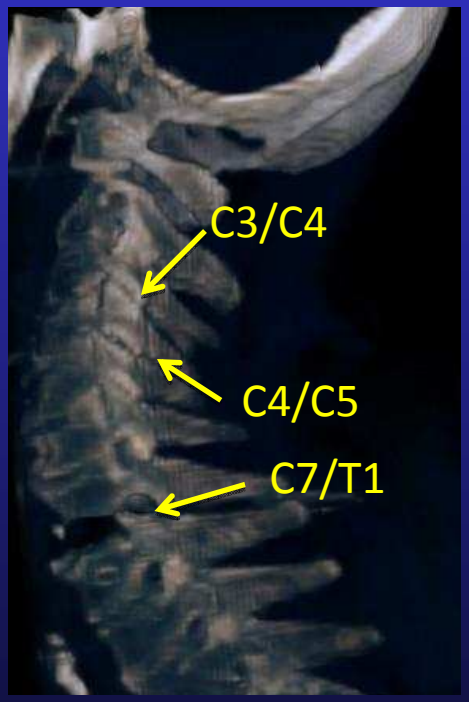


Injury Examples (Post-test CT)

<CT sagittal view>



<Disc rupture w fracture>



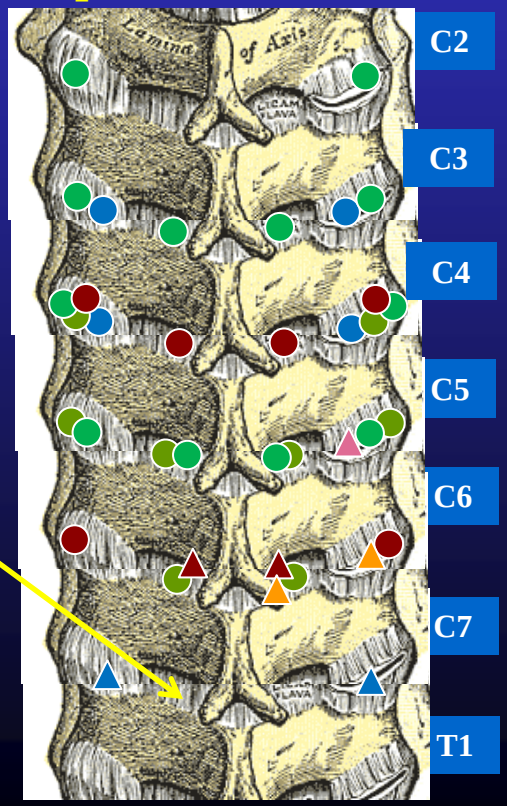
<Facet joint>

Documentation of Injuries

: disc rupture
: subluxation
: laceration (tear)

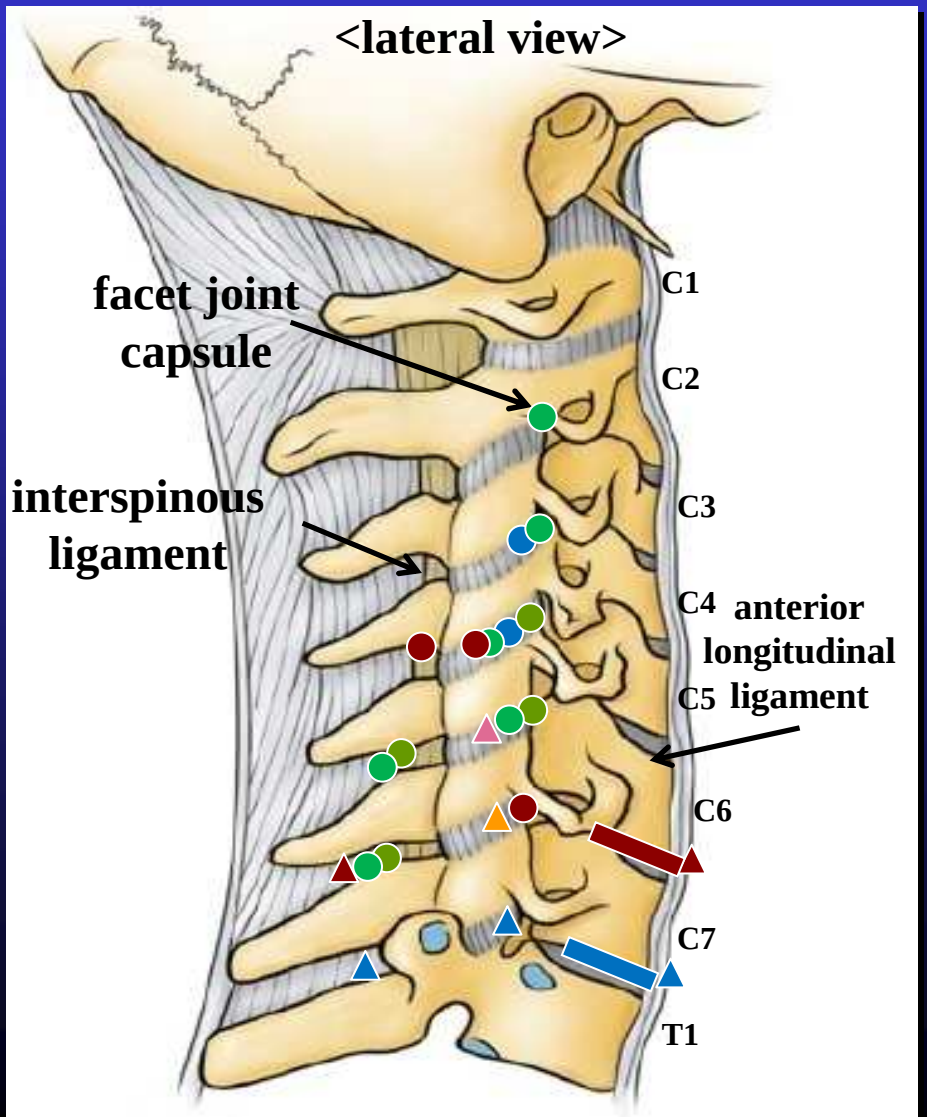
PMHS03
PMHS04
PMHS05
PMHS06
PMHS07
PMHS08

