Collaboration Works (USA & JAPAN)

Neck Injury Parameters based on PMHS Tests

MLIT/JASIC/Japan

1. Selection of five cases for accident reconstruction using the FE model in a 2009 IRCOBI paper
2. Relationship between strain and strain rate of cervical vertebrae and IV-NIC
3. Relationship between IV-NIC and NIC, Neck force/Moment
4. Summary of results
5. Discussion of relationship between physical parameters and IV-NIC based on the results of FE simulation
6. Conclusions
7. Further verification of the relationship between “Strain and Strain-rate” and “IV-NIC”

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Verification of the peak response time of “Strain” and “IV-NIC”

The peak response time of “Strain” and “IV-NIC” was verified. Based on the pattern of the waveform, the four phases of head/neck responses were classified.
The classification of four phases is shown in the Table below.
For the running simulation of accident reconstruction, 5 cases were selected 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.

Four phases of H/N responses

Phase	Occupant behavior
1	Before HR contact
2	From HR contact to the time when the head velocity against the HR reached 0m/s
3	Untile the end of HR contact
4	After the end of HR contact

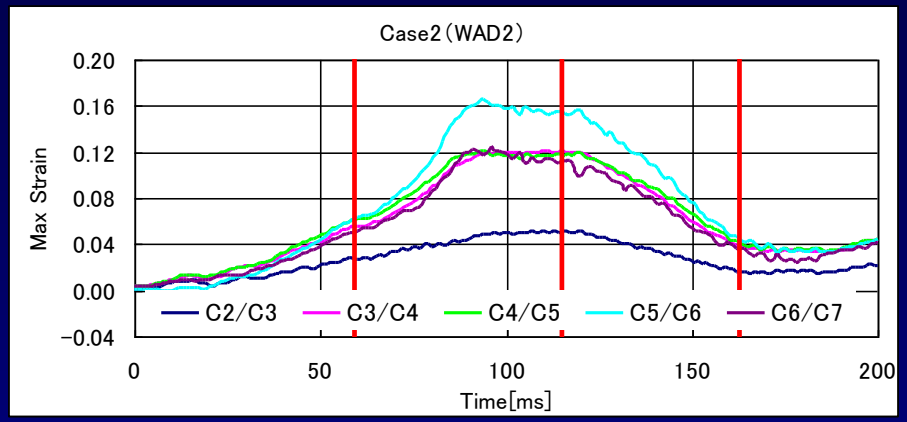
Selected 5 cases

No.	⊿v [km/h]	WAD
Case1	10.8	1
Case2	20.4	2
Case3	26.0	3
Case4	14.3	0
Case5	14.7	2

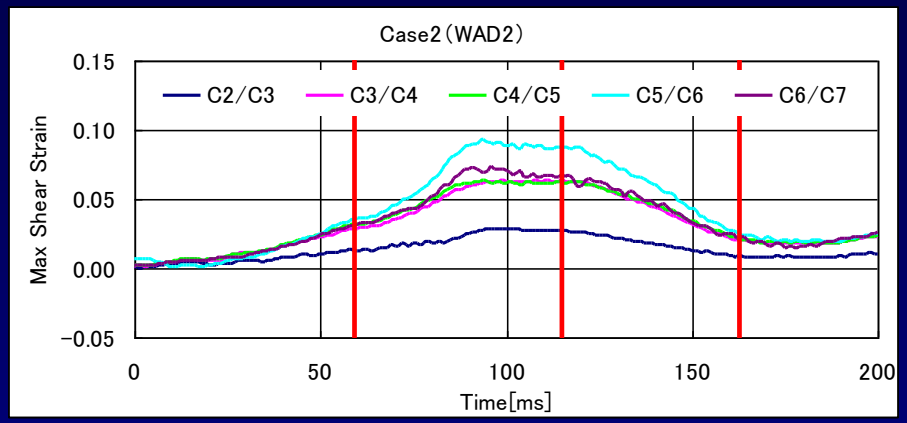
For all 5 cases, the running simulation were performed. Here, the results of the accident reconstruction for the case are shown as an example for the representative pattern.

Phase on the peak response time of “Strain” and “Strain-rate”

