Collaboration Works (USA & JAPAN)

Neck Injury Parameters based on PMHS Tests

Preliminary (Tentative) Results for HR-GTR 7 Meeting on December 5 and 6

J-MLIT/JASIC/JARI

Japan Automobile Research Institute

Japan

Validation Kinematics

Accident case

Human FE model

Human Volunteer

ΔV=8～28km/h

Accident reconstruction by FE model

Strain threshold

Calculation of strains

Selection of physical parameters in relation to the strains to be measured by the dummy

Injury Risk Curve

USA

PMHS Tests

ΔV=24km/h

Calculation of IV-NIC

Selection of physical parameters in relation to the IV-NIC to be measured by the dummy

Injury Risk Curve

Neck Injury Parameters by the Strains

Validation of Relationship

Neck Injury Parameters by the IV-NIC

Collaboration works

Acc. Reconstruction

Human FEM

2.

Selected cases (Acc. Reconstruction)

3.

IV-NIC Calculation

・Relationship between strain and strain rate of cervical vertebrae and IV-NIC
・Discussion of relationship between physical parameters and IV-NIC based on the results of FE simulation

1.

Necessary data for IV-NIC Calculation based on references

－$IV\text{-}NIC_i = \theta_{trauma,\ i} / \theta_{physiological,\ i}$

$\theta_{physiological,\ i}$:: Quoted by references

$\theta_{trauma,\ i}$: Values calculated by FEM simulation based on selected accident cases

－IV-NIC: Rotation, Compression, Sliding

－Defined by Local coordinate system for the calculation of IV-NIC

1. Preparation for IV-NIC CAE Simulation

2. Selection of three cases (tentative) for accident reconstruction using the FE model in a 2009 IRCOBI paper

3. Current works:

- Relationship between strain and strain rate of cervical vertebrae and IV-NIC
- Discussion of relationship between physical parameters and IV-NIC based on the results of FE simulation

4. Conclusions

Outline of the IV-NIC

The following three definitions of IV-NIC based on cervical vertebral motion is proposed.

1）Rotation (Flexion and Extension)
2）Axial (Compression)
3）Shear (Sliding)

・Rotation（Flexion and Extension）

$$IV-NIC_i = \frac{\theta_{trauma,i}}{\theta_{physiological,i}}$$

・Axial（Compression）

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

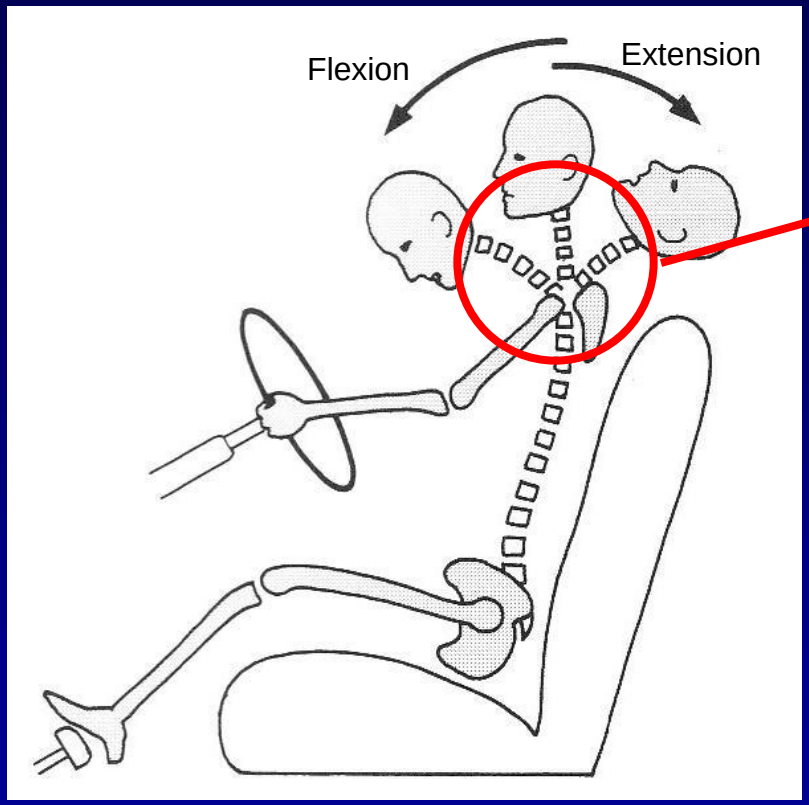
・Shear（Sliding）

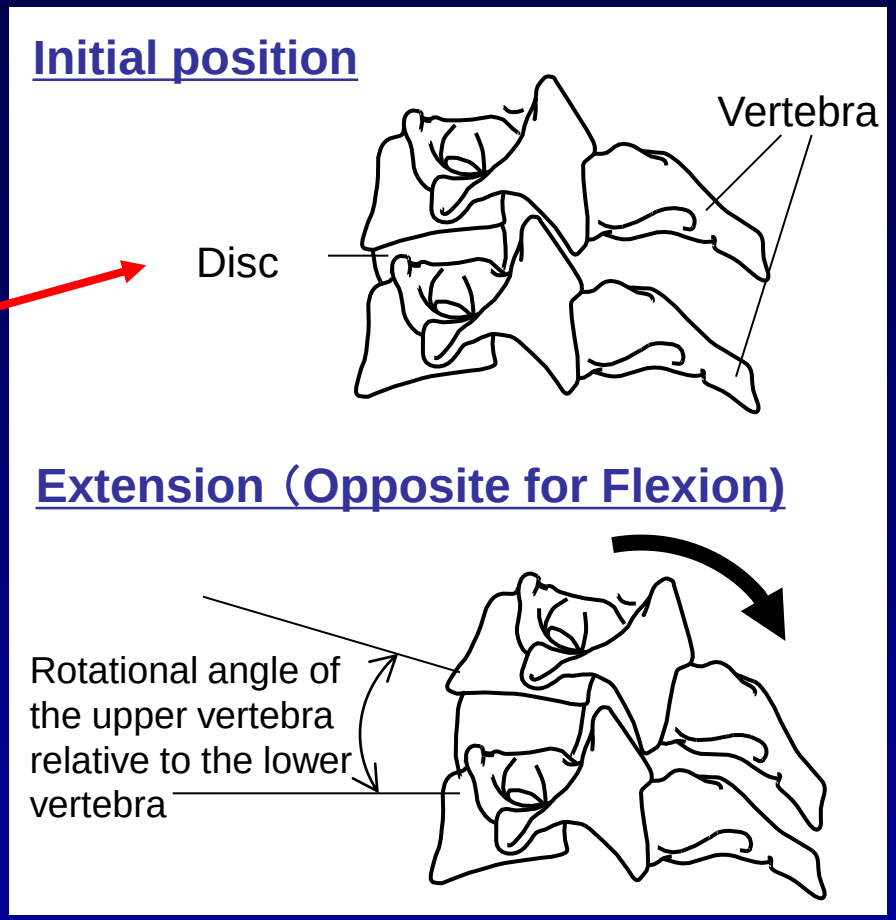
$$IV-NIC_{sliding,i} = \frac{Disp_{trauma,i}}{Disp_{physiological,i}}$$

The definition of the three IV-NIC is introduced in the following page.

IV NIC - Rotation

・Motion of neck during rear-end impacts





IV-NIC（Inter-Vertebral Neck Injury Criterion）: It is proposed based on a hypothesis that the relative exercise between each vertebral body happens in the case beyond the physiological limit. One of the IV-NIC is a parameter index using the relative angle of rotation between each vertebral body.