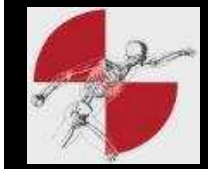
<posterior view>



ligamentum flavum

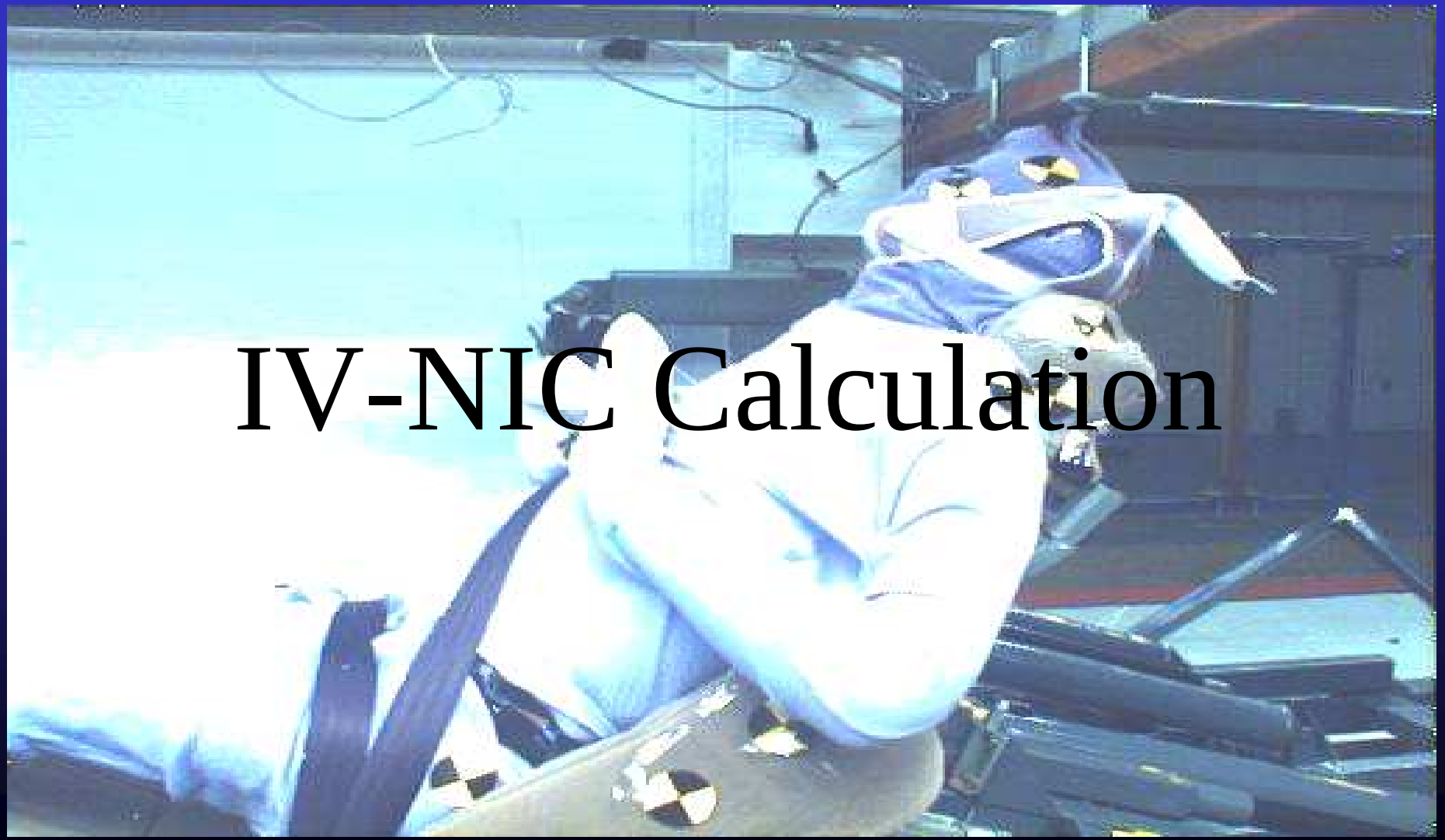
<lateral view>





Documentation of Injuries

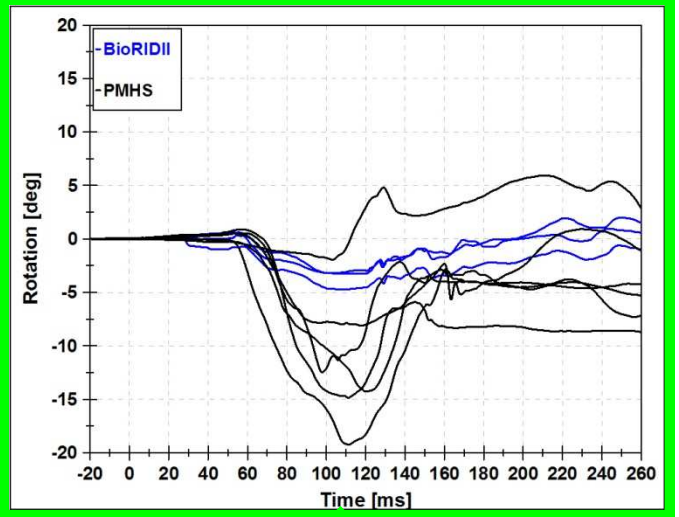
PMHS	#1	#2	#3	#4	#5	#6	#7	#8
C2/C3	No injury	No injury	No injury	No injury	Subluxation bilateral@ FJ (AIS3)	No injury	No injury	No injury
C3/C4	No injury	No injury	Subluxation bilateral@ FJ (AIS3)	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum (AIS1)	No injury	No injury	No injury
C4/C5	No injury	No injury	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig(AIS1)	No injury
C5/C6	No injury	No injury	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig(AIS1)	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig(AIS1)	Facet joint capsule tear on right side/ degeneration disc-mild subluxation (AIS1)	No injury	No injury