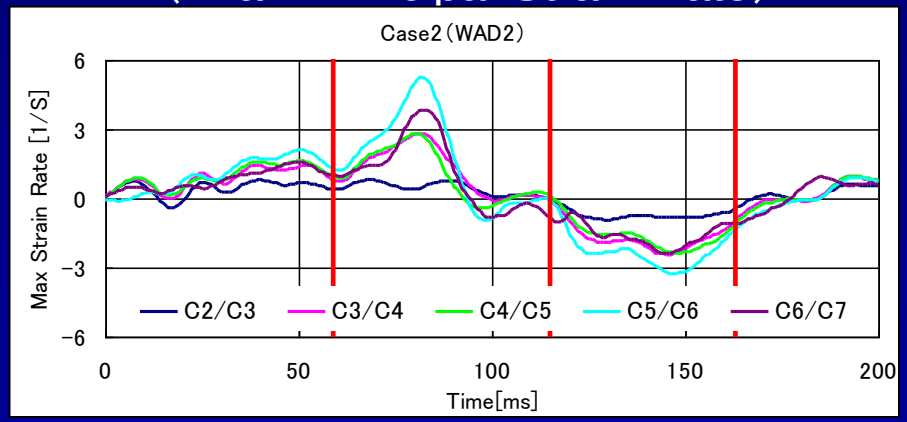
（Max. Principal Strain）



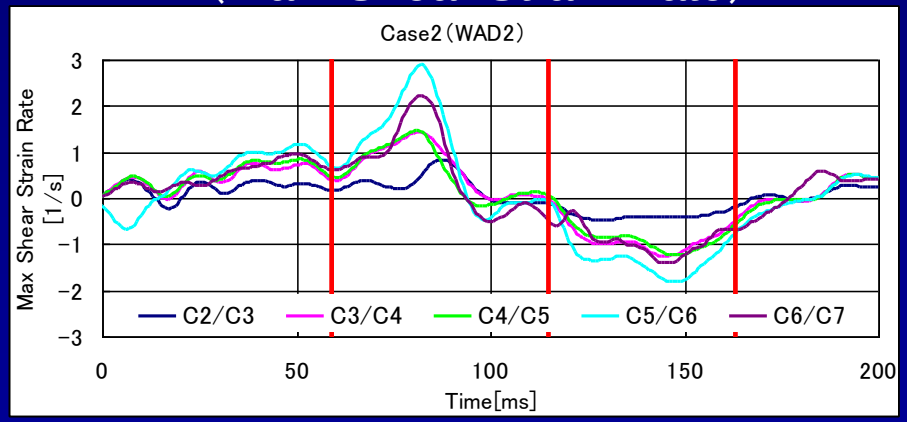
（Max. Shear Strain）



（ Max. Principal Strain Rate）



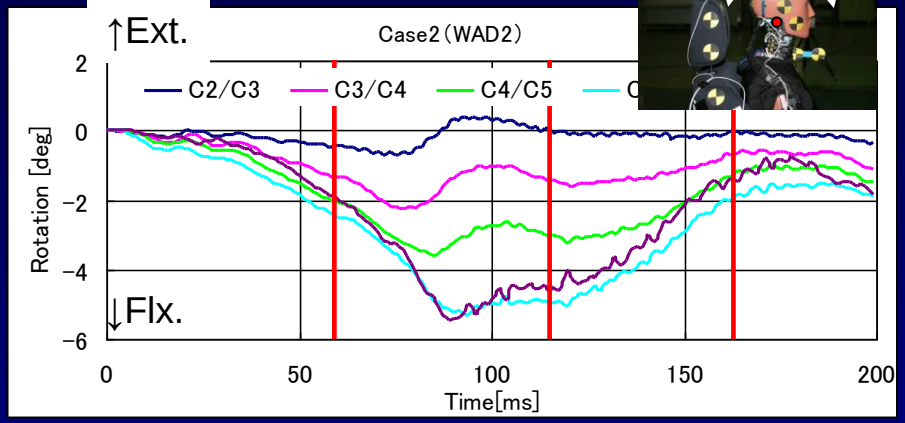
（Max. Shear Strain Rate）



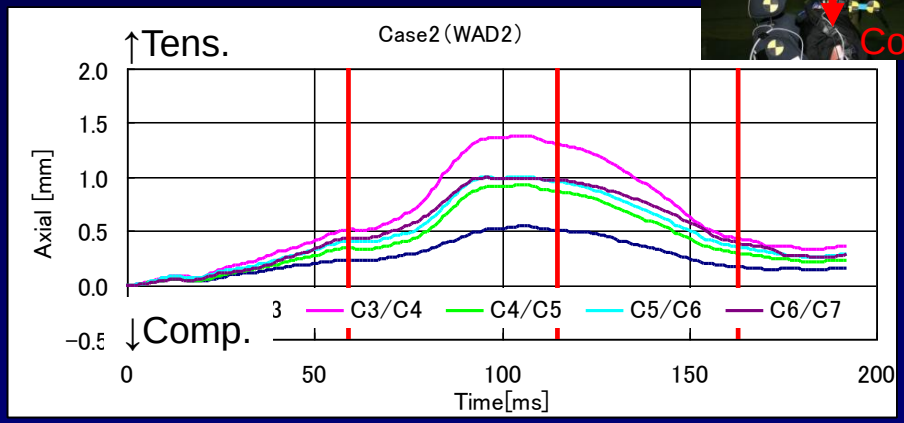
The peaks of Strain and Strain-rate were observed in the Phase 2

Phase on the peak response time of “Rotation”, “Shear (Sliding) ”, and “Axial Motion (Tension/Compression)”

