International Rear Impact Dummy Harmonization Meeting

November 6, 2009

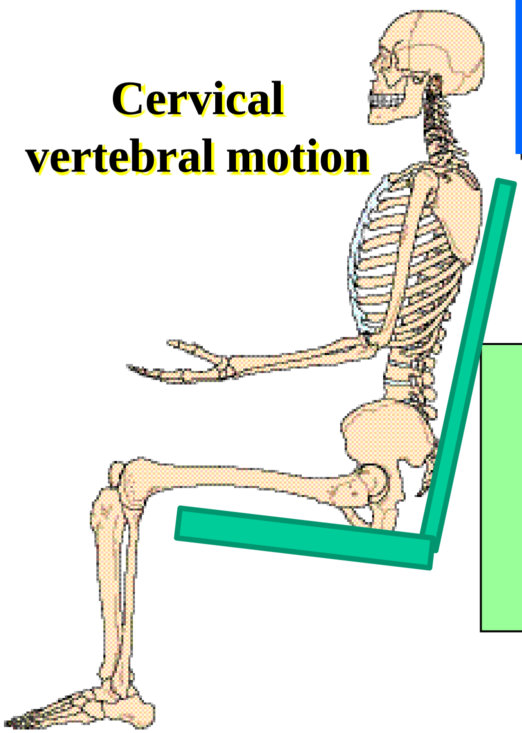
U.S Department of Transportation, Washington, DC

Minor neck injury

Not only neck region

Focus on whole spine motion

Cervical vertebral motion



S-shape motion
(Vertical, Horizontal Motion)

Spine straightening
Ramping-up

Current evaluation method
Not enough
focuses only on upper neck
1) Angle
2) Moment, axial force

Neck angle

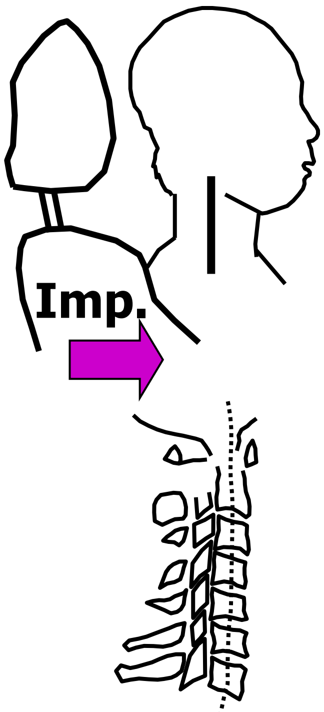
Additional parameters

Lower neck
1) Axial, shear forces
2) Neck angle wrt T1

Needs to consider proper neck injury parameters

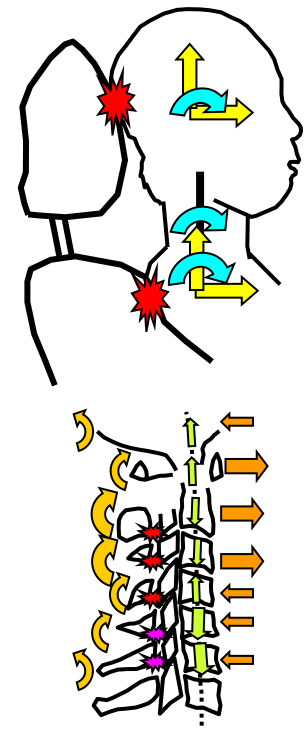
Proper minor neck injury parameters in rear impact

Necessary Method for Neck Injury Evaluation



◆Impact loading to the neck is dependent on the interaction patterns between the H/N/T and the seat with HR.

◆To assess the motion of cervical vertebrae caused by impact loading and the interaction between the H/N/T and the seat with HR.



Evaluation Parameters and Criteria for the Reduction of Minor Neck Injuries during Rear-end Impacts

Human Volunteer Experiments and Accident Reconstruction Using Human FE Model Simulations

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Tokyo Institute of Technology

Koji Kaneoka
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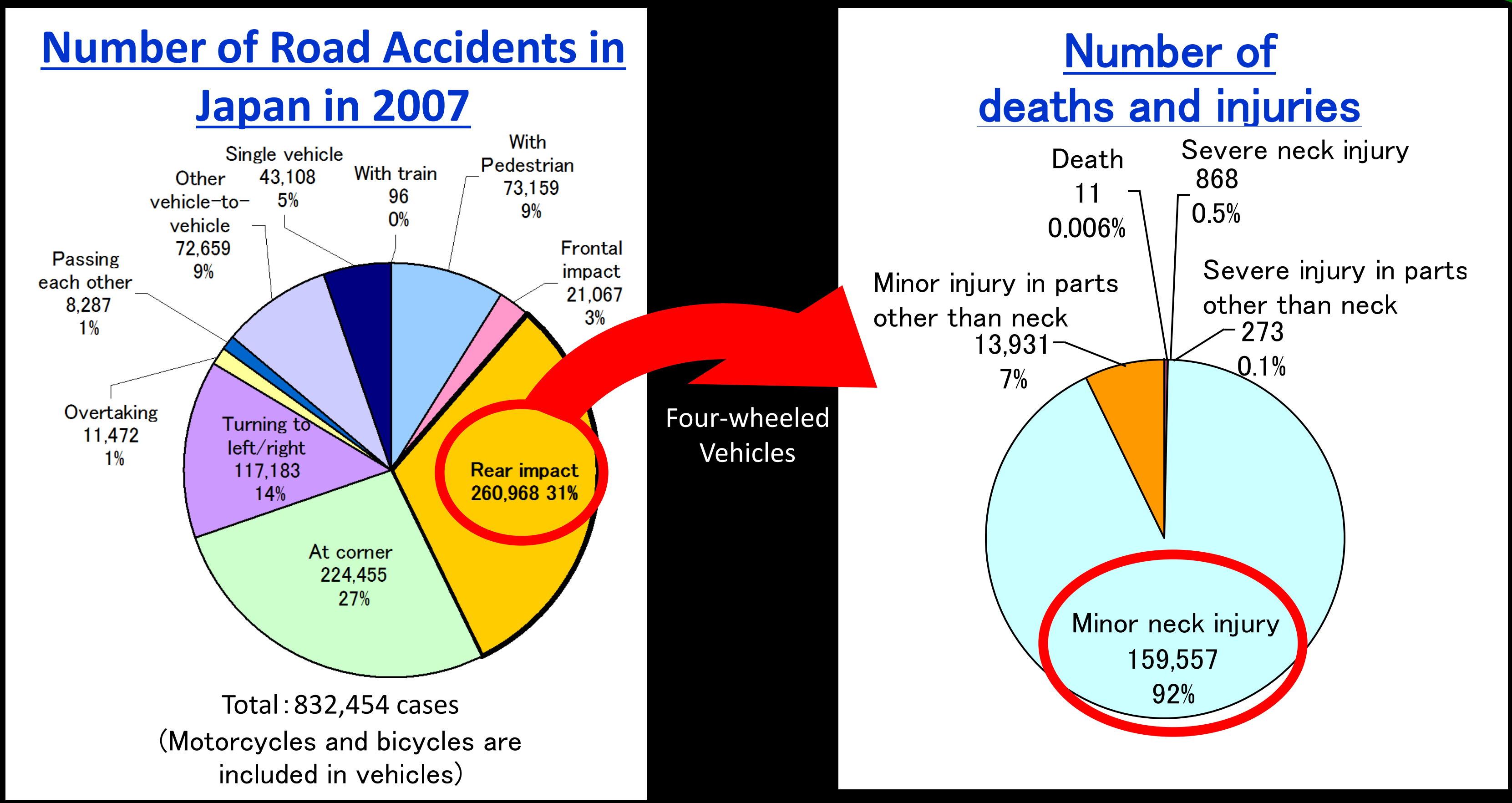
Number of Road Accidents in Japan