C6/C7	No injury	No injury	No injury	Subluxation bilateral@ ligamentum flavum (AIS1) & interspinous lig (AIS1)	Subluxation @ Interspinous lig (AIS1)	No injury	Anterior longitudinal lig tear (posterior intact), Severe Subluxation @ FJ on both sides, ligamentum flavum tear, Disc injury w ruptured (AIS3), Interspinous lig tear (AIS1)	Seperation of degenerative disc, ligamentum flavum tear @ right side close to spinous process, facet joint capsule tear on the right side (AIS1)
C7/T1	No injury	No injury	Anterior longitudinal lig. tear (posterior intact), FJ capsule tear on both sides, ligamentum flavum tear on left side, Disc rupture w fracture (AIS3), Interspinous lig. tear (AIS1)	Seperation of degenerative disc	No injury	No injury	No injury	No injury



IV-NIC Calculation

IV-NIC Calculation

Physiological Relative Rotation (Panjabi, 2005)		
	Physiological Flexion(-)/Extension(+)	Max values Flexion/Extension
C2/C3	-5.4(2.3)/+3.6(1.8)	-7.7/+5.4
C3/C4	-5.7(2.7)/+4.2(1.9)	-8.4/+6.1
C4/C5	-7.6(2.7)/+6.7(2.9)	-10.3/+9.6
C5/C6	-7.7(4.5)/+6.5(3.5)	-12.2/+10.0
C6/C7	-8.0(1.6)/+7.1(2.2)	-9.6/+9.3
C7/T1	-3.7(1.6)/+3.1(1.1)	-5.3/+4.2