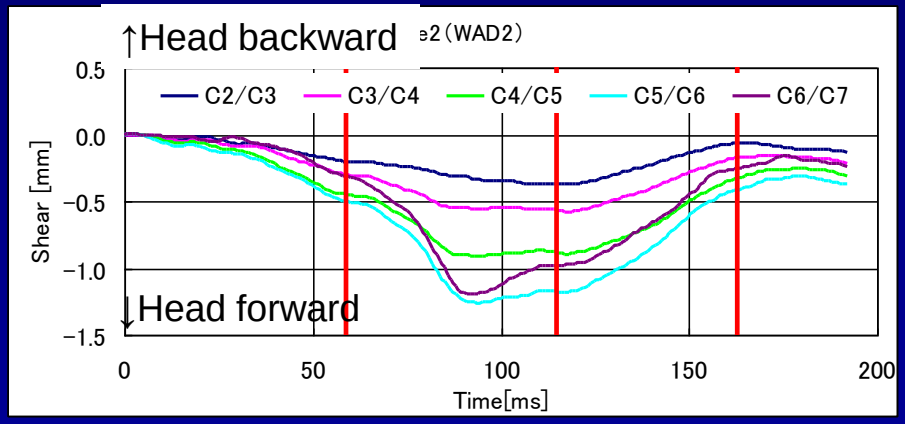
（Rotation）



（Axial Motion）



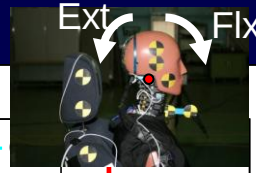
（Shear [Sliding]）

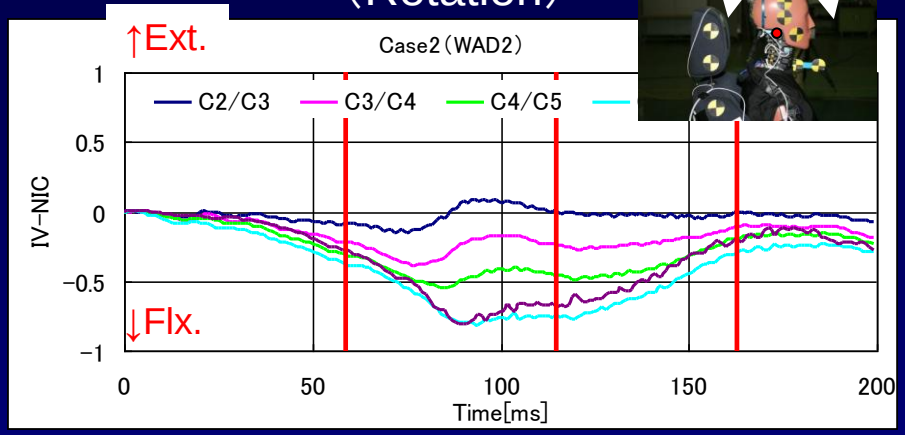


- No peak for “Rotation (Extension side)”. Peak of “Rotation (Flexion)” in Phase 2
- No peak for “Axial motion (Compression side).” Peak of “Axial motion (Tension side)” in Phase 2.
- No peak for “Shear (head backward).” Peak of “Shear (head forward)” in Phase 2.

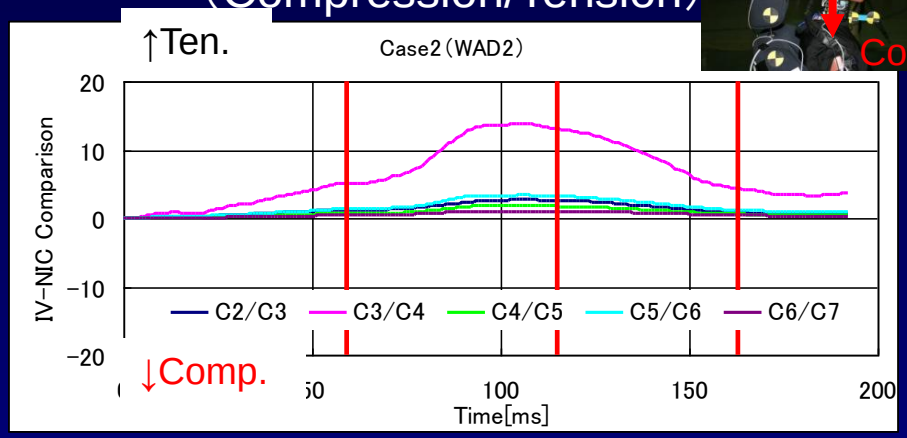
Phase on the peak response time of “IV-NIC”