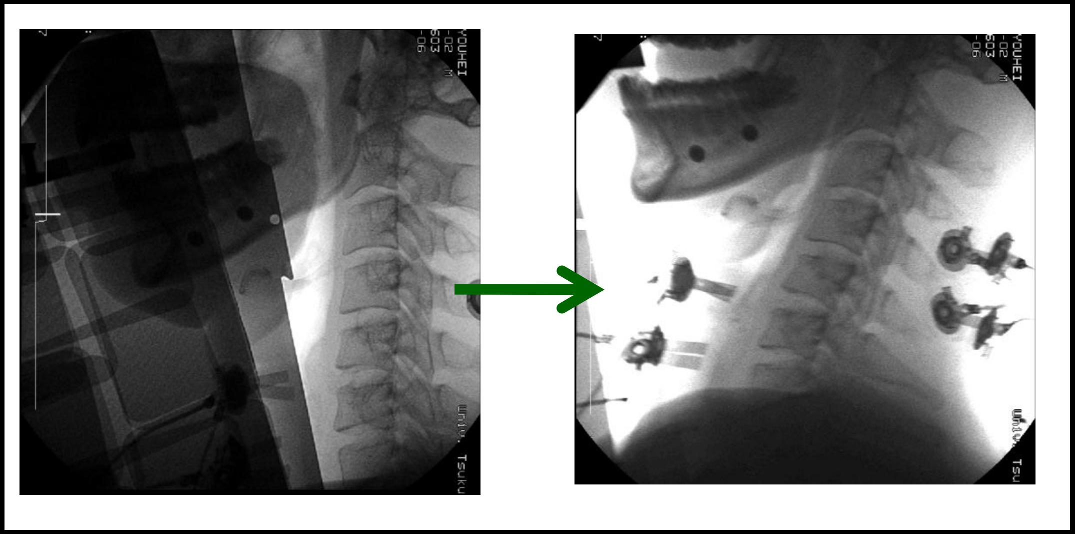
For the reduction of minor neck injuries

Proposal of evaluation parameters and criteria for neck injury

Neck Injury in Rear-end Impacts

Minor neck injury

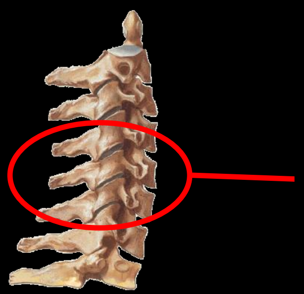
- Whiplash-associated disoeders
- Neck sprain

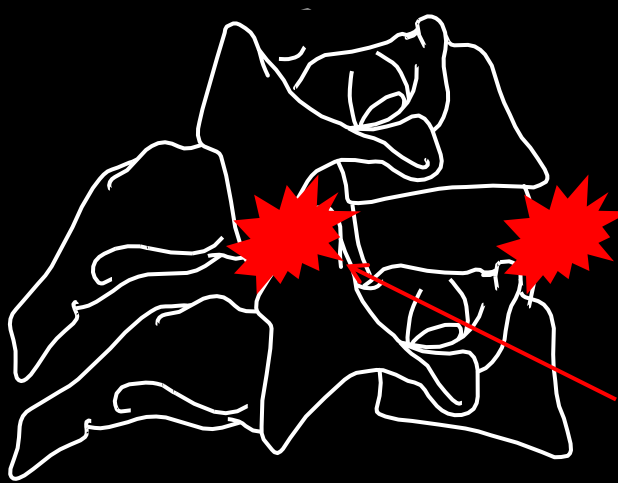


Difficulty of diagnosis with CT and MRI

Neck injury mechanism has not been clarified yet

Injured Regions in PMHS Tests and Clinical Findings





PMHS tests : Excessive deflection → Soft tissue injury (Panjabi, 1997; Yoganandan ,1998 and etc.)

Clinical findings : Facet joint injury is most common (Manchikanti et al.,1995 Lord et al.1996, Barnsley et al. and etc.)

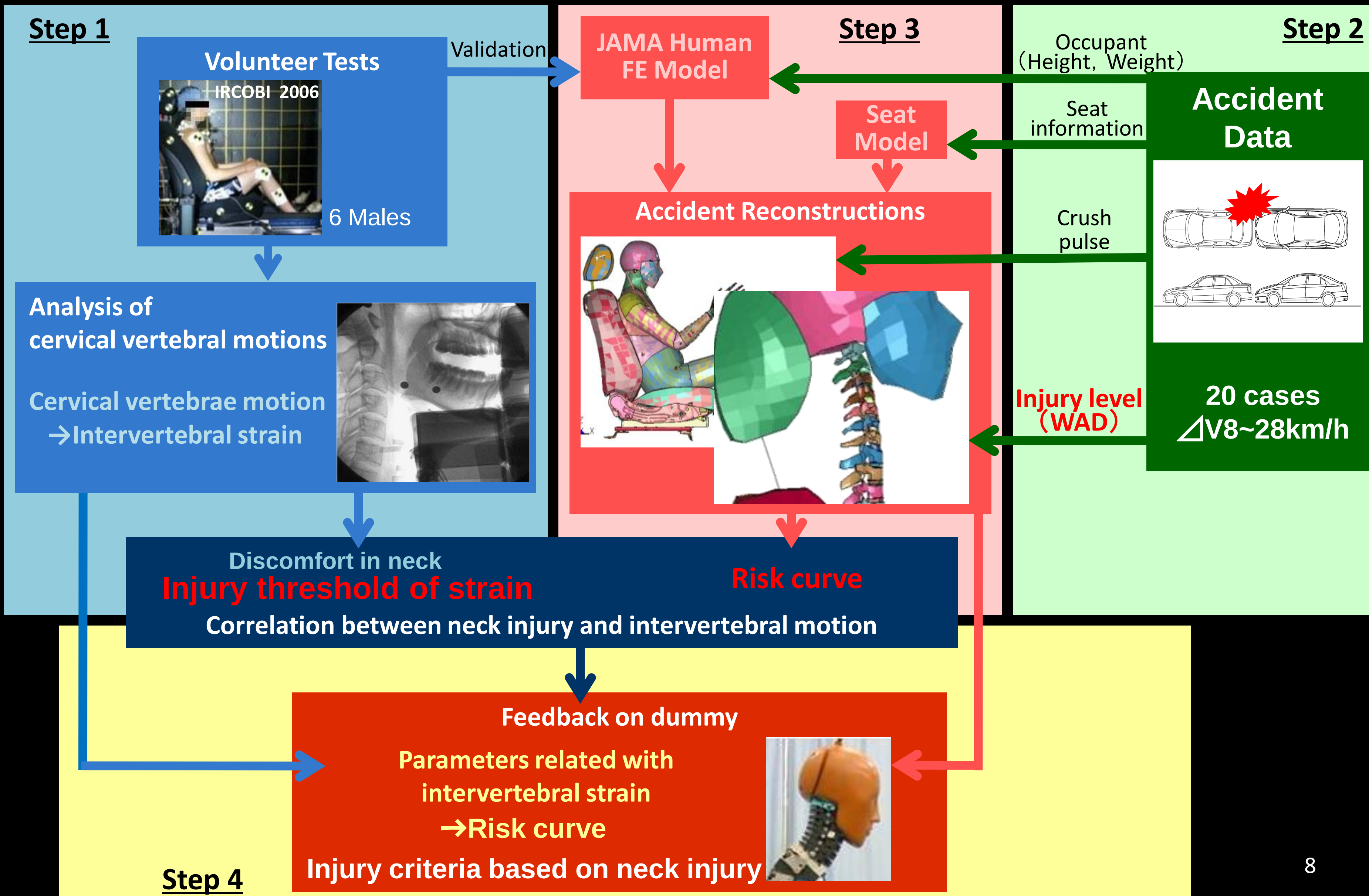
Animal test : Stretch of Facet capsule is related with pain (Lee , 2004 and etc.)