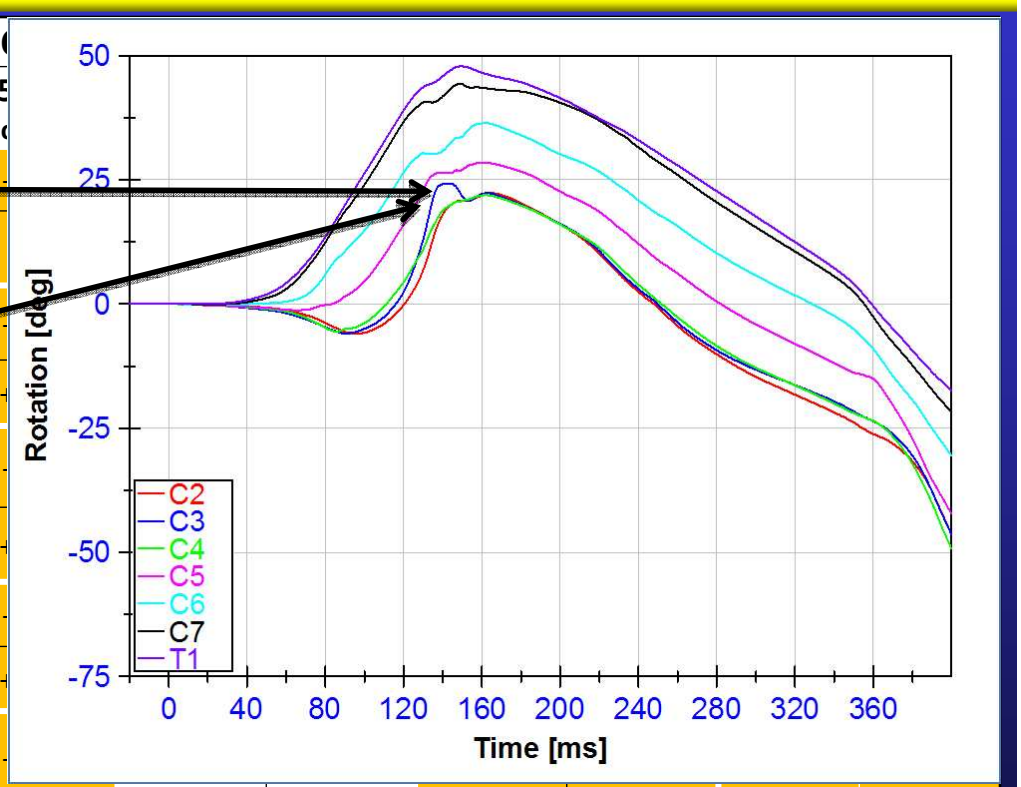


$$IV - NIC = \frac{\Theta_{trauma}}{\Theta_{physiological}}$$

IV-NIC Results

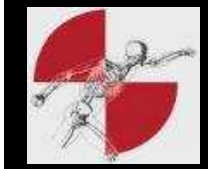
IV-NIC

	PMHS03		PMHS04		PMHS05							
	Low	Moderate	Low	Moderate	Low	Mo						
C2/C3	-0.85	-0.79	-1.06**	-0.87	-1.84							
	+0.26	+0.67	+0.17	+0.26	0.46							
C3/C4	-1.18	-1.07	-0.27	-0.41	-1.59							
	+0.48	+1.05	+1.02**	+0.51	+0.05							
C4/C5	-1.47	-1.87	-1.17	-1.40	-1.37							
	+0.01	+0.01	+0.00	+0.00	+0.00							
C5/C6	-0.56	-0.40	-0.96	-1.00	-1.08							
	+0.27	+0.30	+0.00	+0.01	+0.01							
C6/C7	-0.33	-0.54	-1.15	-1.33	-0.84							
	+0.05	+0.68	+0.00	+0.00	+0.44	+0.20	+0.05	+0.47	+0.06	+1.69	+0.00	+0.35
C7/T1	-0.61	-0.73	-0.80	-0.68	-0.69	-0.56	-0.48	-0.32	-0.73	-0.76	-0.89	-1.16
	+0.19	+3.79	+0.00	+1.93	+0.81	+0.90	+0.10	+0.96	+0.84	+1.86	0.05	1.54



IV-NIC Results

IV-NIC (Rotation)												
	PMHS03		PMHS04		PMHS05		PMHS06		PMHS07		PMHS08	
	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate
C2/C3	-0.85	-0.79	-1.06**	-0.87	-1.84	-1.52	-0.40	-0.49	-0.90	-0.99	-0.34	-0.45
	+0.26	+0.67	+0.17	+0.26	0.46	0.86	0.23	+0.41	+0.21	+0.30	+0.04	+0.19
C3/C4	-1.18	-1.07	-0.27	-0.41	-1.59	-1.54	-0.09	-0.07	-0.87	-1.00	-0.68	-0.90
	+0.48	+1.05	+1.02**	+0.51	+0.05	+0.18	+0.54	+0.94	+0.15	+0.10	+0.19	+0.28
C4/C5	-1.47	-1.87	-1.17	-1.40	-1.37	-1.16	-0.13	-0.19	-1.48	-1.44	-0.54	-0.79
	+0.01	+0.01	+0.00	+0.00	+0.00	+0.05	+0.39	+0.62	+0.05	+0.09	+0.05	+0.10
C5/C6	-0.56	-0.40	-0.96	-1.00	-1.08	-1.19	-0.09	-0.09	-0.85	-0.91	-0.69	-0.69
	+0.27	+0.30	+0.00	+0.01	+0.01	+0.00	+0.36	+1.00	+0.00	0.00	+0.00	+0.50
C6/C7	-0.33	-0.54	-1.15	-1.33	-0.84	-1.20	-0.16	-0.16	-0.72	-0.73	-0.79	-1.05
	+0.05	+0.68	+0.00	+0.00	+0.44	+0.20	+0.05	+0.47	+0.06	+1.69	+0.00	+0.35
C7/T1	-0.61	-0.73	-0.80	-0.68	-0.69	-0.56	-0.48	-0.32	-0.73	-0.76	-0.89	-1.16
	+0.19	+3.79	+0.00	+1.93	+0.81	+0.90	+0.10	+0.96	+0.84	+1.86	0.05	1.54