（Rotation）

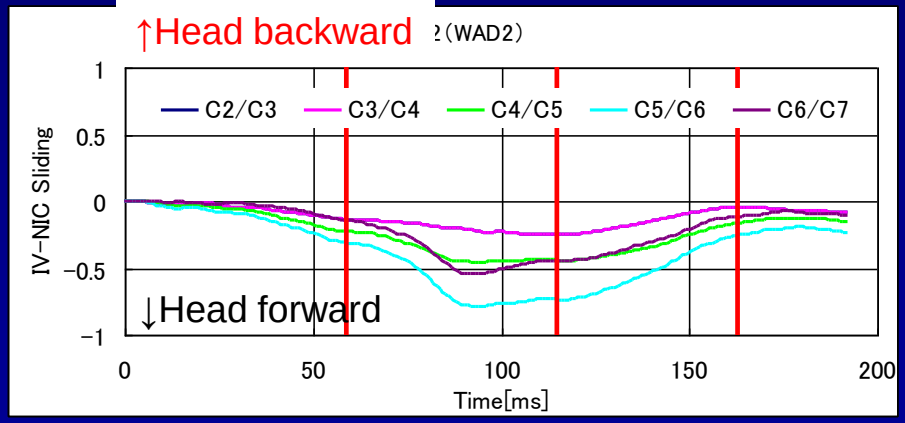


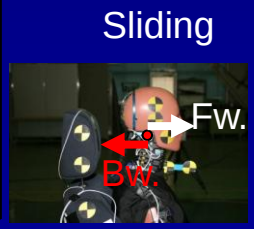


（Compression/Tension）



（Sliding）

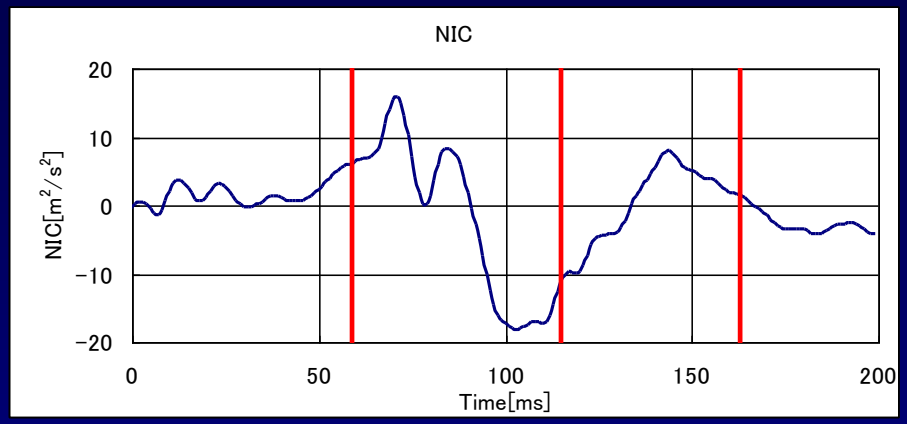




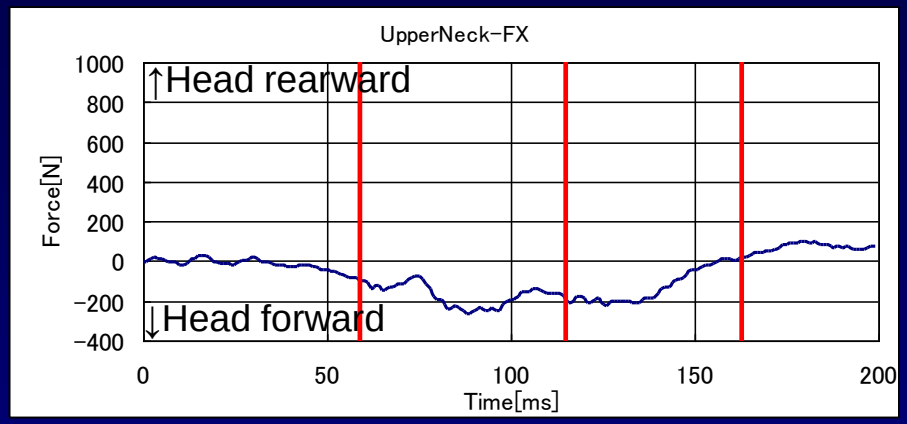
- Rotation：No peak in the extension-side. Peak of flexion-side in Phase 2.
- Compression： No peak in the comparison-side. Peak of tension-side in Phase 2.
- Sliding：No peak in the Head backward-side. Peak of Head forward-side in Phase 2.

Phase on the peak response time of “NIC and UpperNeck (force/moment)”

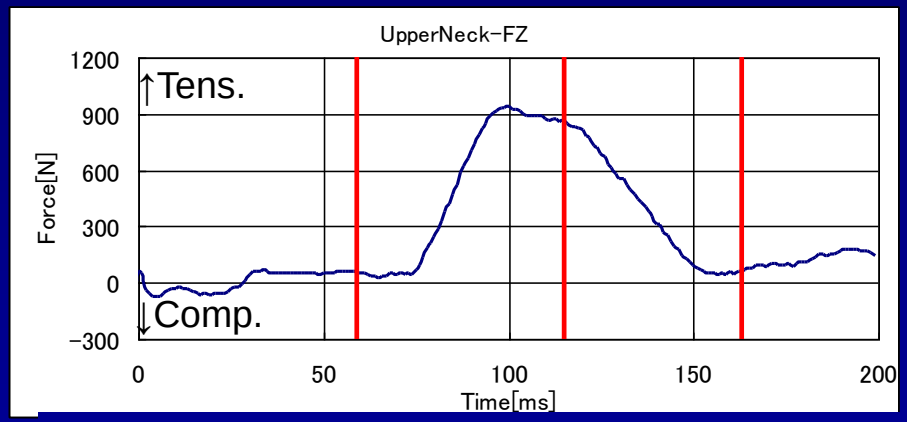
（NIC）



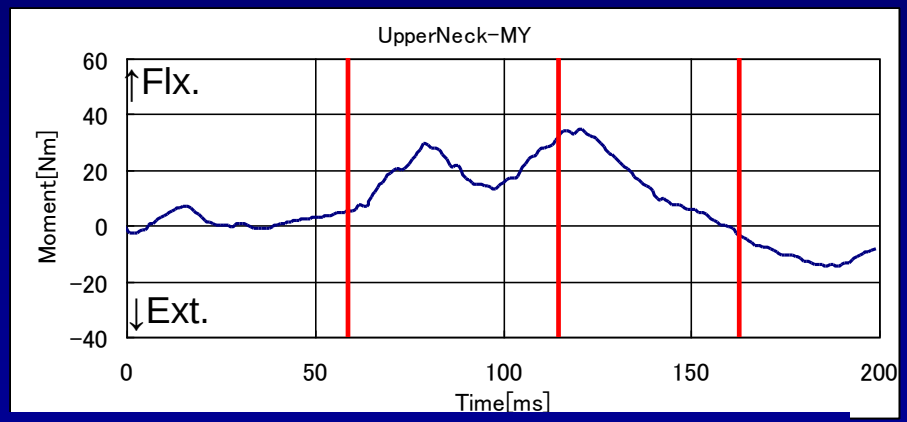
（FX）



（FZ）



（MY）



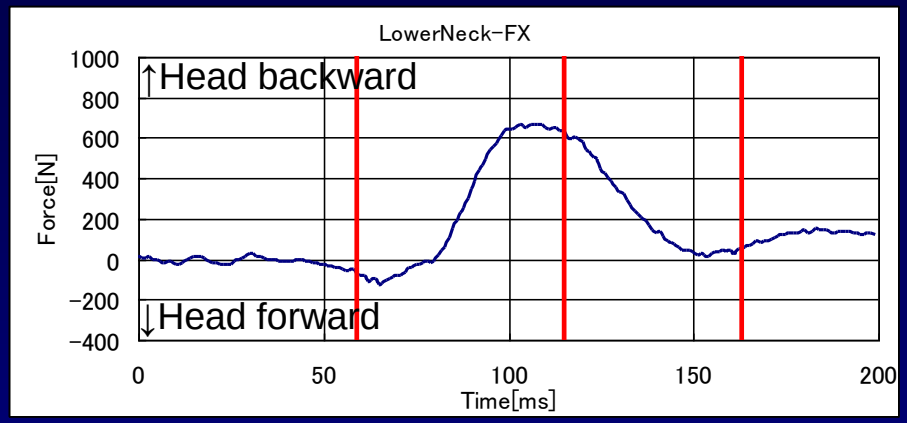
NIC: Phase 2

UpperNeck (force and moment):