PMHS test : Strain rate affects rupture strength of soft tissue (Yoganandan), 2001)

Excessive deflection between vertebrae → Intervertebral soft tissue injury

Prediction of neck injury level by strain and strain rate of intervertebral soft tissue

Research Process - Flowchart

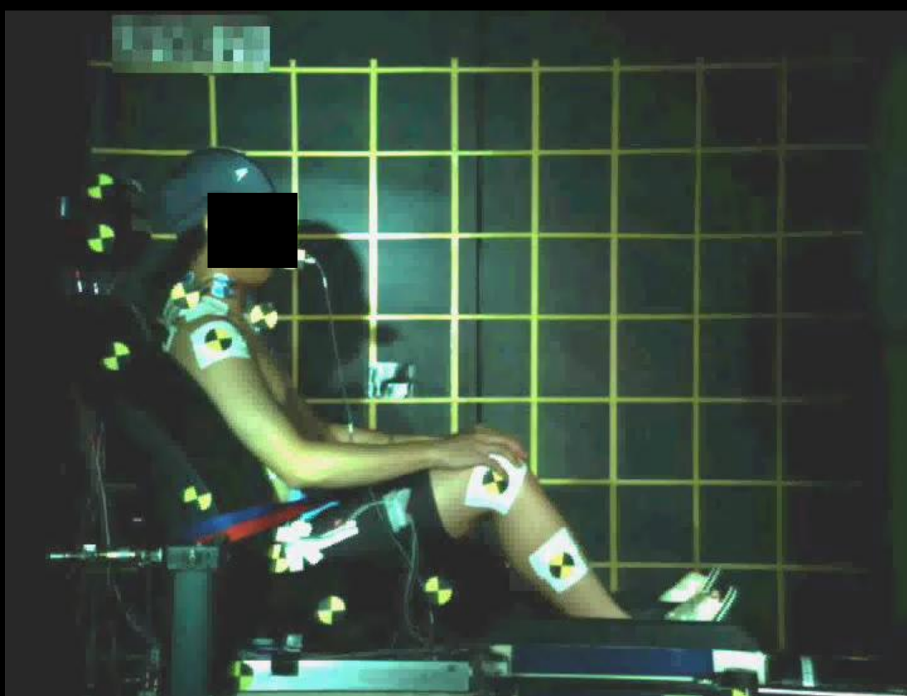


Human Volunteer Test

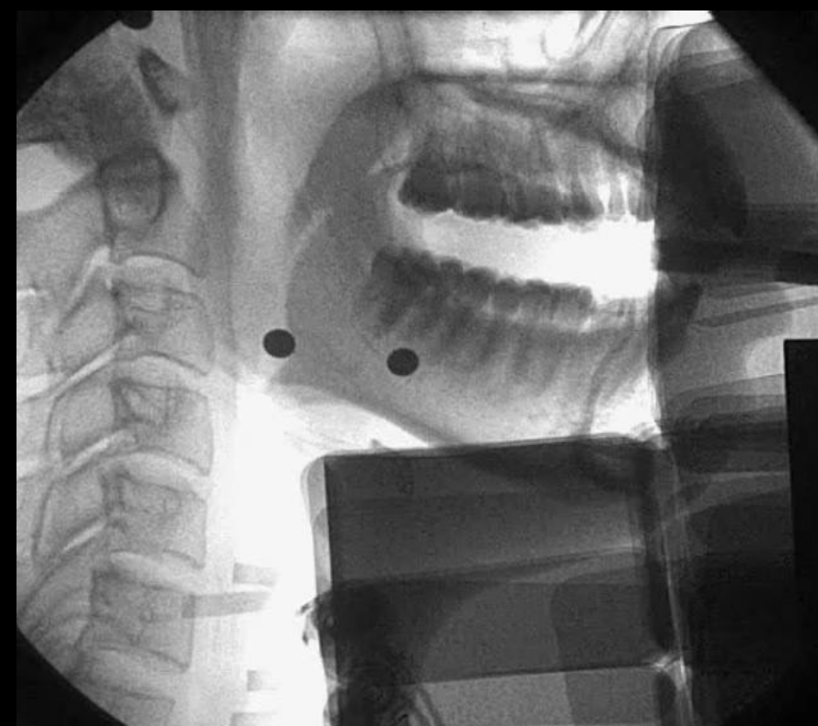
Test Conditions:

Seatback Angle：25 degree, Sled Acc.：40m/s^2 , Muscle Tone: Relaxed Condition

Volunteer Motion

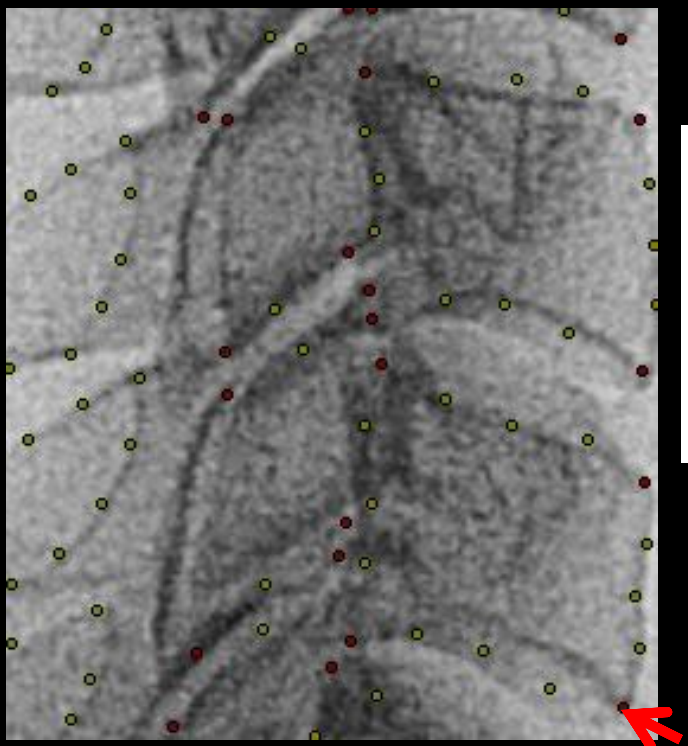


Cervical Vertebral Motion



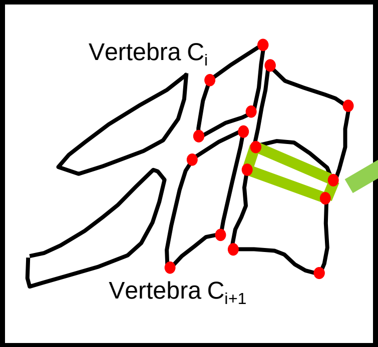
Analysis of Cervical Vertebral Motion

Localized deformation between cervical vertebrae

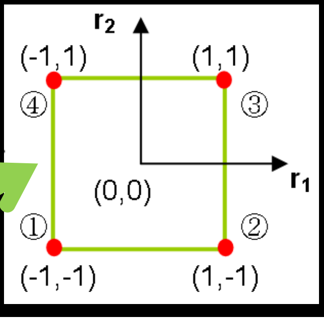


Sequential X-ray image

Representative point



Strain Calculation



$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) + \frac{1}{2}\left(\frac{\partial u_i}{\partial x_i}\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\frac{\partial u_j}{\partial x_j}\right)$$