Qualitative Correlation - IV-NIC and Injuries

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Injury Documentation						
	PMHS03	**PMHS04**	**PMHS05**	**PMHS06**	**PMHS07**	**PMHS08**
C2/C3	No injury	No injury	Subluxation bilateral@ FJ (AIS3)	No injury	No injury	No injury
C3/C4	Subluxation bilateral@ FJ (AIS3)	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum	No injury	No injury	No injury
C4/C5	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig.	No injury
C5/C6	No injury	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig.	Subluxation bilateral@ FJ (AIS3) and ligametum flavum/interspinous lig.	Facet joint capsule tear on right side/ degeneration disc-mild subluxation	No injury	No injury
C6/C7	No injury	Subluxation bilateral@ ligamentum flavum & interspinous lig.	Subluxation @ Interspinous lig	No injury	Anterior longitudinal lig. tear (posterior intact), Severe Subluxation @ FJ on both sides, ligamentum flavum tear, Disc injury w ruptured (AIS3), Interspinous lig. tear (AIS1)	Seperation of degenerative disc, ligamentum flavum tear @ right side close to spinous process, facet joint capsule tear on the right side
C7/T1	Anterior longitudinal lig. tear (posterior intact), FJ capsule tear on both sides, ligamentum flavum tear on left side, Disc injury w ruptured (AIS3), Interspinous lig. tear (AIS1)	Seperation of degenerative disc	No injury	No injury	No injury	No injury

Qualitative Correlation - IV-NIC and Injuries

IV-NIC (Rotation)												
	PMHS03		PMHS04		PMHS05		PMHS06		PMHS07		PMHS08	
	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate
C2/C3	-0.85	-0.79	-1.06**	-0.87	-1.84	-1.52	-0.40	-0.49	-0.90	-0.99	-0.34	-0.45
	+0.26	+0.67	+0.17	+0.26	0.46	0.86	0.23	+0.41	+0.21	+0.30	+0.04	+0.19
C3/C4	-1.18	-1.07	-0.27	-0.41	-1.59	-1.54	-0.09	-0.07	-0.87	-1.00	-0.68	-0.90
	+0.48	+1.05	+1.02**	+0.51	+0.05	+0.18	+0.54	+0.94	+0.15	+0.10	+0.19	+0.28
C4/C5	-1.47	-1.87	-1.17	-1.40	-1.37	-1.16	-0.13	-0.19	-1.48	-1.44	-0.54	-0.79
	+0.01	+0.01	+0.00	+0.00	+0.00	+0.05	+0.39	+0.62	+0.05	+0.09	+0.05	+0.10
C5/C6	-0.56	-0.40	-0.96	-1.00	-1.08	-1.19	-0.09	-0.09	-0.85	-0.91	-0.69	-0.69
	+0.27	+0.30	+0.00	+0.01	+0.01	+0.00	+0.36	+1.00	+0.00	0.00	+0.00	+0.50
C6/C7	-0.33	-0.54	-1.15	-1.33	-0.84	-1.20	-0.16	-0.16	-0.72	-0.73	-0.79	-1.05
	+0.05	+0.68	+0.00	+0.00	+0.44	+0.20	+0.05	+0.47	+0.06	+1.69	+0.00	+0.35
C7/T1	-0.61	-0.73	-0.80	-0.68	-0.69	-0.56	-0.48	-0.32	-0.73	-0.76	-0.89	-1.16
	+0.19	+3.79	+0.00	+1.93	+0.81	+0.90	+0.10	+0.96	+0.84	+1.86	0.05	1.54

Injury Criteria Analysis Plan

Injury Analysis Plan

- **Analogous process for displacement**

$$IV-NIC_{Shear,i}=\frac{Disp_{trauma,i}}{Disp_{physiological,i}}$$

$$IV-NIC_{Axial,i}=\frac{Disp_{trauma,i}}{Disp_{physiological,i}}$$

Correlation?