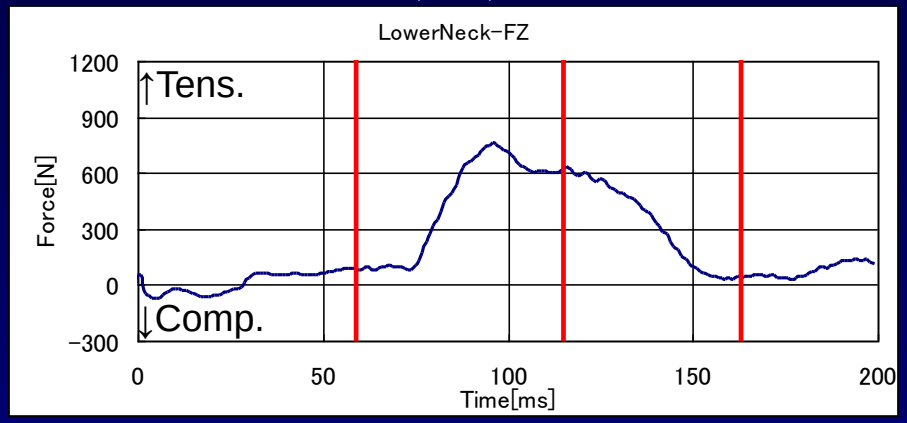
- FX：Phase 4 (head backward (+)), Phase 2 (head forward (−))
- FZ：Phase 2 (Tension (+)), Phase 1 compression (-))
- MY：Phase 2 (flexion (+)), Phase 4 (extension (-))

Phase on the peak response time of “LowerNeck (force/moment)”

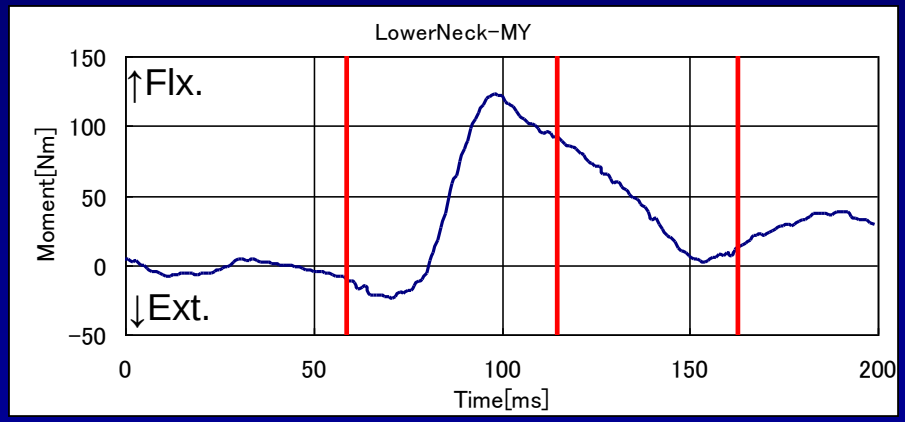
（FX）



（FZ）



（MY）

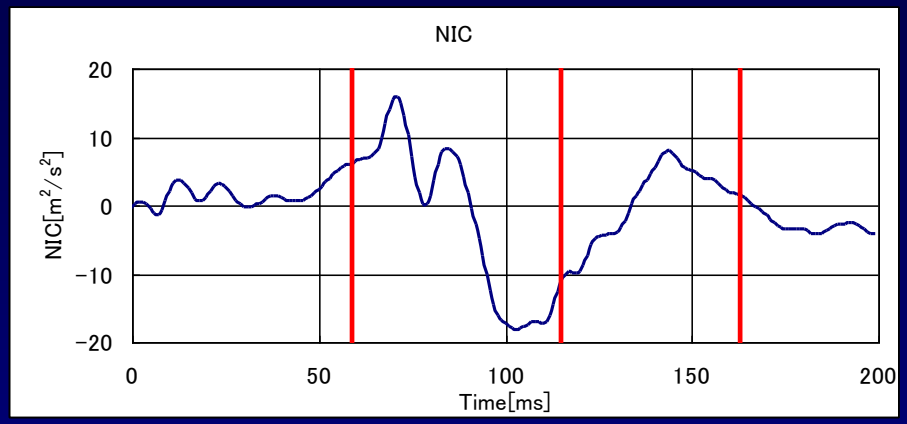


LowerNeck (force and moment):

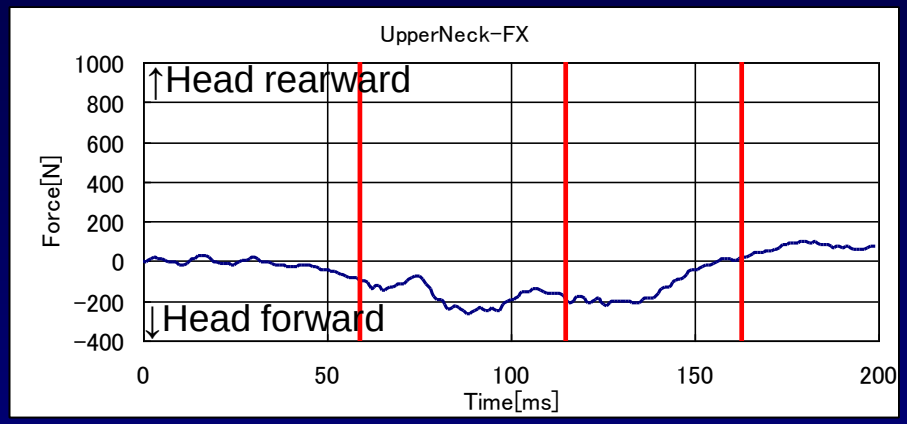
- FX：Phase 2 (head backward (+)), Phase 2 (head forward (−))
- FZ：Phase 2 (Tension (+)), Phase 1 (compression (−))
- MY：Phase 2 (flexion (+)), Phase 2 (extension (−))