IV-NIC＝the vertebral body angle during impact / the physiological angle of vertebral body

Determination for Physiological range of cervical vertebral motion on IV-NIC

1. Sample of C1-T1 including Occiput without soft tissues
2. Fixation of T1 mount（Fig.1）
3. To give flexion and extension force (1.5Nm) to the OC mount（Fig.1）→ 1.5Nm is limit for uninjured level.
4. Two times pre-loading → Fig.2 cycle1, 2
5. At third loading, the physiological range of motion (ROM) is obtained. → Fig.2 cycle3
6. Repeatability tests done 2 to 5 times for the cervical specimen. Averaged value of ROM was determined

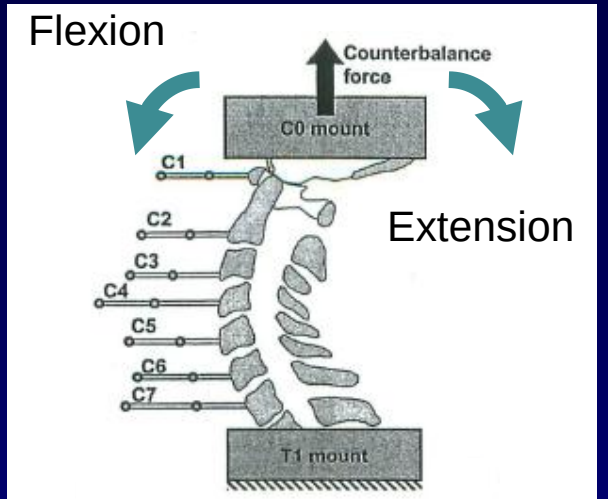


Fig. 1 Whole cervical spine model

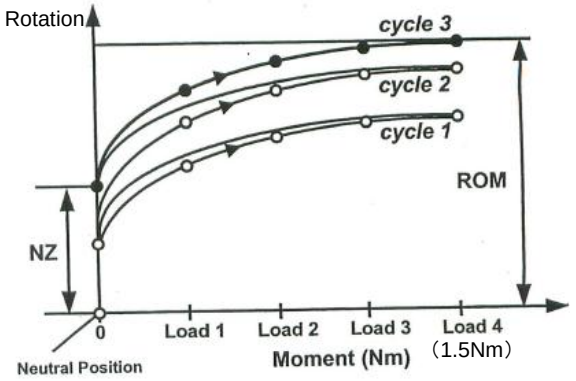


Fig. 2 Schematics of the flexibility test protocol

ROM: Range of motion, NZ: Neutral zone

Ito et al., Soft tissue injury threshold furing simulated whiplash, Spine 29(9), 2004

References
•Panjabi, The stabilizing system of the spine, Part II Neutral zone and instability hypothesis, Journal of Spinal Disorders, Vol. 5, No. 4, 00 390-397, 1992
•Panjabi et al., Whiplash injuries and the potential for mechanical instability, Eur Spine J, 7: 484-492, 1998
•Ito et al., Soft tissue injury threshold furing simulated whiplash, Spine 29(9), 2004
•Pearson et al., Facet joint kinematics and injury mechanisms during simulated whiplash, Spine, Vol. 29, No. 4, pp 390-397, 2004
•Panjabi et al., Evaluation of the intervertebral neck injury criterion using simulated rear impacts, Journal of Biomechanics, 38, 1694-1701, 2005
•Ivancic et al., Predicting multiplanar cervical spine injury due to head-turned rear impacts using IV-NIC, Traffic Injury Prevention, 7:264-275, 2006

IV-NIC（Rotation：Ivancic 2006, Panjabi, 2005）

IV-NIC = the vertebral body angle (t) during impact / the physiological angle of vertebral body

Physiological range of motion (ROM) for IV-NIC（Rotation）is reported by Ivancic 2006, and Panjabi 2005 as the following tables. The average values is also shown in the table at the bottom.

IV-NIC	Ivancic 2006 (n = 6)			
	Extension		Flexion	
	Mean	SD	Mean	SD
C0/C1	13.00	3.60	11.50	4.80
C1/C2	6.70	2.80	10.40	1.50
C2/C3	5.20	1.50	4.40	2.00
C3/C4	5.00	2.10	6.10	2.00
C4/C5	6.10	2.80	5.50	2.70
C5/C6	6.50	3.60	5.30	3.80
C6/C7	7.80	1.10	5.50	3.40
C7/T1	4.30	2.90	3.00	1.10

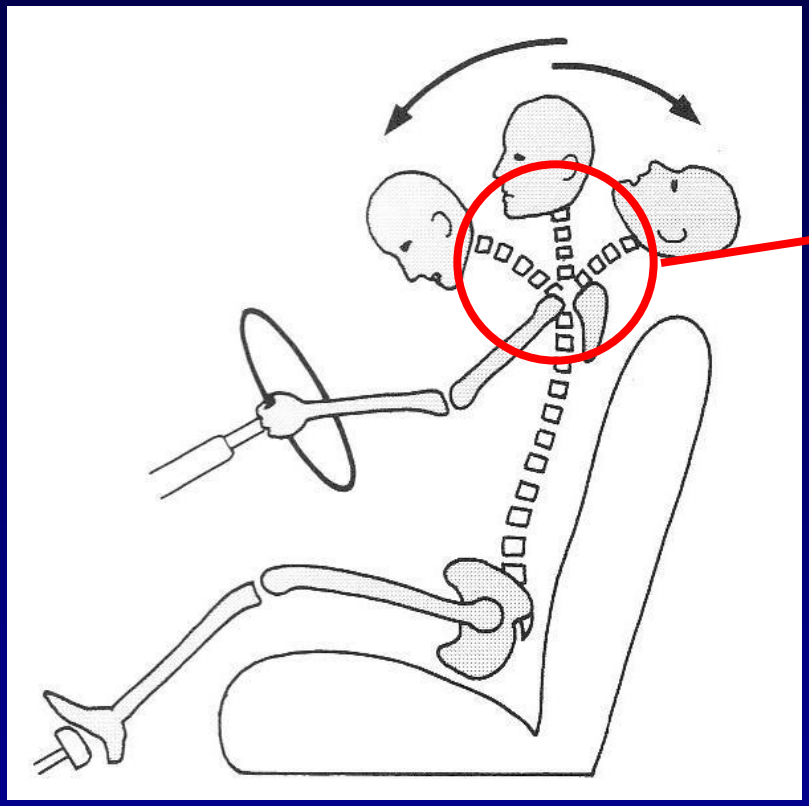
IV-NIC	Panjabi 2005 (n = 6)			
	Extension		Flexion	
	Mean	SD	Mean	SD
C0/C1	13.70	4.30	13.70	3.40
C1/C2	6.40	2.80	8.80	1.50
C2/C3	3.60	1.80	5.40	2.30
C3/C4	4.20	1.90	5.70	2.70
C4/C5	6.70	2.90	7.60	2.70
C5/C6	6.50	3.50	7.70	4.50
C6/C7	7.10	2.20	8.00	1.60
C7/T1	3.10	1.10	3.70	1.60

Average

IV-NIC	Mean and SD			
	Extension		Flexion	
	Mean	SD	Mean	SD
C0/C1	13.35	3.95	12.60	4.10
C1/C2	6.55	2.80	9.60	1.50
C2/C3	4.40	1.65	4.90	2.15
C3/C4	4.60	2.00	5.90	2.35
C4/C5	6.40	2.85	6.55	2.70
C5/C6	6.50	3.55	6.50	4.15
C6/C7	7.45	1.65	6.75	2.50
C7/T1	3.70	2.00	3.35	1.35

Cervical spine motion during rear-end impacts

- Axial：Compression
- Shear：Sliding



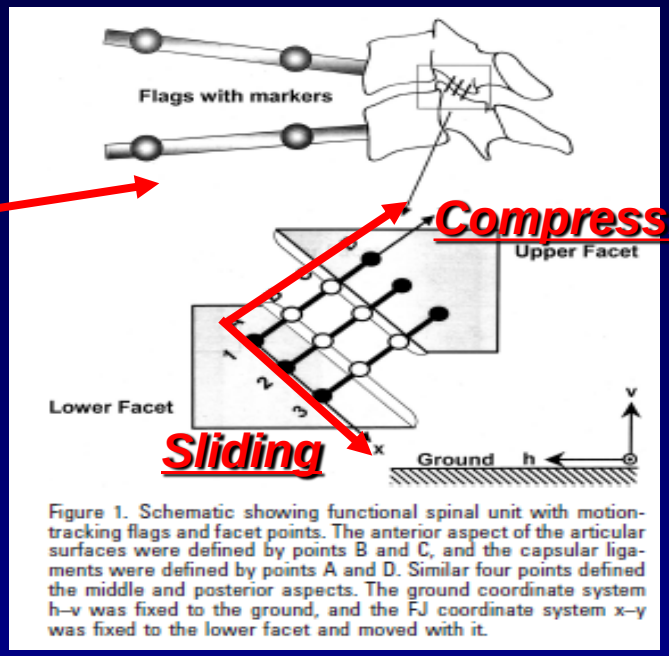


Figure 1. Schematic showing functional spinal unit with motion-tracking flags and facet points. The anterior aspect of the articular surfaces were defined by points B and C, and the capsular ligaments were defined by points A and D. Similar four points defined the middle and posterior aspects. The ground coordinate system h–v was fixed to the ground, and the FJ coordinate system x–y was fixed to the lower facet and moved with it.