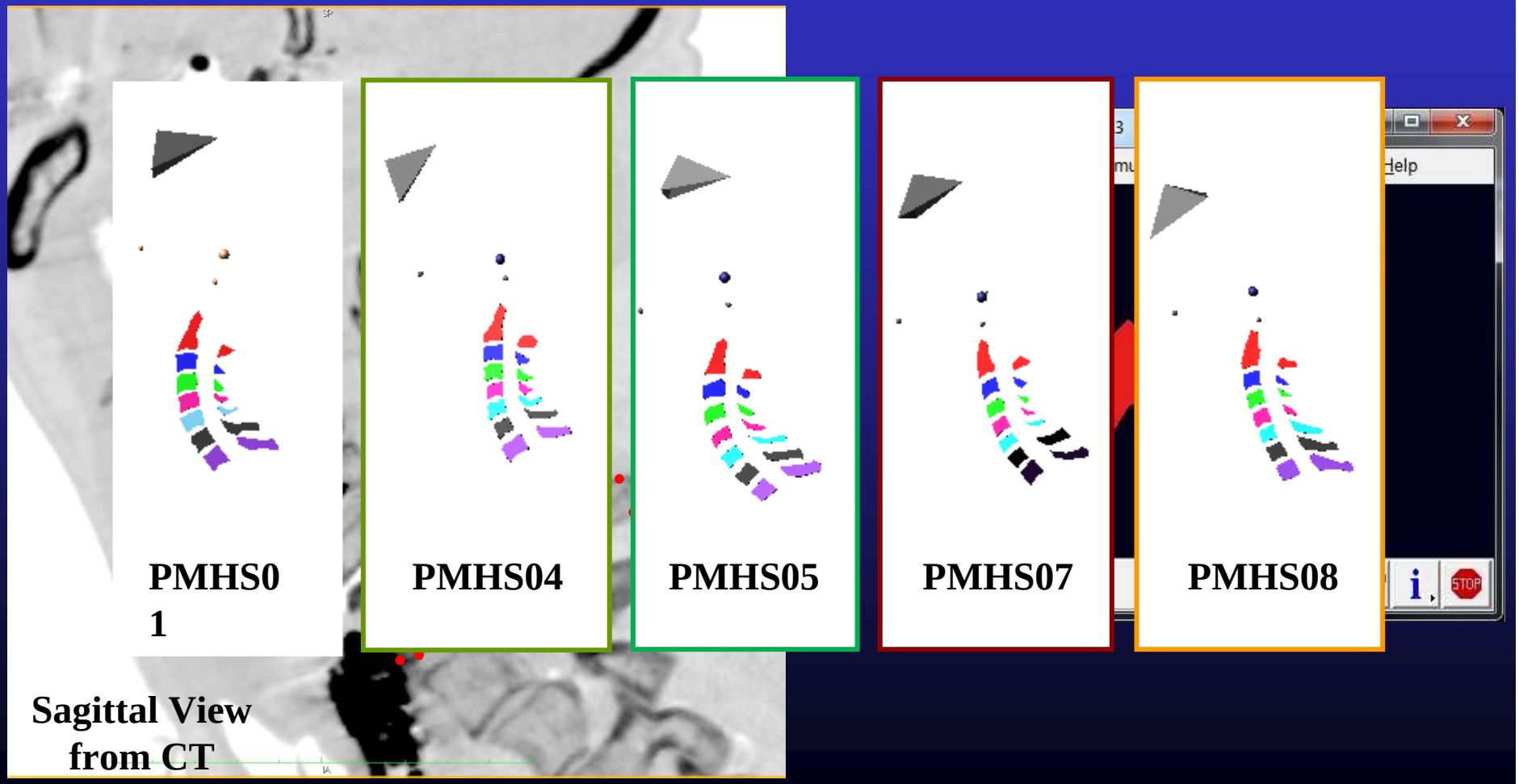
Yes

Possibly linear combination of translational and rotational IV-NIC

$$IV-NIC_{Comb,i}=IV-NIC_{i}+IV-NIC_{Shear,i}+IV-NIC_{Axial,i}$$

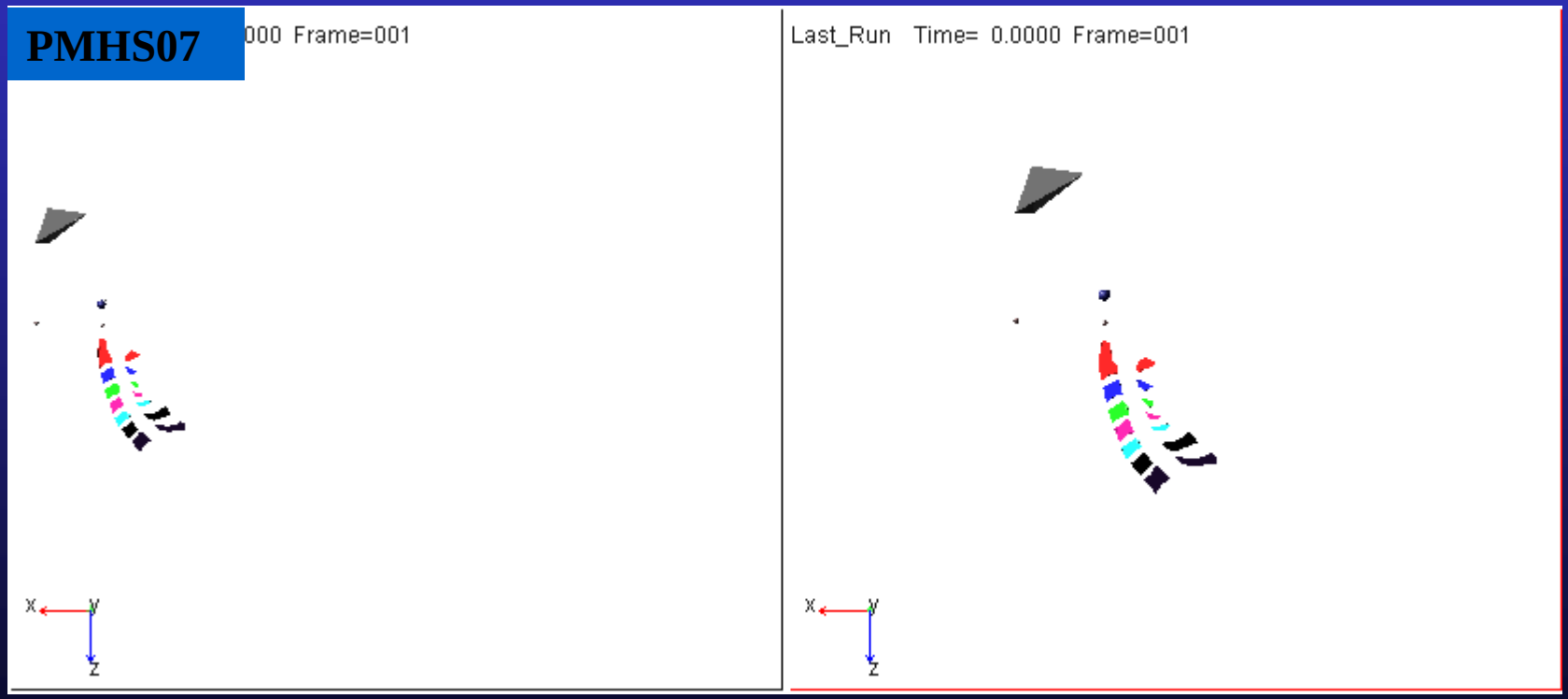
Cervical Kinematics (detailed geometry)

- **Detailed cervical model**