Phase on the peak response time of “NIC and UpperNeck (force/moment)”

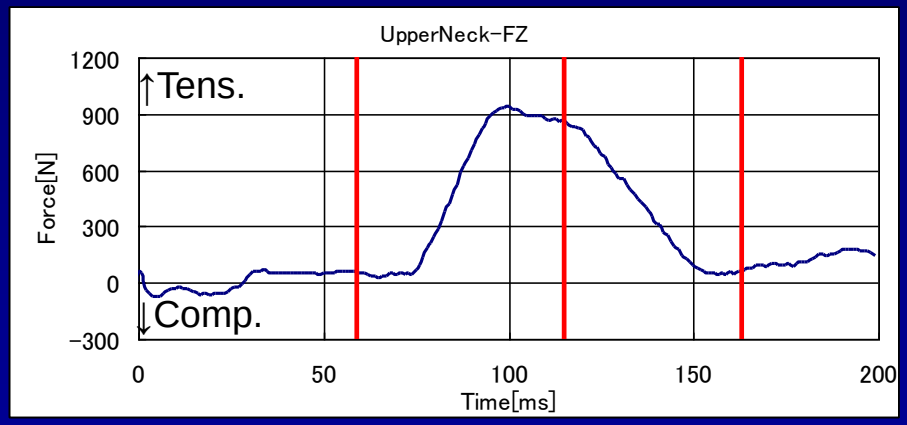
（NIC）



（FX）



（FZ）



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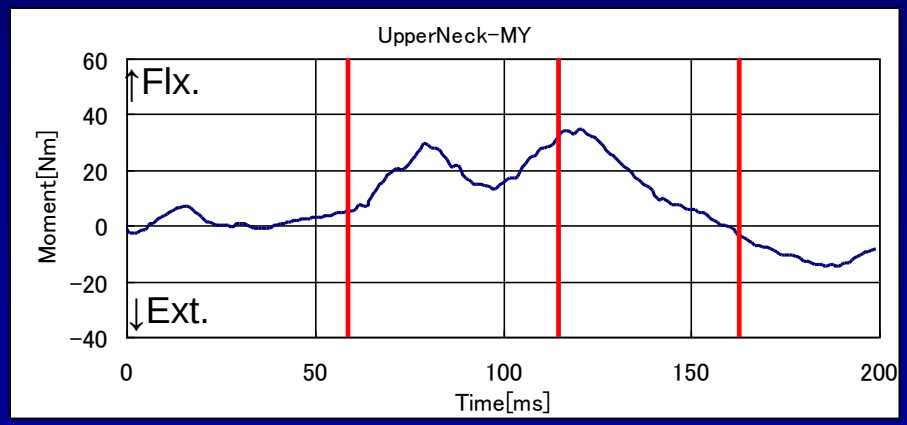


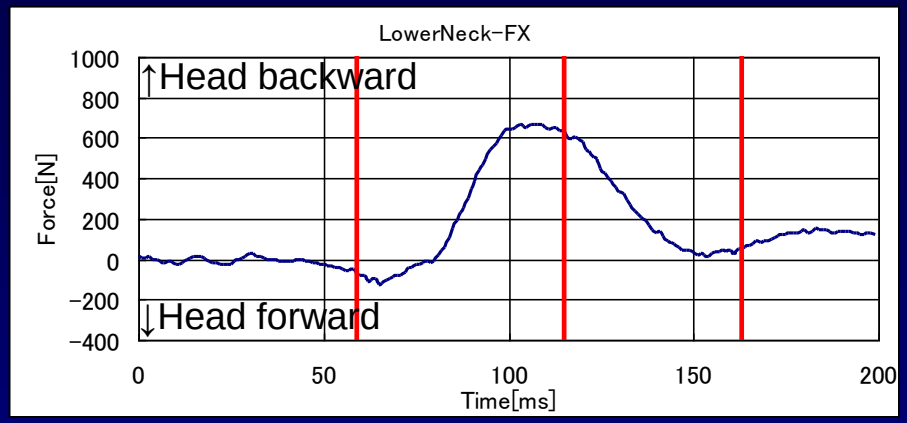
NIC: Phase 2

UpperNeck (force and moment):

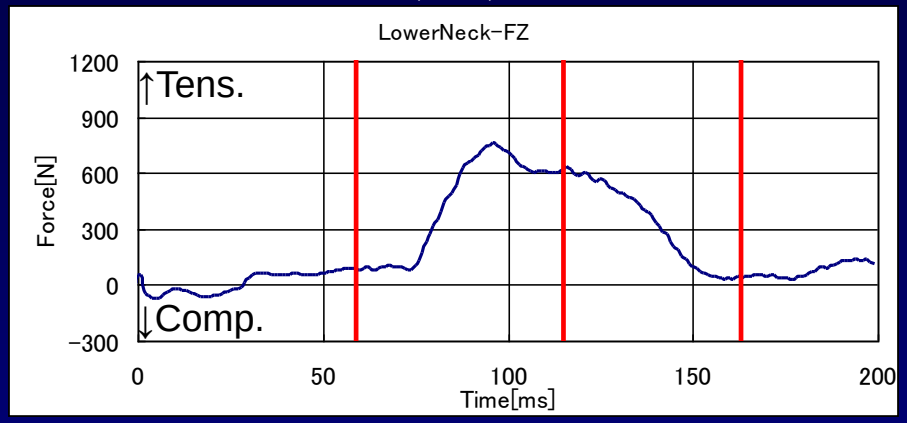
- FX：Phase 3 (head backward (+)), Phase 2 (head forward (−))
- FZ：Phase 2 (compression (+)), Phase 1 compression (-))
- MY：Phase 2 (flexion (+)), Phase 3 (extension (-))