IV-NIC（Compression），and IV-NIC（Sliding）are defined by the hypothesis that the relative exercise between each vertebral body happens in the case beyond the physiological limit. One of the IV-NIC is a parameter index using the relative angle of rotation between each vertebral body.

IV-NIC（Compression）=the vertebral body compressed displacement（t) during impact / the physiological motion of vertebral body

IV-NIC (Sliding)= the vertebral body sliding displacement（t) during impact / the physiological motion of vertebral body

IV-NIC（Compression：Pearson, 2004）
IV-NIC（Sliding：Pearson, 2004）

IV-NIC (Compression) = the vertebral body compresed displacement (t) during impact / the physiological motion of vertebral body

IV-NIC (Sliding) =IV-NIC (Sliding)= the vertebral body sliding displacement (t) during impact / the physiological motion of vertebral body

Physiological range of cervical vertebral motion for IV-NIC（Compression）and IV-NIC（Sliding）are defined based on the Table below (References of Compression：Pearson, 2004, Pearson, 2004)

Compression

IV-NICD	Pearson 2004 (n = 6)			
	Axial		Shear	
	Compression (mm)		Sliding (mm)	
	Mean	SD	Mean	SD
C0/C1	–	–	–	–
C1/C2	–	–	–	–
C2/C3	−0.20	0.20	1.50	0.90
C3/C4	−0.10	0.10	1.00	0.60
C4/C5	−0.50	0.50	2.00	0.80
C5/C6	−0.30	0.30	1.60	1.10
C6/C7	−1.00	0.80	2.20	0.70
C7/T1	–	–	–	–

Sliding

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2. Selection of three cases (tentatively) for accident reconstruction using the FE model in a 2009 IRCOBI paper

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Selection of Accident cases for FEM Simulation

3 cases (tentative) from 20 cases presented to 2009 IRCOBI were selected under the following criteria in order to calculate the IV-NIC（Rotation, Compression, and Sliding）.

【Selection criteria】
To select 3 cases for WAD 1, 2, and 3 from low speed to a higher rear-end impact speed in order to consider the injury-risk-curve-related impact speeds. According to this idea, 3 accident cases were selected through the following steps:

- Specific accident cases were selected based on all 20 cases on WAD1, WAD2, and WAD3.
- Specific impact speed of (ΔV: 8～28km/h) from those involved in the cases of low-to-mild rear-end impacts
- Gender：Male only

Selected Cases for Accident Reconstruction

【Selected accident cases】

- Occupants: Male only
- Size of occupants: almost same size as the BioRID-II dummy (175cm・78kg) except for Case 3.
- Injury levels from WAD 1, 2, and 3
- Rear-end impact speeds (ΔV) from 10 to 26 km/h

No.	⊿v [km/h]	Mean Acc. [g]	Peak Acc. [g]	WAD	Gender	Age	Height	Weight
Case1	10.8	3.7	7.1	1	M	65	176	82
Case2	20.4	5.2	12.8	2	M	18	179	80
Case3	26.0	5.6	12.6	3	M	57	178	100

Accident reconstruction: under the progress of running FEM simulation. Here, tentative results (3 cases) are provided.

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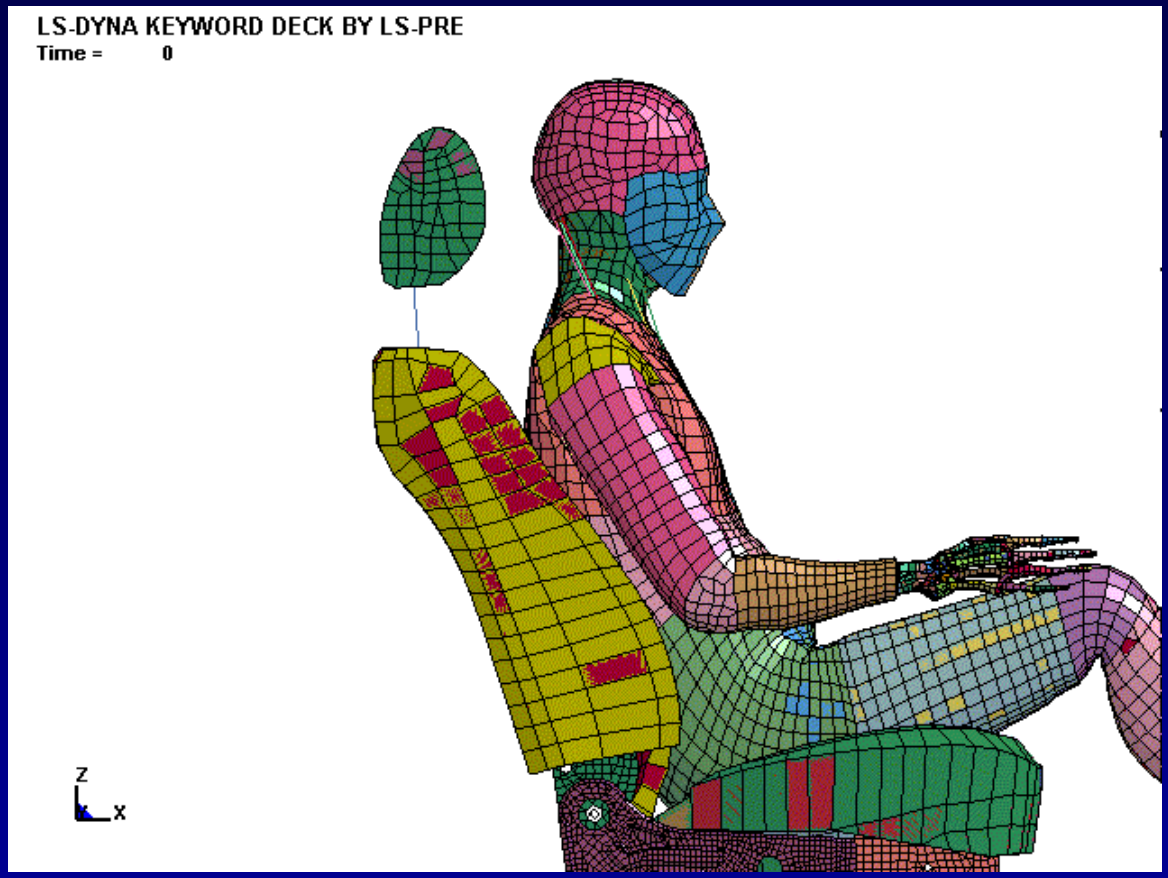
4. Conclusions

Accident reconstrucion by FEM simulation（Case2）

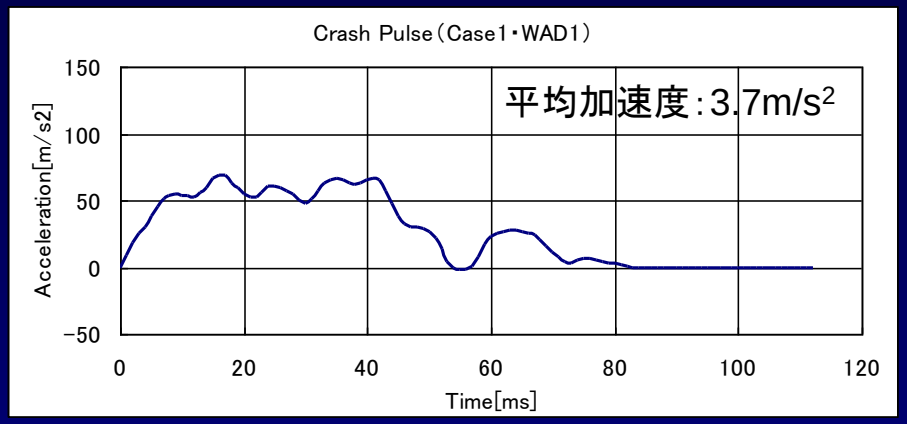


The following results were obtained tentatively based on the FEM simulation.