Cervical Kinematics (detailed geometry)

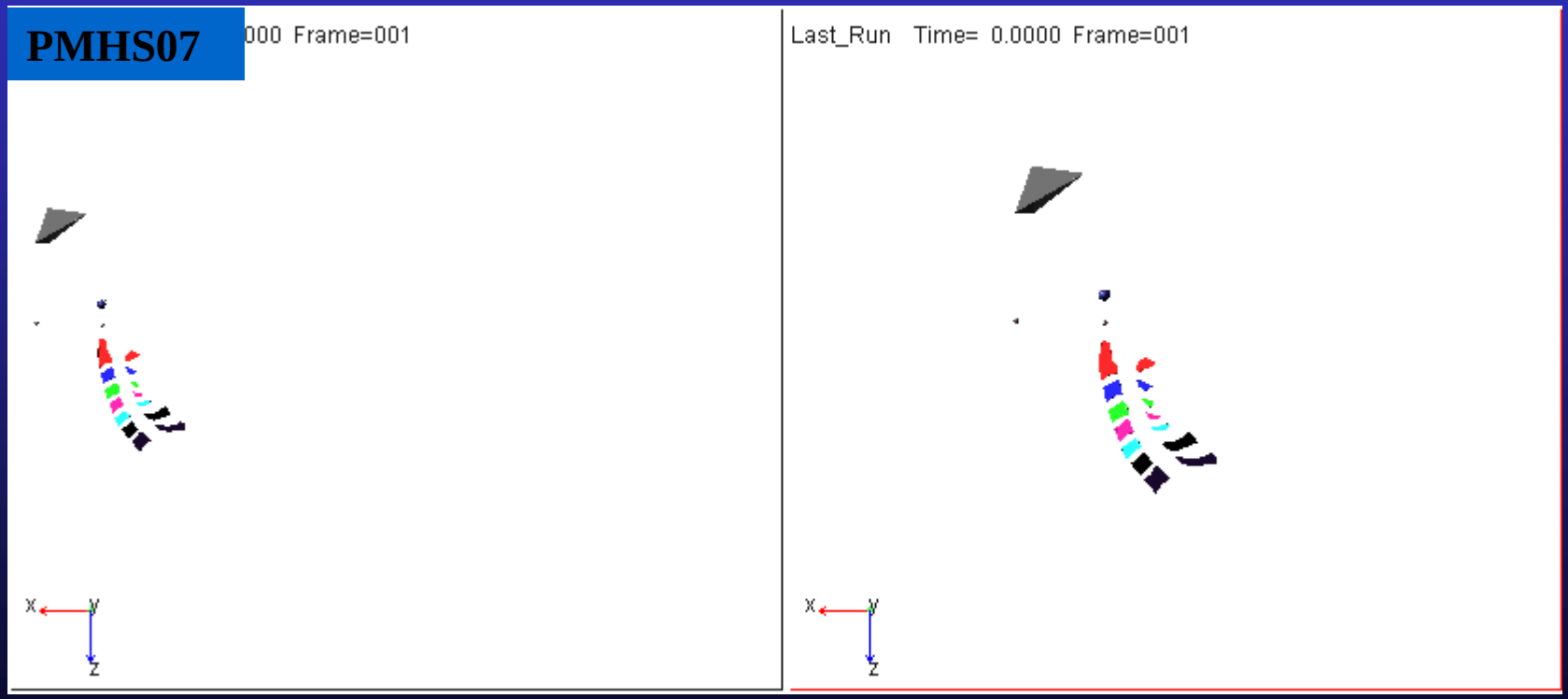
- **Detailed cervical model**
  - able to calculate strain and strain rate between vertebrae



correlation between strain/strain rate and injuries at each level

Cervical Kinematics (detailed geometry)