Cervical strain, strain rate

Max. principal strain

$$\varepsilon_{MP} = \frac{\varepsilon_{11} + \varepsilon_{22}}{2} + \sqrt{\left(\frac{\varepsilon_{11} - \varepsilon_{22}}{2}\right)^2 + \varepsilon_{12}^{\ 2}}$$

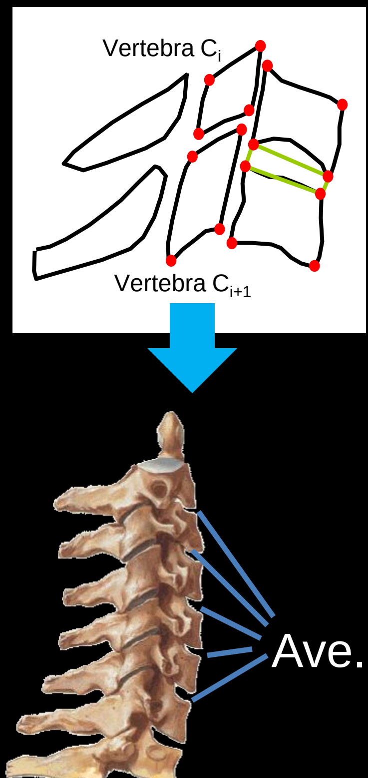
Max. shear strain

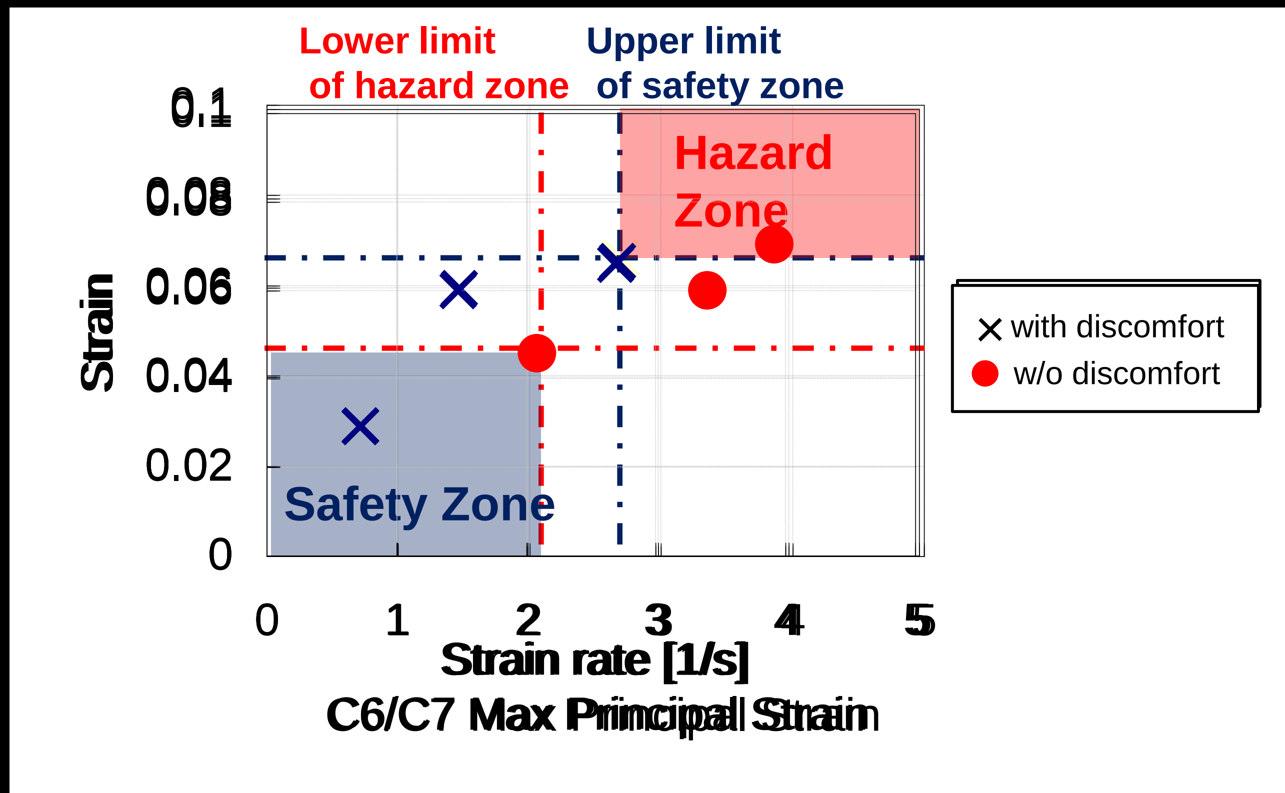
$$\varepsilon_{MS} = \sqrt{\left(\frac{\varepsilon_{11} - \varepsilon_{22}}{2}\right)^2 + \varepsilon_{12}^{\ 2}}$$

Strain rate : Temporal differentiation of strain

Threshold of Strain and Strain Rate

・with/without discomfort around neck
→Region of cervical intervertebral strain for occurrence of neck discomfort





Threshold	Max. Principal Strain	Max. Shear Strain	Max. Principal Strain rate	Max. Shear Strain Rate
Average （Ave. between C2/C3～C6/C7）	0.06	0.05	2.68	1.81

Accident Data（Folksam）

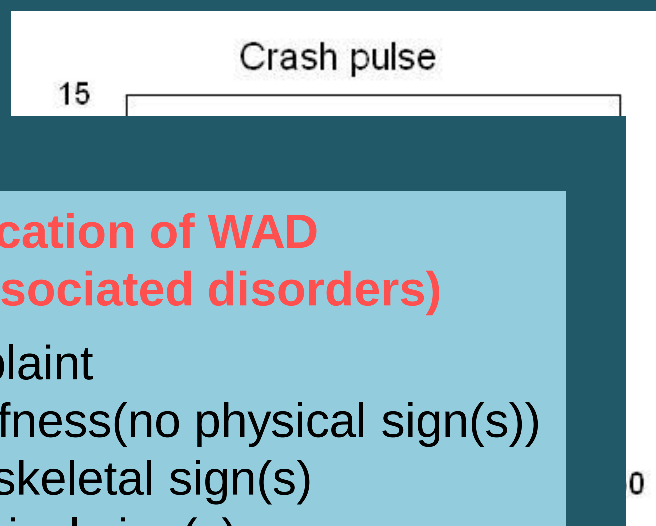
<u>Acceleration</u>
Crush Pulse

<u>Injury Level</u>
WAD

<u>Occupant</u>
Height・Weight

CASE		RECORDED CRASH PULSE			REPORTED INJURY			PASSENGER CHARACTERISTICS			
No.	D/P	⊿v [km/h]	Mean Acc.[g]	Peak Acc. [g]	Neck/Spine	Symptoms	WAD	Gender	Age	Height	Weight
1	Driver	28.2	5.8	10.6	Injured	1-6 m	2	F	26	175	55
4	Driver								57	178	100
4	Passenge								57	168	80
2	Driver								59	156	60
									22	171	63
									18	179	80
									67	167	84
									72	165	63
									74	175	62
									74	160	57
									59	165	65
									88	170	70
									61	176	77
									61	154	69
									50	171	85
									35	178	65
									65	176	82
									68	176	77
24	Driver								35	165	55
3	Driver				Injured		2		35	165	55