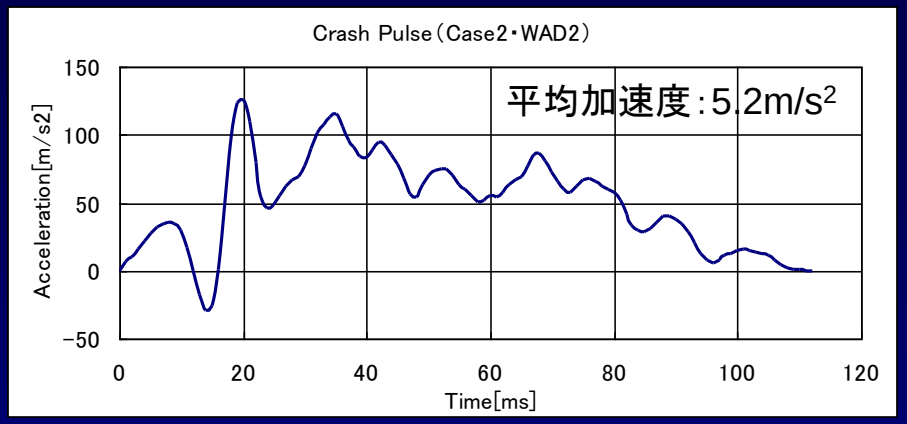
- Max Principal Strain
- Max Shear Strain
- IV-NIC（Rotation）

Crash Pulse

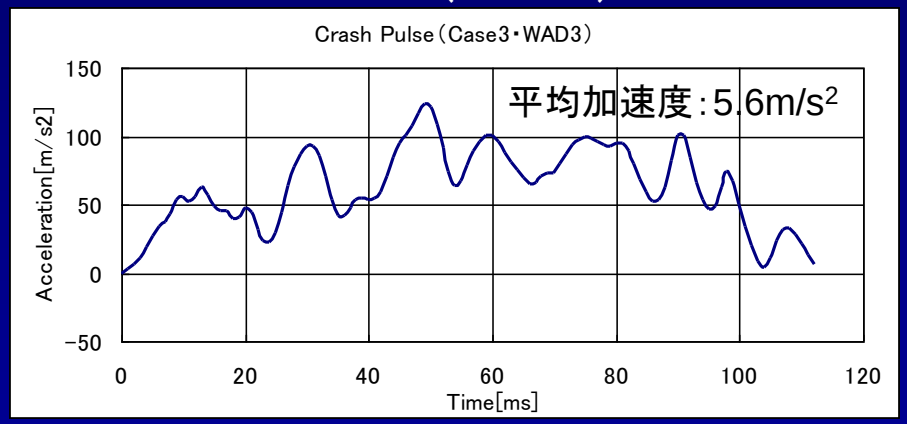
Case1（WAD1）



Case2（WAD2）



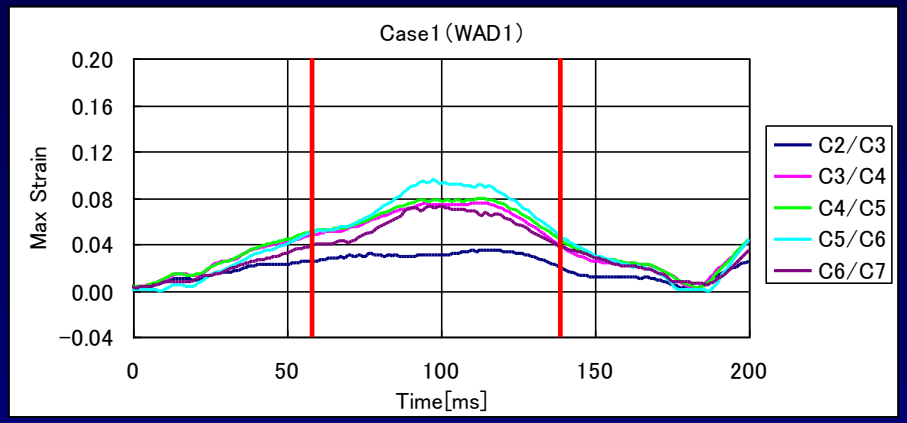
Case3（WAD3）



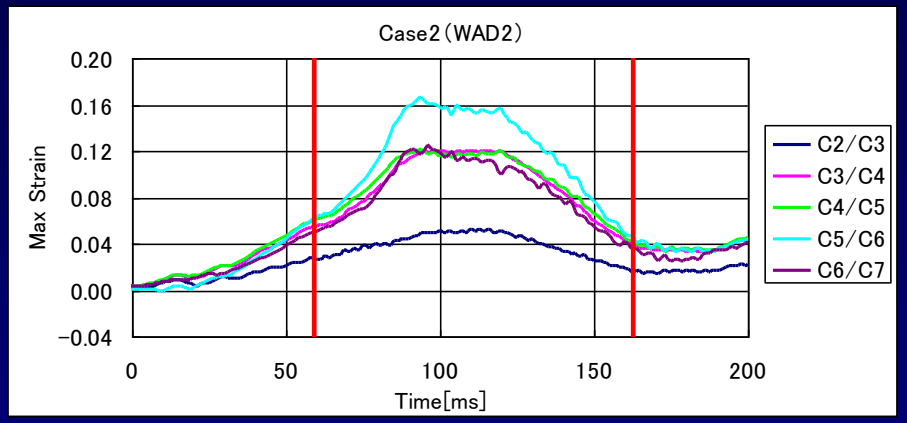
- The peak acceleration of Case2 and Case3 is almost the same. For the average acceleration, Case 3 is slightly higher than other cases.
- Accordingly an increasing in crash pulse, means that the WAD (Whiplash Associated Disorder) will also become higher.

Max Principal Strain

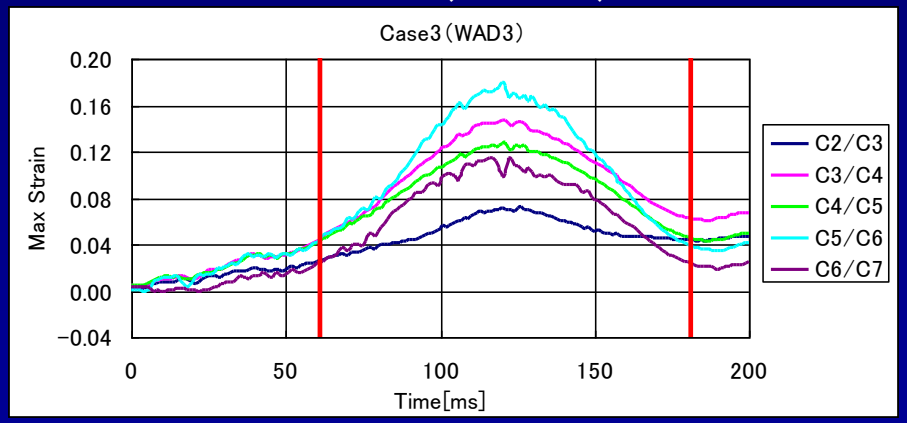
Case1（WAD1）



Case2（WAD2）



Case3（WAD3）

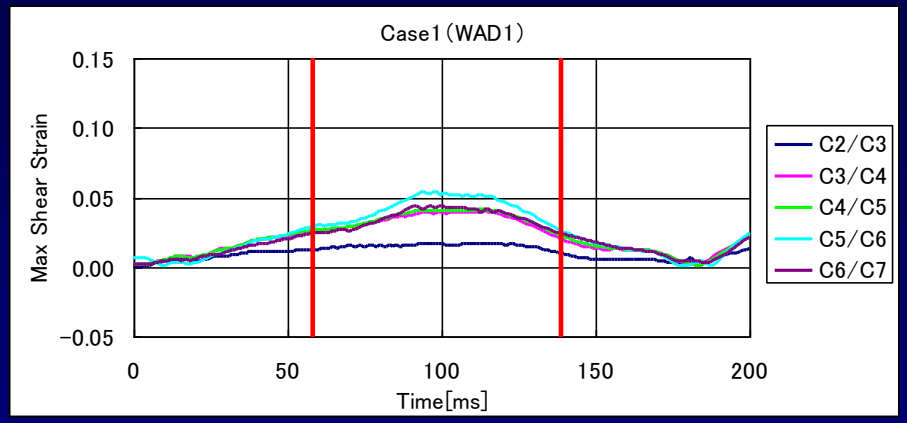


For all cases,

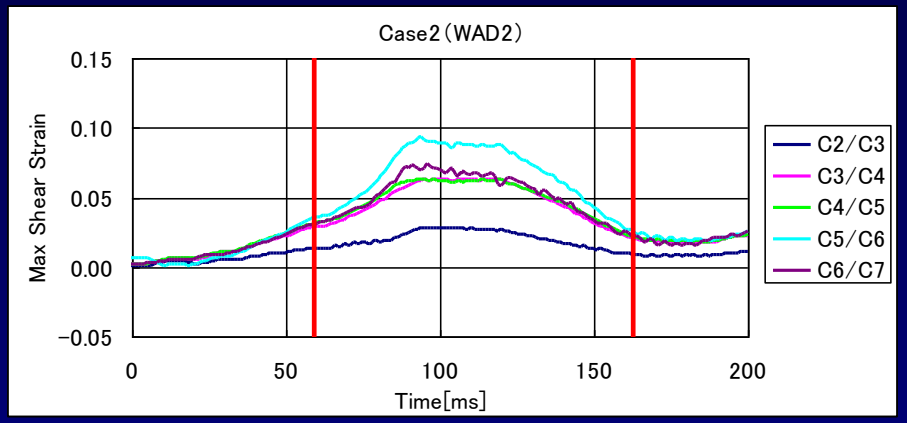
- The highest strain of the cervical vertebral region (CVR) is located in C5/C6.
- The smallest strain of the CVR is located in C2/C3.
- Accordingly an increasing crash pulse, means that the WAD will become higher.