Phase on the peak response time of “LowerNeck (force/moment)”

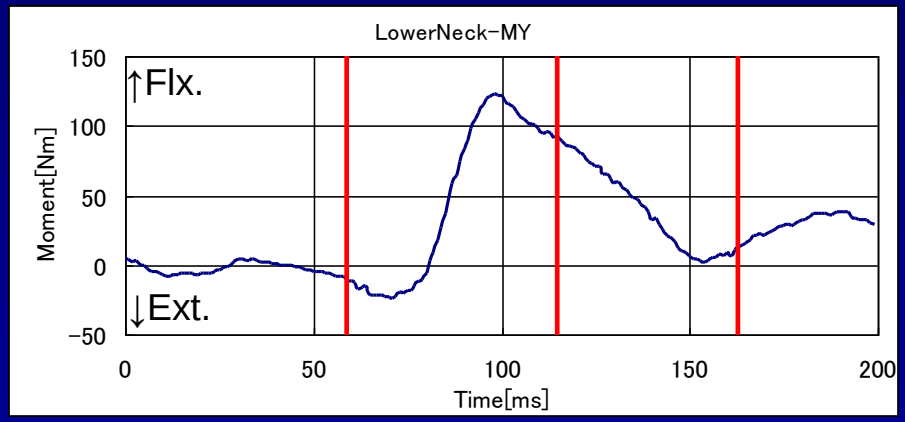
（FX）



（FZ）



（MY）



LowerNeck (force and moment):

- FX：Phase 2 (head backward (+)), Phase 2 (head forward (−))
- FZ：Phase 2 (Tension (+)), Phase 1 (compression (−))
- MY：Phase 2 (flexion (+)), Phase 2 (extension (−))

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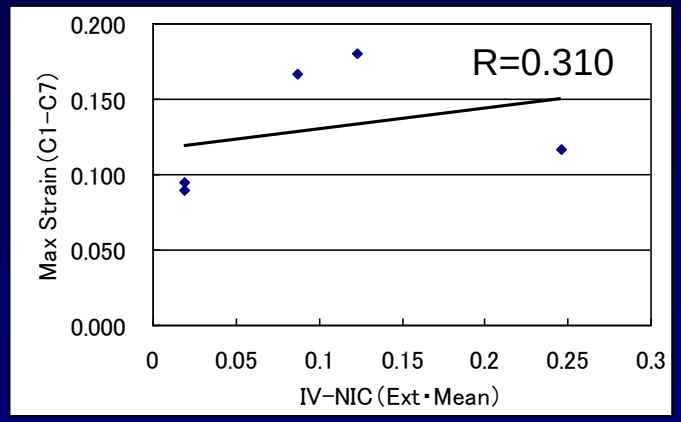
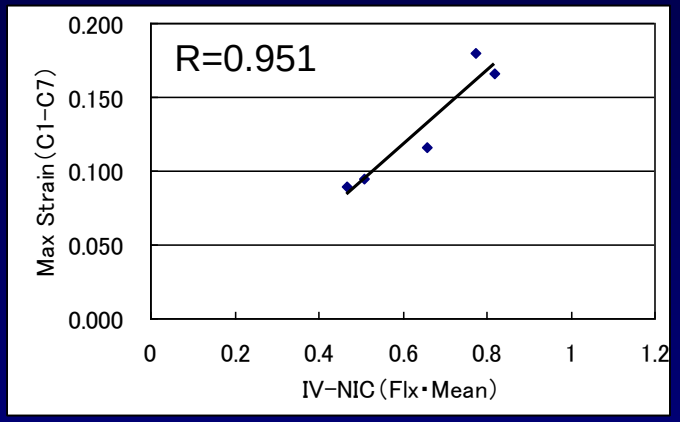
Correlations between max principal strain and IV-NIC(Rotation, Tension n and Sliding)