20
Cas



ecorder

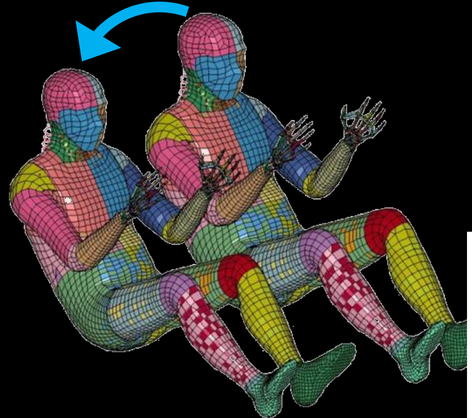
⊿v 8 ~ 28 km/h

Classification of WAD
(Whiplash-associated disorders)

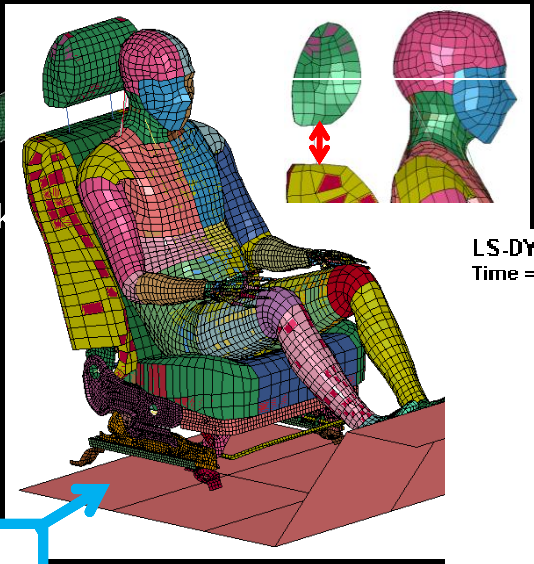
grade 0：No complaint
grade 1：Pain, stiffness(no physical sign(s))
grade 2：Musculoskeletal sign(s)
grade 3：Neurological sign(s)
grade 4：Fracture or dislocation

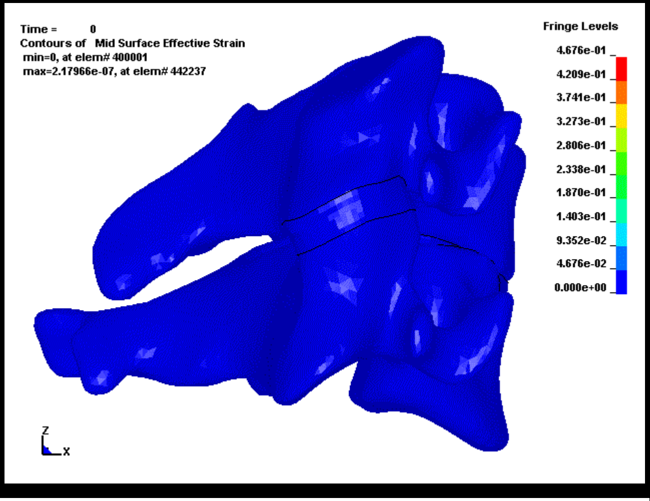
Accident Reconstruction -FE Model Simulations

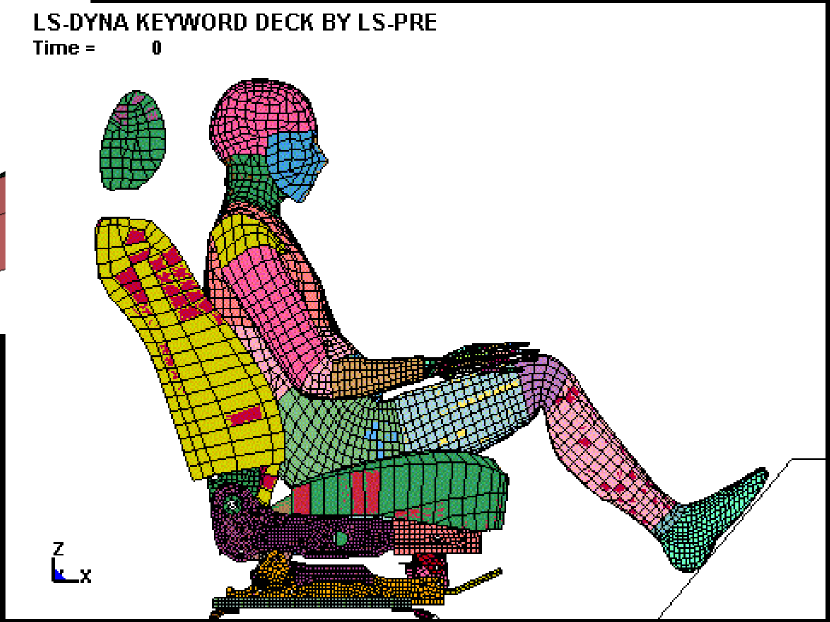
Scaling

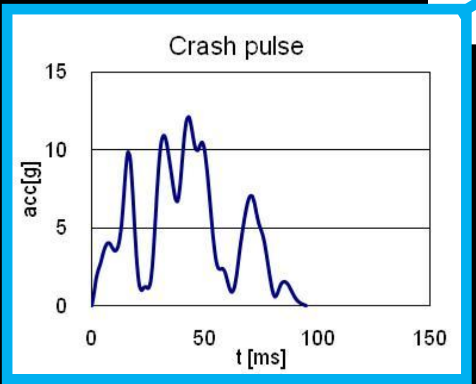


Positioning



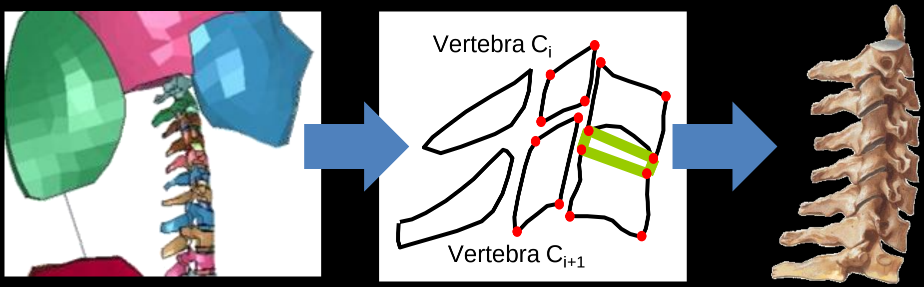




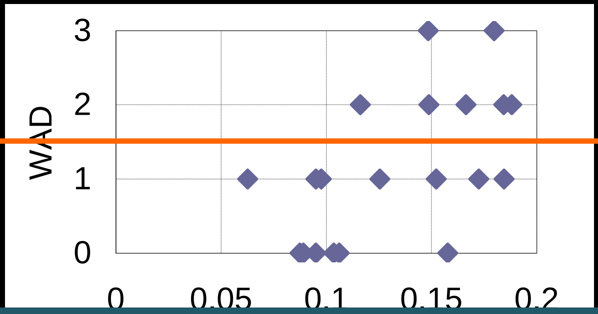


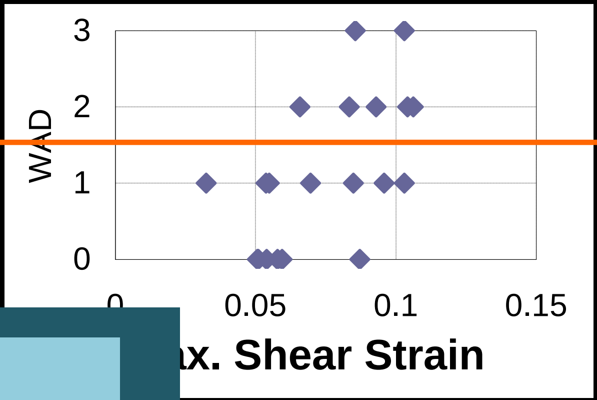
Relationship between cervical strain and WAD