Max Shear Strain

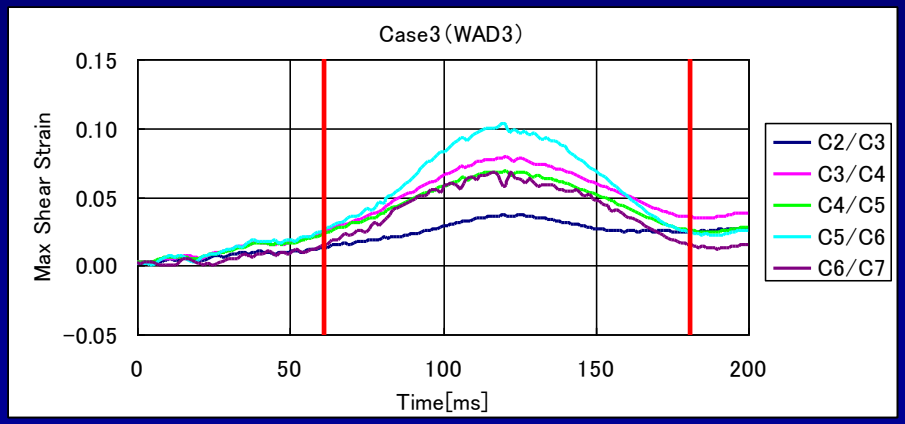
Case1（WAD1）



Case2（WAD2）



Case3（WAD3）

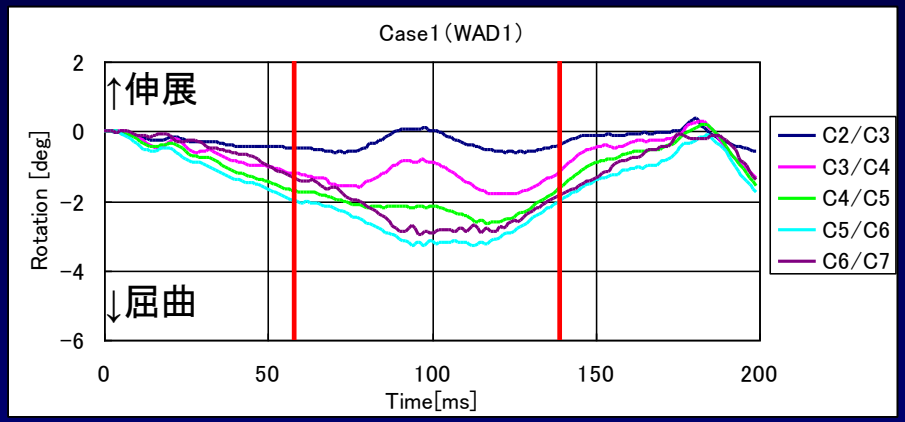


For all cases,

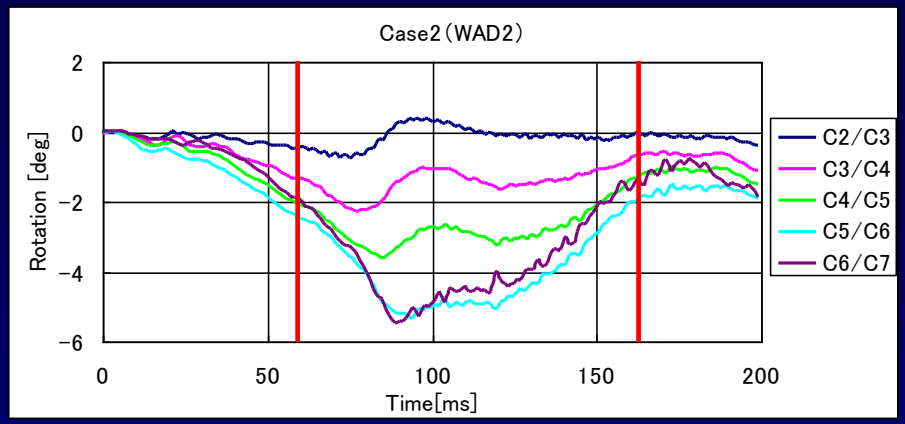
- The highest strain of the cervical vertebral region (CVR) is located in C5/C6.
- The smallest strain of the CVR is located in C2/C3.
- Accordingly an increasing crash pulse, means that the WAD will become higher.

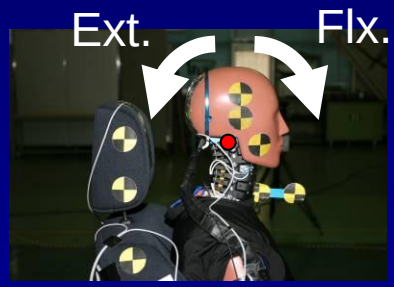
C. V. Rotation

Case1（WAD1）

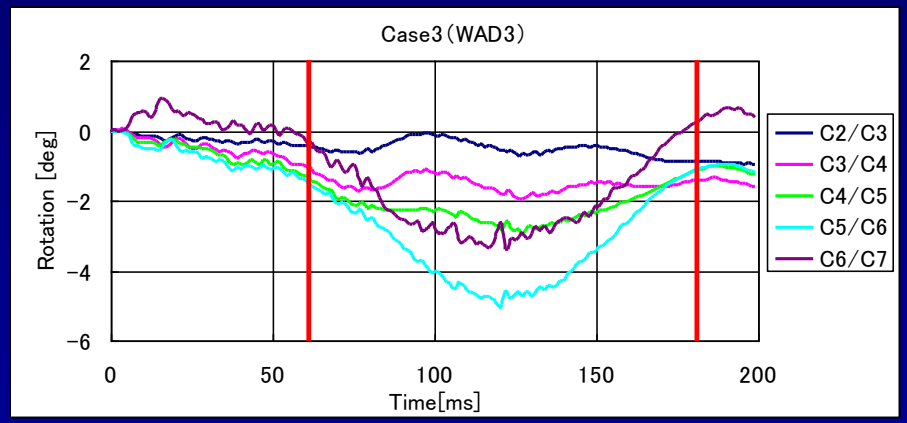


Case2（WAD2）





Case3（WAD3）

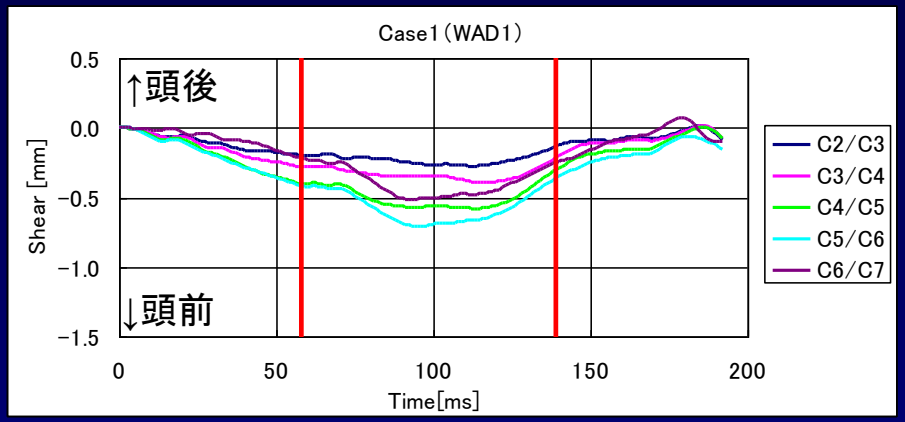


For all cases,

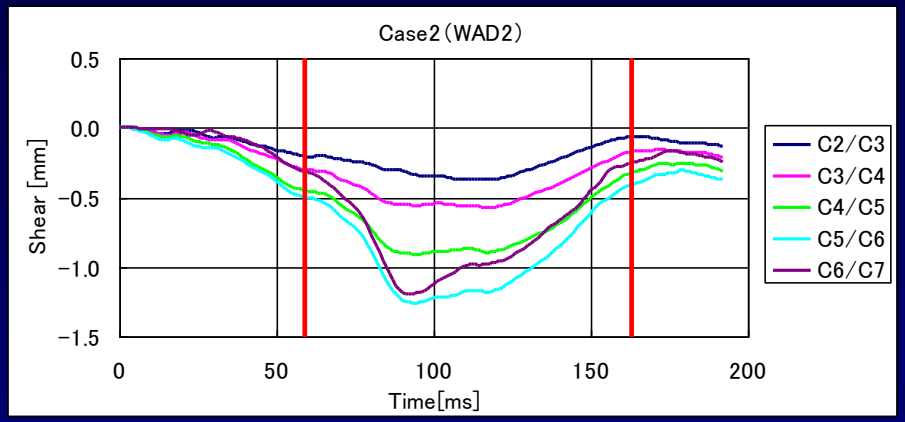
- The flexion angle rather than the extension of CV is getting larger.
- The peak angle of the extension side is shown in the C5/C6. However, for case 2, the C5/C6 and C6/C7 is almost the same.
- Accordingly an increasing rotational angle of CV, means that the WAD will also become higher.