- **Detailed cervical model**
  - able to calculate strain and strain rate between vertebrae



correlation between strain/strain rate and injuries at each level

Injury Analysis Plan

- **Correlation between injury / IV-NIC and existing injury criteria**

Injuries

$IV-NIC_i$

$IV-NIC_{Axial,i}$

$IV-NIC_{Shear,i}$

$IV-NIC_{Comb,i}$

Strain

Strain Rate

Correlation?

Yes

$$NIC = 0.2 \times a_{rel} + v_{rel}^{2}$$

$$N_{km} = \frac{F_x}{F_{\text{int}}} + \frac{M_y}{M_{\text{int}}}$$

NDC, Nij
Head-to-T1 Rotation
Upper/Lower Fx, Fz, My
T1G
Rebound V
Any physical parameters

$$LNL-index(t) = \left| \frac{\sqrt{My_{lower}(t)^2 + Mx_{lower}(t)^2}}{C_{moment}} \right| + \left| \frac{\sqrt{Fx_{lower}(t)^2 + Fy_{lower}(t)^2}}{C_{shear}} \right| + \left| \frac{Fz_{lower}(t)}{C_{tension}} \right|$$

Select correlated variables for injury risk curves (IARV) for PMHS

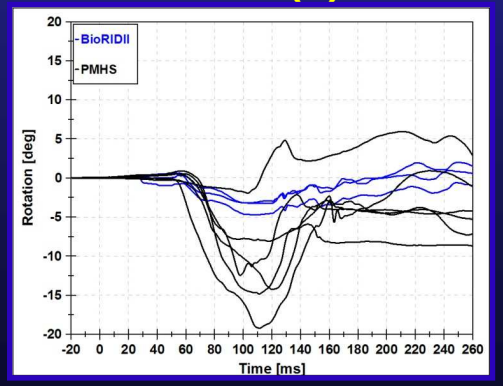
Injury Analysis Plan

PMHS and BioRID II in identical test conditions

<PMHS>

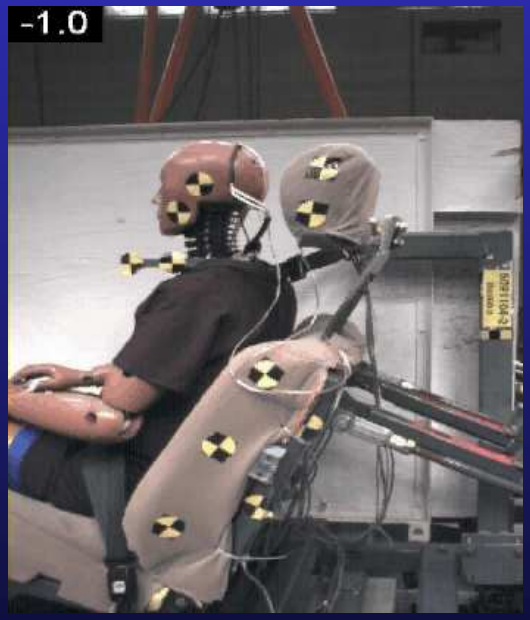
Scaling technique for IARV(s)

Transfer function for IARV(s)



<Intervertebral rotation @ C4/C5>

<BioRIDII>



Injury Criteria Analysis Plan

- **Analysis completed to date**
  - Incorporated subject-specific vertebral geometry
  - Documented all injuries/damage
  - Calculated corresponding IV-NIC values
  - Demonstrated qualitative correlation between injuries and IV-NIC

Injury Criteria Analysis Plan

- **Analysis plan for next meeting**
  - Calculate IV-NIC$_{shear}$ and IV-NIC$_{axial}$
  - Calculate intervertebral strain and strain rate
  - Quantitative correlation
    - Physical injuries ←→ IV-NIC criteria ← → strain /strain rate
    - All of the above ← → Rear impact injury criteria
  - Develop injury risk curves for PMHS using appropriate IARV
  - PMHS IARV / risk curves → BioRID II IARV / risk curves

Thanks for your attention

Questions?

PMHS Test Matrix

7 PMHS at each speed

PMHS		
Test Number	Test Speed	Driver Side Dummy
1	M	PMHS 01
2	L (4)	PMHS 02
3	L/M	PMHS 03
4	L/M	PMHS 04
5	L/M	PMHS 05
6	L/M	PMHS 06
7	L/M	PMHS 07
8	L/M	PMHS 08