- Calculate cervical strain with Volunteer's method
- Extract max. value of the strain (C2/C3～C6/C7)



Cervical Strain





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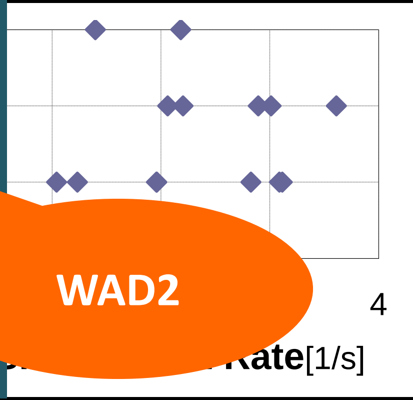


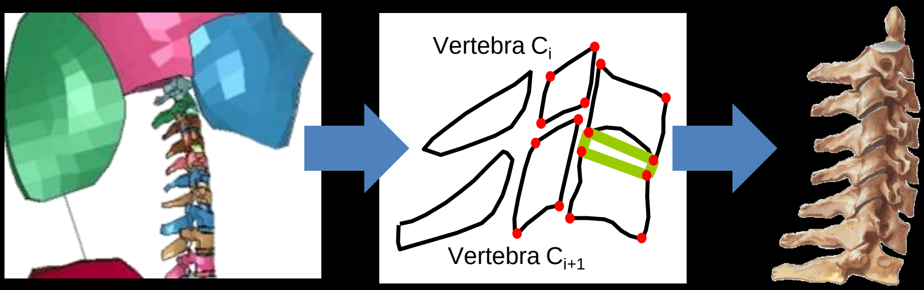
Classification of WAD (Whiplash-associated disorders)

grade 0：No complaint
grade 1：Pain, stiffness(no physical sign(s))
grade 2：Musculoskeletal sign(s)
grade 3：Neurological sign(s)
grade 4：Fracture or dislocation

WAD2

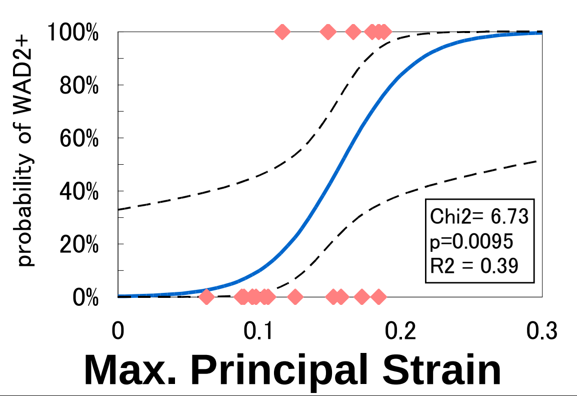
Relationship between cervical strain and WAD

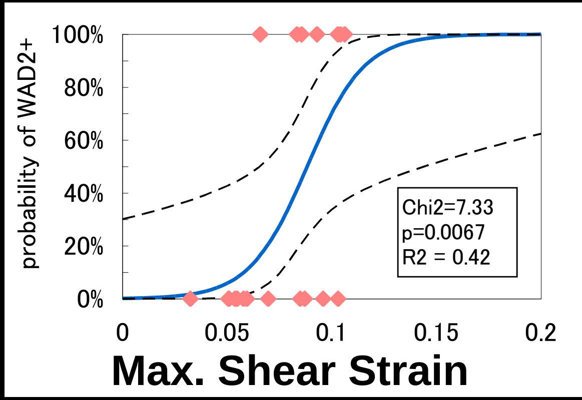
- Calculate cervical strain
  with Volunteer's method
- Extract max. value of the strain
  (C2/C3～C6/C7)



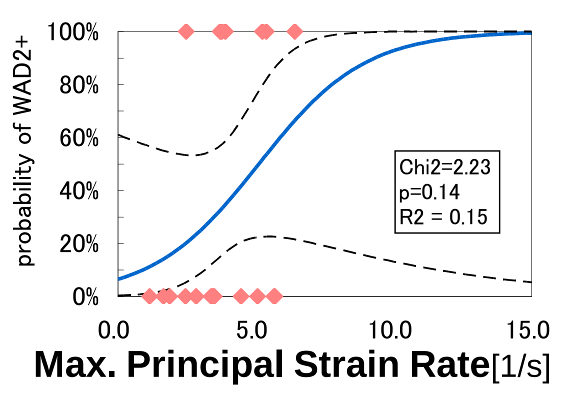
Max.
Value

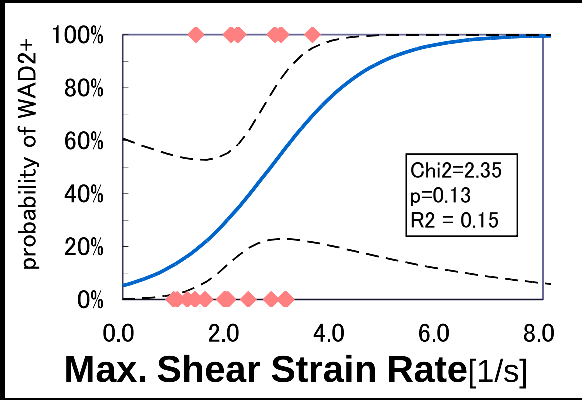
Cervical Strain





Cervical Strain rate

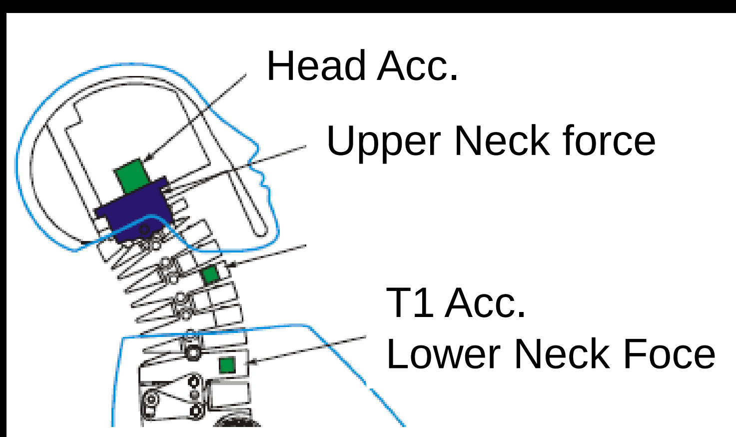




Feedback on Dummy

Calculating cervical strain
is difficult

Selection of neck injury evaluation parameters which can be obtained from dummy



<u>Neck injury criteria</u>

- NIC Relative motion between Head and T1
- Nkm Upper neck force
- LNL Lower neck force
- Rebound V Velocity after rebound