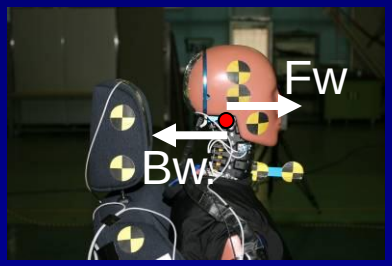
Shear (Sliding) Motion

Case1（WAD1）

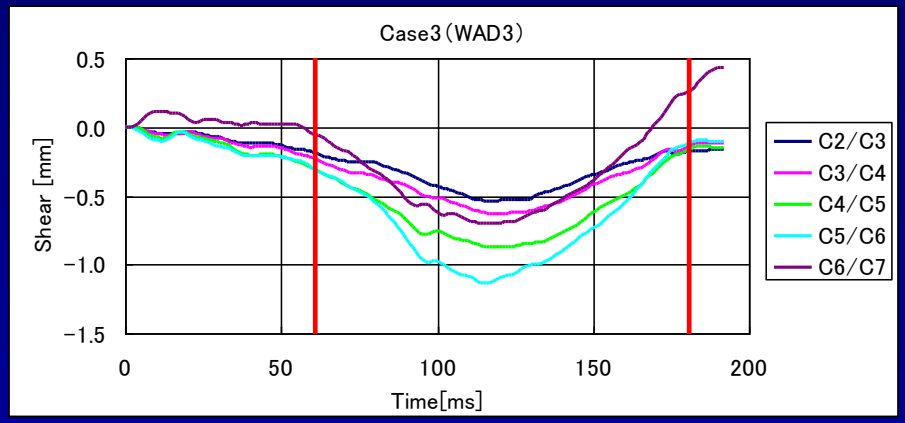


Case2（WAD2）





Case3（WAD3）

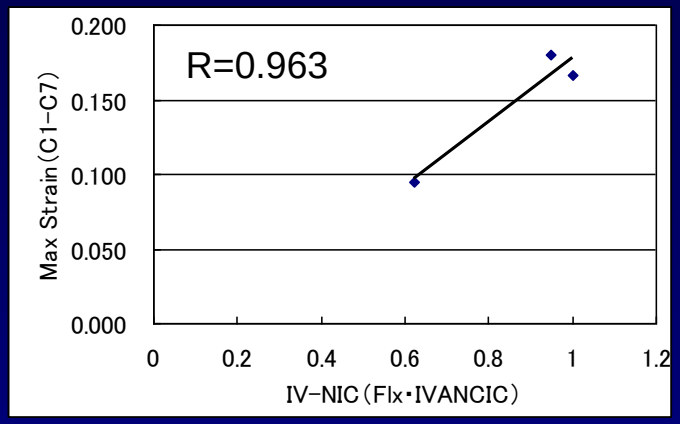


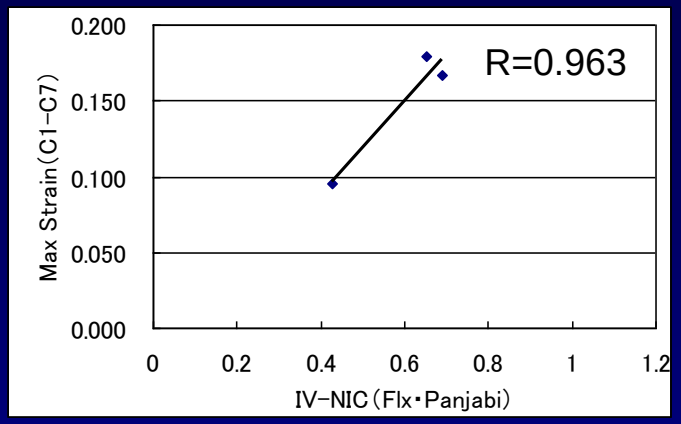
For all cases,

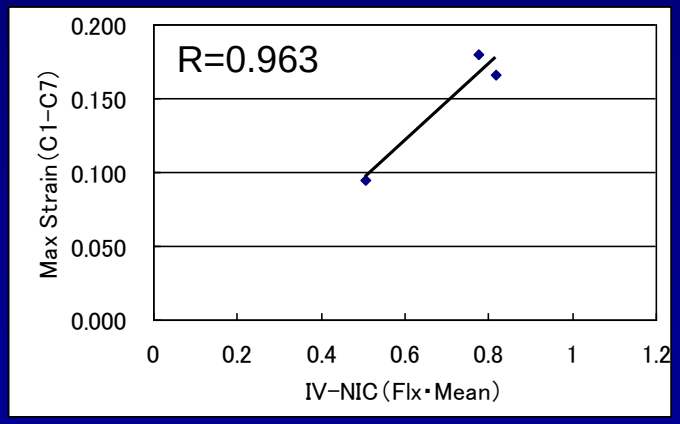
- The sliding motion in head forward than one in head backward is getting higher.
- The peak sliding motion in head forward is largest in the C5/C6.
- Accordingly an increasing sliding motion in head forward, means that the WAD will also become higher.

Relationship between Max. Principal Strain and IV-NIC・Rotation

Flexion



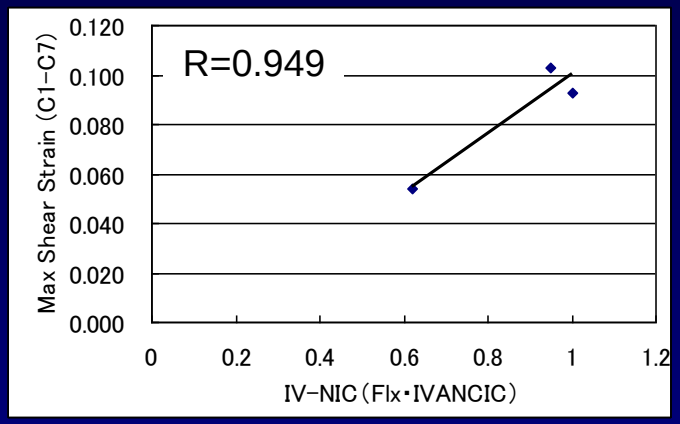


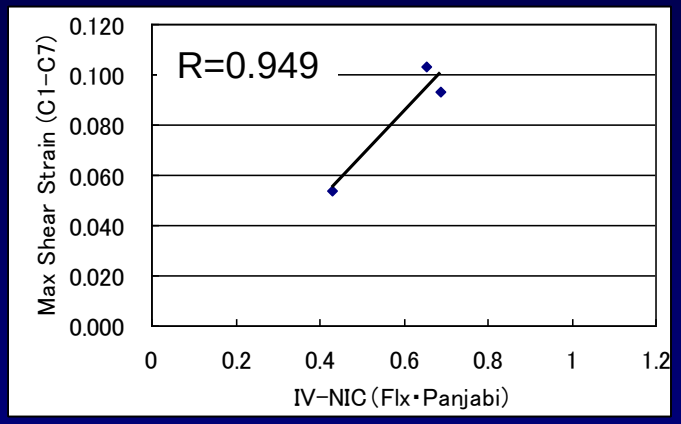


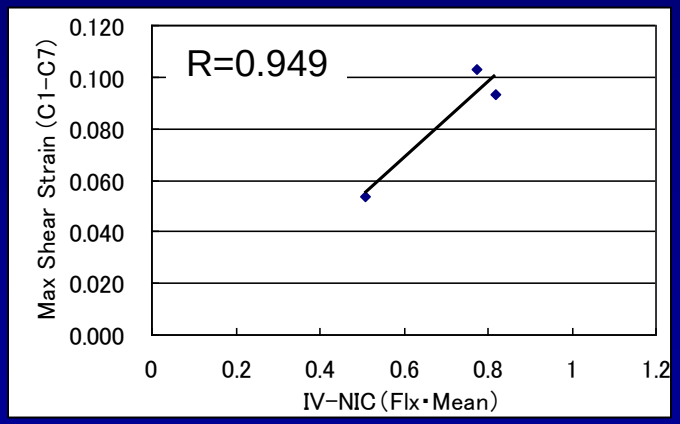
Correlation between maximum principal strain and IV-NIC (Rotation - Flexion): Coefficient of correlation (R) of only 3 accident cases is 0.963.

Relationship between Max. Shear Strain and IV-NIC・Rotation

Flexion



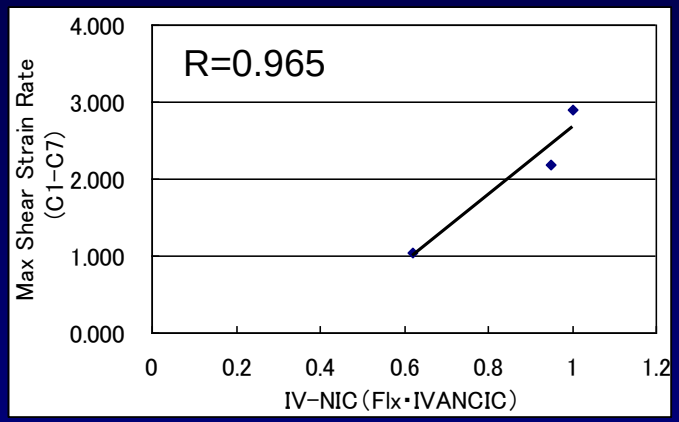


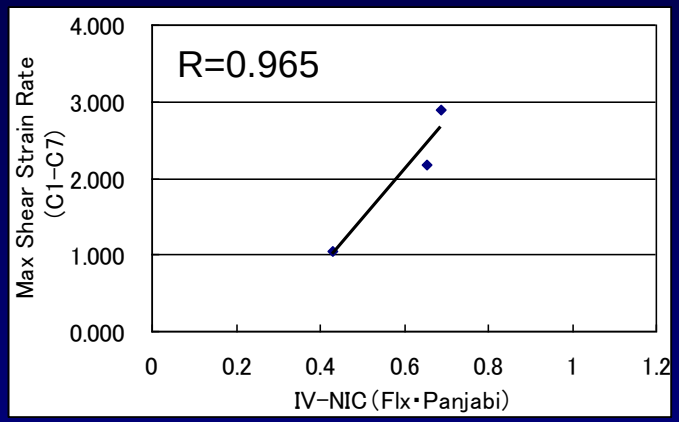


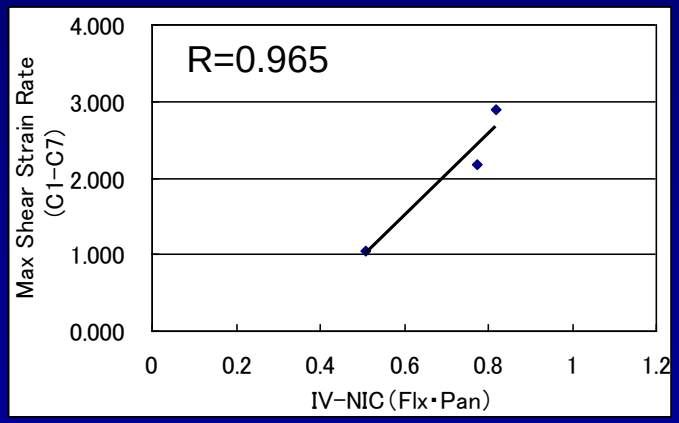
Correlation between maximum shear strain and IV-NIC (Rotation - Flexion): Coefficient of correlation (R) of only 3 accident cases is 0.949.

Relationship between Max. Shear Strain-rate and IV-NIC・Rotation

Flexion







Correlation between maximum shear strain-rate and IV-NIC (Rotation - Flexion): Coefficient of correlation (R) of only 3 accident cases is 0.965.

IV-NIC・Rotation

Rotation：Extension

	Extension					
	IVANCIC		Panjabi		Mean	
Case1・WAD1	C2/C3	0.0758	C2/C3	0.1095	C2/C3	0.0896
Case2・WAD2	C2/C3	0.0738	C2/C3	0.1067	C2/C3	0.0873
Case3・WAD3	C6/C7	0.1175	C6/C7	0.1291	C6/C7	0.1230

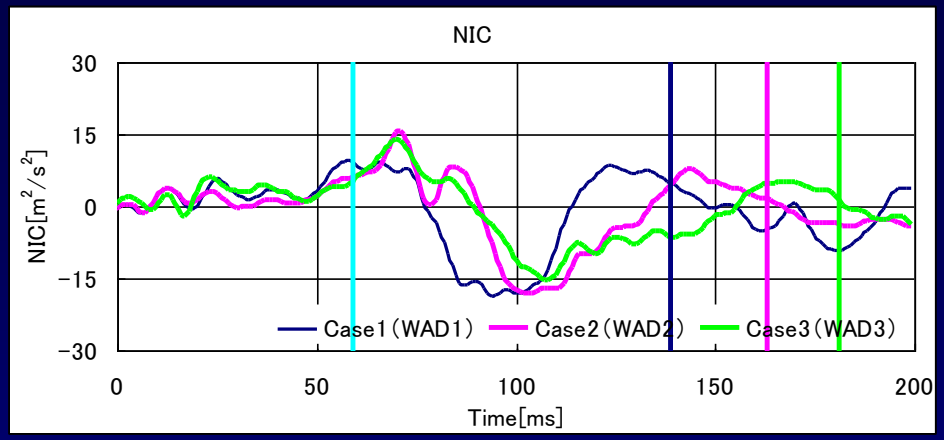
Rotation：Flexion

	Flexion					
	IVANCIC		Panjabi		Mean	
Case1・WAD1	C5/C6	0.6223	C5/C6	0.4283	C5/C6	0.5074
Case2・WAD2	C5/C6	1.0018	C5/C6	0.6896	C5/C6	0.8169
Case3・WAD3	C5/C6	0.9500	C5/C6	0.6539	C5/C6	0.7746

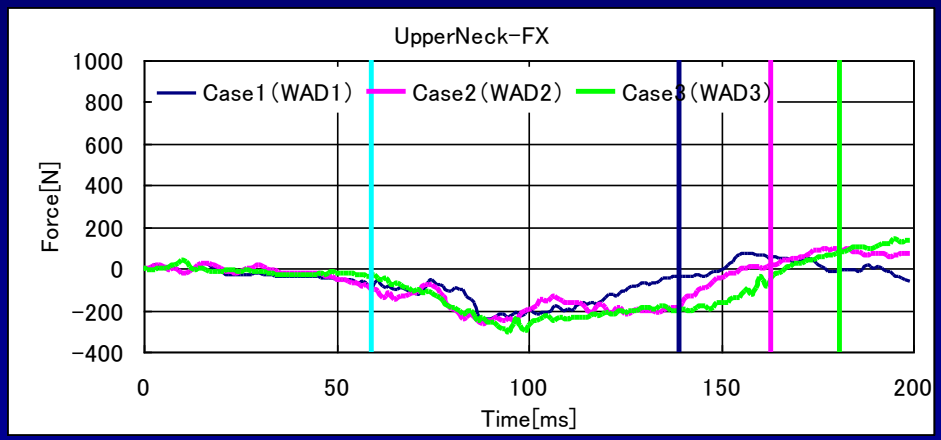
※ Symptoms (WAD) may occur when IV-NIC exceeds "1".