<u>Kinematics</u>

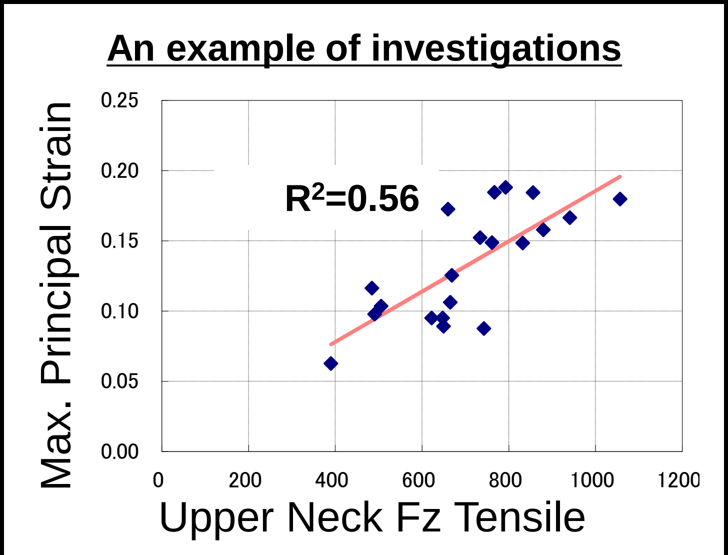
- OC-T1 disp
- Head-Chest rotational angle

Selection of Neck Injury Evaluation Parameters

- Investigations of the relationship between

  Volunteer test

  Accident Reconstruction with FE models



Neck Force	Upper	Fx	Forward
			Backward
		Fz	Tensile
			Compression
		My	Extension
			Flexion
	Lower	Fx	Forward
			Backward
		Fz	Tensile
			Compression
		My	Extension
			Flexion
NIC			
T1G			
Nkm			
LNL			
Rebound V			
OC-T1 disp			
Head-Chest rot. ang.			

Selection of Neck Injury Evaluation Parameters

Neck Force	Upper	Fx	Forward
			Backward
		Fz	**Tensile**
			Compression
		My	Extension
			Flexion
	Lower	Fx	Forward
			Backward
		Fz	**Tensile**
			Compression
		My	Extension
			Flexion
NIC			
T1G			
Nkm			
LNL			
Rebound V			
OC-T1 disp			
Head-Chest rot. ang.			

T1 G is involved in NIC

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

Relative Acc. (Head, T1)

Relative Vel. (Head, T1)

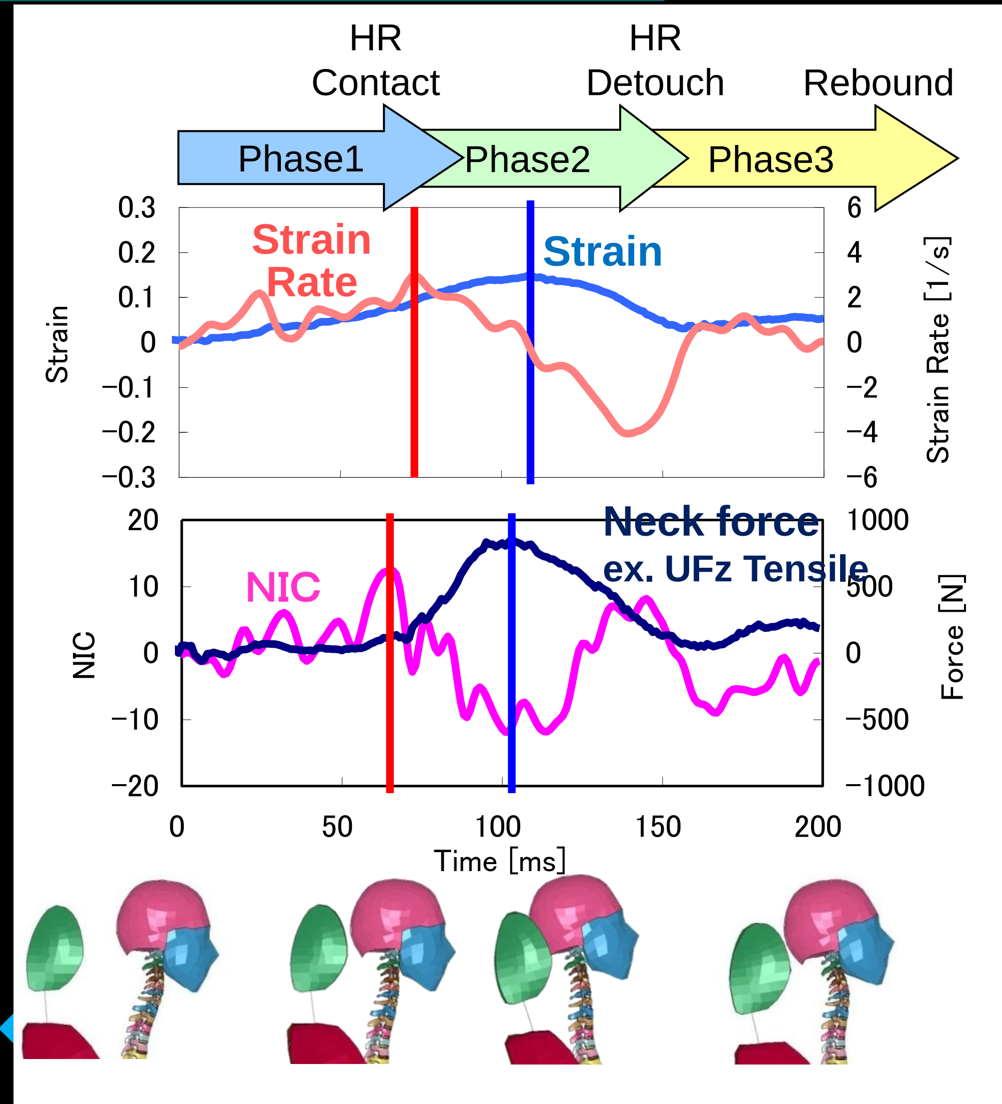
L… Lo… y

OC-T1 is displacement and substitute for Lower Fx

Head-Chest rot. ang. is angular displacement and substitute for Lower My

Selection of Neck Injury Evaluation Parameters

Neck Force	Upper	Fx	Forward
			Backward
		Fz	Tensile
			Compression
		My	Extension
			Flexion
	Lower	Fx	Forward
			Backward
		Fz	Tensile
			Compression
		My	Extension
			Flexion
NIC			
T1G			
Nkm			
LNL			
Rebound V			
OC-T1 disp			
Head-Chest rot. ang.			



Selection of Neck Injury Evaluation Parameters

Neck Force	Upper	Fx	Forward
			Backward
		Fz	Tensile
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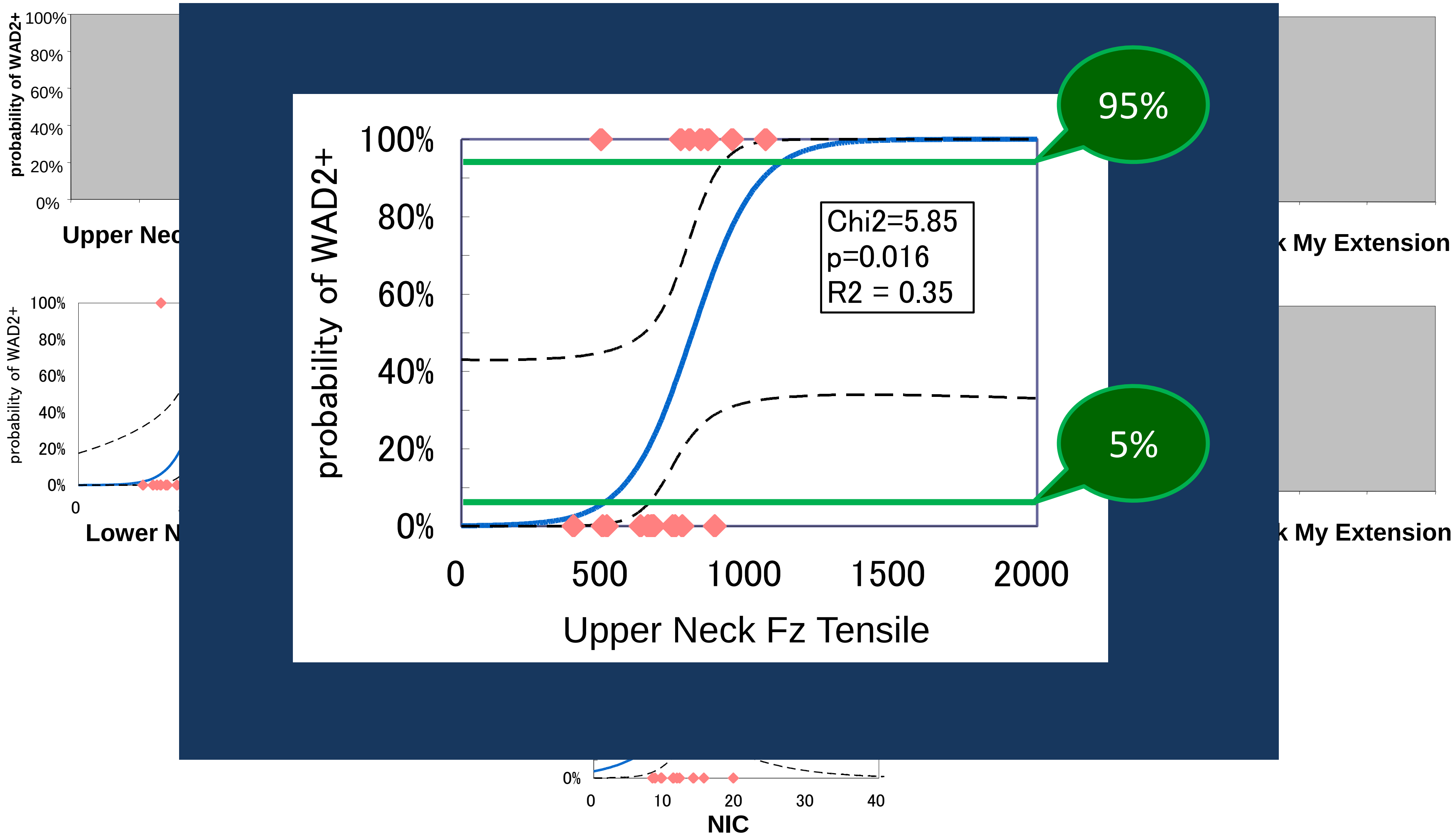
		My	Extension
			Flexion
	Lower	Fx	Forward
			Backward
		Fz	Tensile
			Compression
		My	Extension
			Flexion
NIC			
T1G			
Nkm			
LNL			
Rebound V			
OC-T1 disp			
Head-Chest rot. ang.			

Evaluating hyper-extension

Selection of NIC and neck forces

Neck Injury Risk Curve



Injury Criteria

Evaluation Parameters		WAD 2+ 5%	WAD 2+ 95%
Max. Principal Strain		0.08	0.24
Max. Shear Strain		0.05	0.13
Max. Principal Strain Rate		-	10.8
Max. Shear Strain Rate		-	5.8
NIC		8	30
Upper Fx	Backward	**(340)**	**(730)**
Upper Fz	Tensile	475	1130
Upper My	Extension		
	Flexion	12	40
Lower Fx	Backward	340	730
Lower Fz	Tensile	257	1480
Lower My	Extension		
	Flexion	**(12)**	**(40)**

Upper and Lower neck torelances are assumed to be almost the same

Injury Criteria

Evaluation Parameters		WAD 2+ 5%	WAD 2+ 95%
Max. Principal Strain		0.08	0.24
Max. Shear Strain		0.05	0.13
Max. Principal Strain Rate		-	10.8
Max. Shear Strain Rate		-	5.8
NIC		8	30
Upper Fx	Backward	**(340)**	**(730)**
Upper Fz	Tensile	475	1130
Upper My	Extension	**(12)**	**(40)**
	Flexion	12	40
Lower Fx	Backward	340	730
Lower Fz	Tensile	257	1480
Lower My	Extension	**(12)**	**(40)**
	Flexion	**(12)**	**(40)**

Fexion and extension torelances are assumed to be almost the same

Injury Criteria

Evaluation Parameters		WAD 2+ 5%	WAD 2+ 95%	Volunteer Threshold	Literature Human Tolerance
Max. Principal Strain		0.08	0.24	0.06	-
Max. Shear Strain		0.05	0.13	0.05	-
Max. Principal Strain Rate		-	10.8	2.68	-
Max. Shear Strain Rate		-	5.8	1.81	-
NIC		8	30	-	-
Upper Fx	Backward	**(340)**	**(730)**	-	845[1)2)]
Upper Fz	Tensile	475	1130	-	1134[1)2)]
Upper My	Extension	**(12)**	**(40)**	-	20.3[2)]
	Flexion	12	40	-	50.2[2)]
Lower Fx	Backward	340	730	-	600~800[3)] ⊿V24~25km/h
Lower Fz	Tensile	257	1480	-	-
Lower My	Extension	**(12)**	**(40)**	-	-
	Flexion	**(12)**	**(40)**	-	-

References

1) Mertz, 1971
Strength and Response of the Human Neck, 15th Stapp

2) SAE J885, 2003
Human Tolerance to Impact Condition as related to Motor Vehicle Design

3) Stemper, 2009
Verification of Lower Neck Shear Force as a Rear Impact Injury Criterion

Limitations of this study

1. **Limited Number of Volunteer experiments**
   ⇒6 males and 3 females.

2. **Limited Number of accident reconstruction simulations**
   ⇒ 20 accident cases, the seats used for the experiments
   ⇒ Only one type of mass production car used.

3. **Assumes that these strains and strain rates are equivalent to deformation strains of inter-vertebral joint capsules.**

4. **The use of an Human Finite Element Model to calculate the strains and strain rates**
   ⇒ may also be a limitation on the quality of the validation of the model.

Conclusions

In the past, an evaluation method for minor neck injuries did not exist. Now, the evaluation parameters and thresholds for the reduction of minor neck injuries are obtained.

1. Based on the results of volunteer tests, the threshold of the strain and the strain rate that caused subjects to feel neck discomfort (minor neck injuries) during the test were well defined.
2. The relationship between the strain/strain rate and parameters which can be obtained from dummy was investigated based on the results of the volunteer test and FE analysis. Then, the parameters which have good correlations with the strain/strain rate were selected as evaluation parameters for neck injury.

Conclusions (continued)

3. The risk curve of WAD2+ concerning neck forces/moments and NIC based on the results of volunteer tests and accidents reconstruction simulation was recommended.
4. The risk curve values of 5% and 95% for causation of neck injury were determined as neck injury criteria based on the volunteer test results and FE analysis using the Human FE model.
5. The risk curve value of 5% was the level where volunteers would experience neck discomfort during the volunteer tests, and the risk curve value of 95% was almost the same as the human tolerance values in literature.

Adoption as an Evaluation Injury Criteria for JNACP Test

The proposed neck injury evaluation parameters and criteria were adopted as one of J-NCAP tests for the minor neck injury assessment in rear impact test, starting April 2009.

The result will also be focused at being a primary candidate for an injury evaluation method that would be scrutinized by WP29/GRSP/HR GTR.

Acknowledgment

We would like to acknowledge the accident data provided by Folksam.

Thank you for your attention.