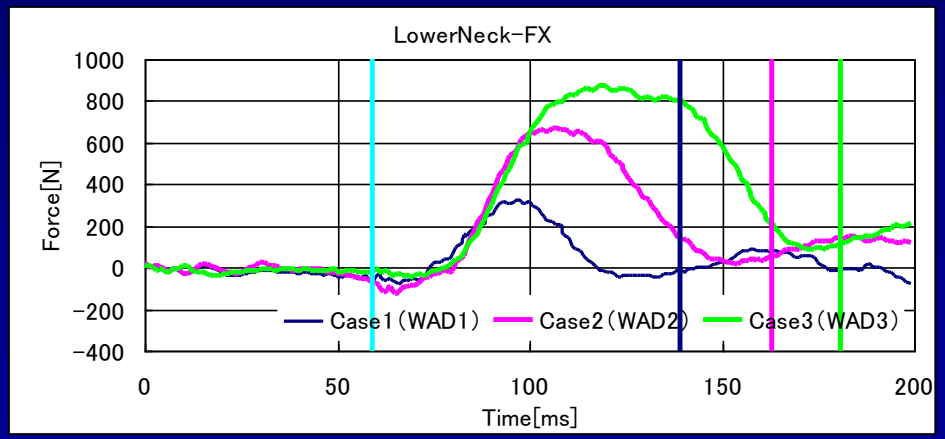
The extension side: "0.1" is shown, and none of the cases have more than "1".
The flexion side: IV-NIC between "0.4-1". In Case2, IV-NIC exceeded "1".

NIC



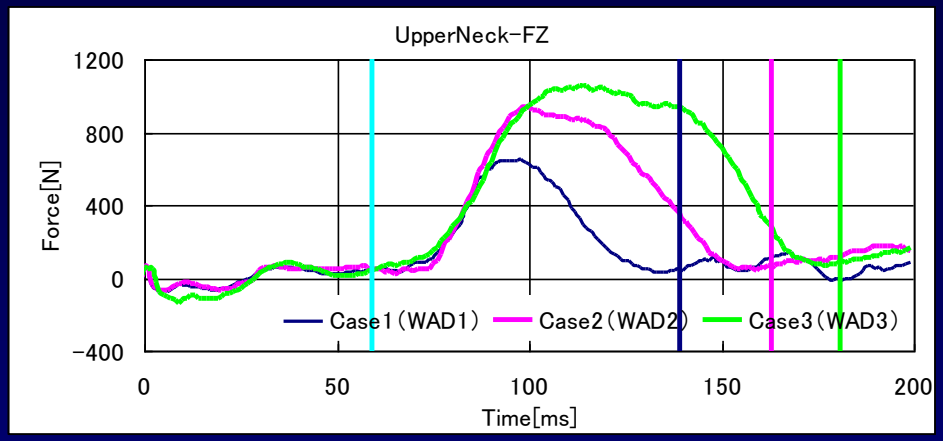
UpperNeck-FX, LowerNeck-FX

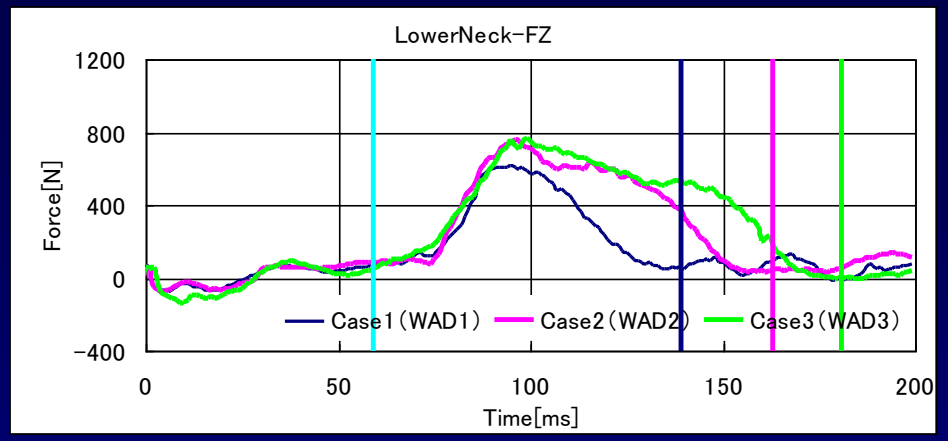




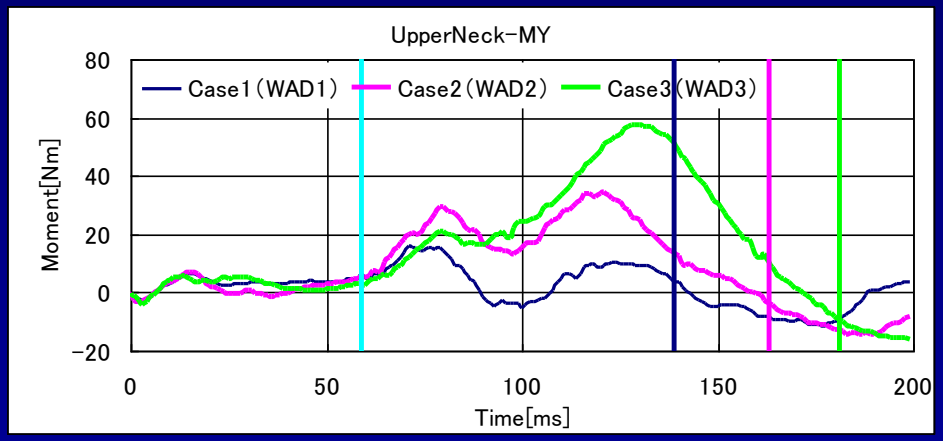
※ Notification in the Figure,
The light blue line shows the starting point of contact to the head/headrest,
The dark blue, the pink, and the yellow green lines show the ending point of contact to the head/headrest.

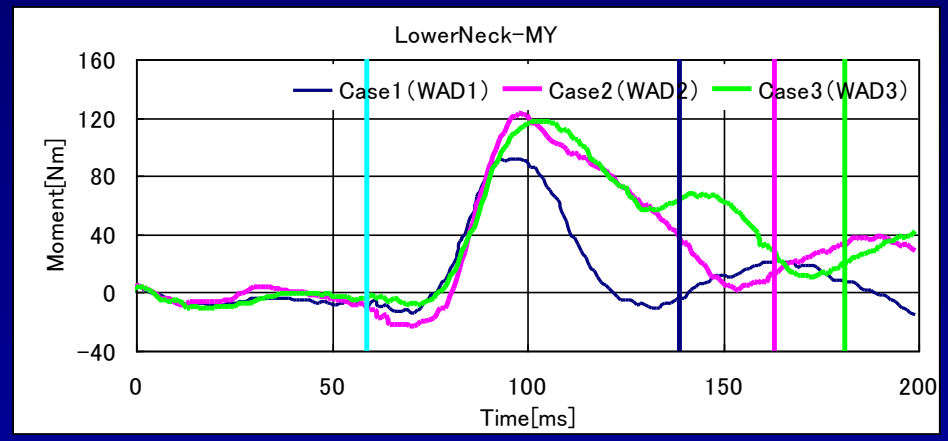
UpperNeck-FZ, LowerNeck-FZ





UpperNeck-MY, LowerNeck-M）





※ Notification in the Figure,
The light blue line shows the starting point of contact to the head/headrest,
The dark blue, the pink, and the yellow green lines show the ending point of contact to the head/headrest.

1. Preparation for IV-NIC CAE Simulation

2. Selection of three cases (tentatively) for accident reconstruction using the FE model in a 2009 IRCOBI paper

3. Current works:

- Relationship between strain and strain rate of cervical vertebrae and IV-NIC
- Discussion of relationship between physical parameters and IV-NIC based on the results of FE simulation

4. Conclusions

Conclusions

- Based on selected conditions, accident cases with different WAD were selected.
- CAE of accident reconstruction for 3 accident cases were tentatively performed.
- Max principal strain, max shear strain, and IV-NIC (rotation, compression, and sliding) were calculated.

Conclusions (continued)

The following results were provided although it was only 3 accident cases.

- The location of CV with respect to max principal strain and max shear strain was C5/C6 for all cases.
- Accordingly an increase in strain, rotational angle, and displacement of CV, means that the WAD also gets higher.
- The higher rotational angle of CV was shown in the flexion side, the higher axial displacement of CV was shown in the tension side, and the higher sliding displacement of CV was shown in the head forward side.
- Correlation among IV-NIC (Rotation, Compression, and Sliding), rotation (flexion side), compression (compression side), and strain/strain-rate trends may be obtained.

Further works

- Although CAE accident reconstruction of only 3 cases were performed, correlations between the strain/strain-rate and IV-NIC (Rotation, Compression, and Sliding) may be obtained.
- CAE accident reconstruction with more cases may be performed soon.
- Based on the results, mutual collaboration works with USA and Japan will be performed in order to clarify relationships between neck injury parameters and IV-NIC (rotation, compression, and sliding).