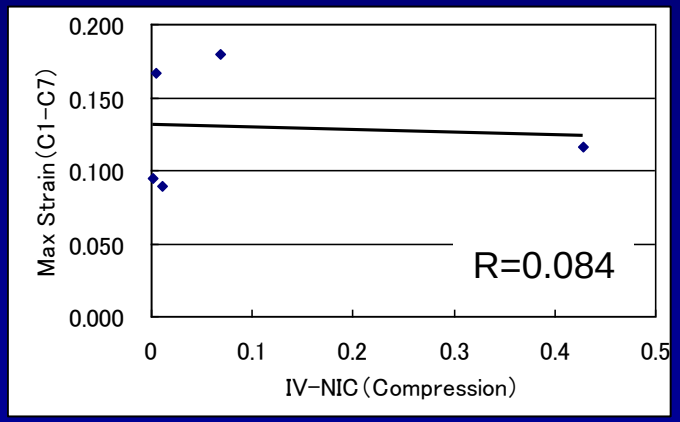
（Rotation: Extension）



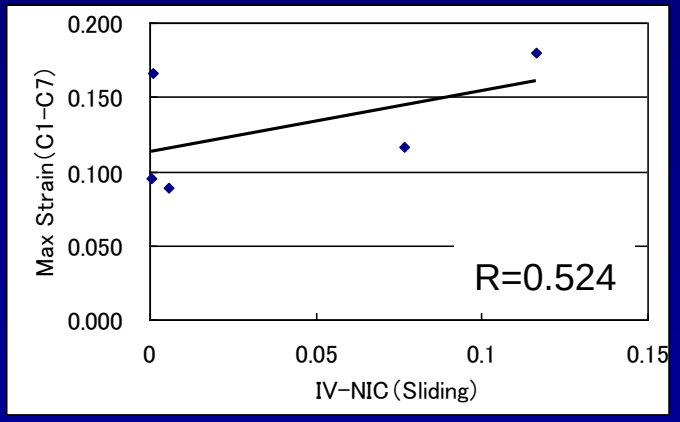
（Rotation: Flexion）



（ Tension ）



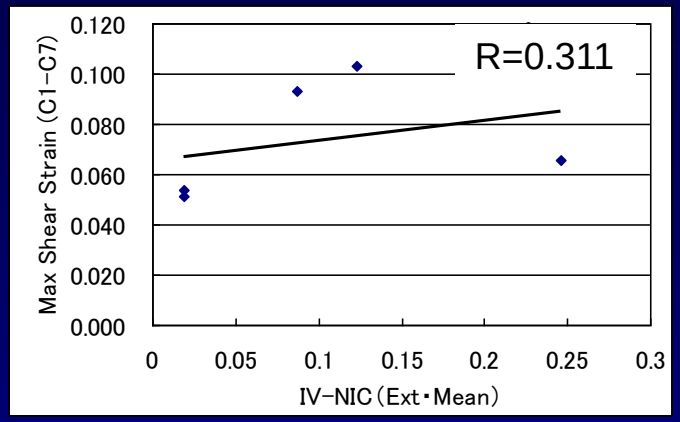
（Sliding ：Headforward ）



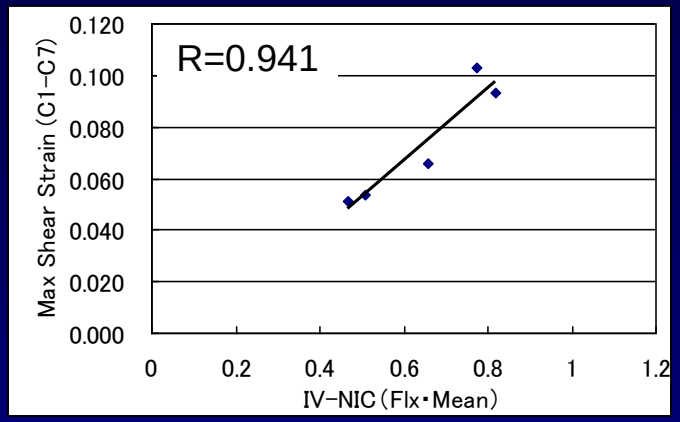
The maximum principal strain has a highest correlation coefficient R of 0.951 with IV-NIC Rotation (Flexion).

Correlations between max shear strain and IV-NIC(Rotation, Tension and Sliding)

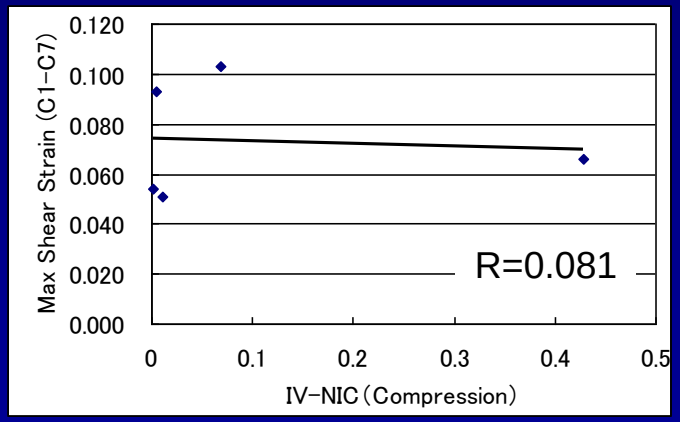
（Rotation: Extension）



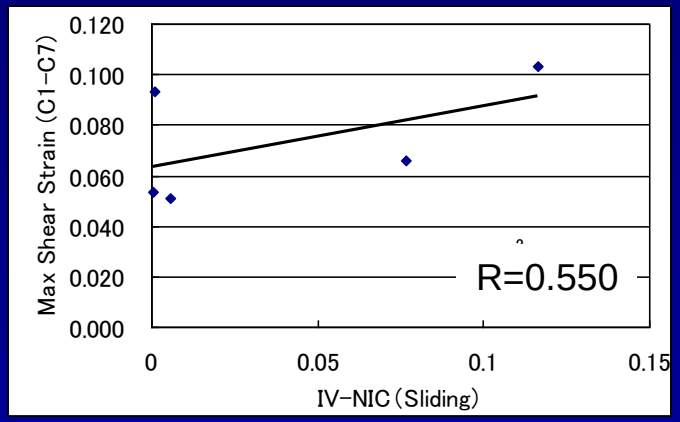
（Rotation: Flexion）



（ Tension ）



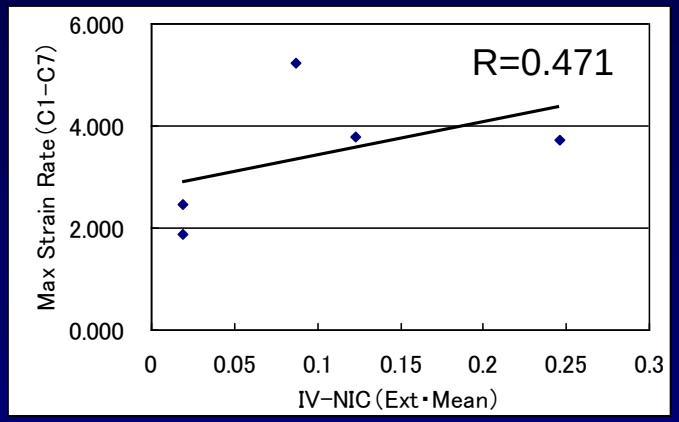
（Sliding ：Headforward



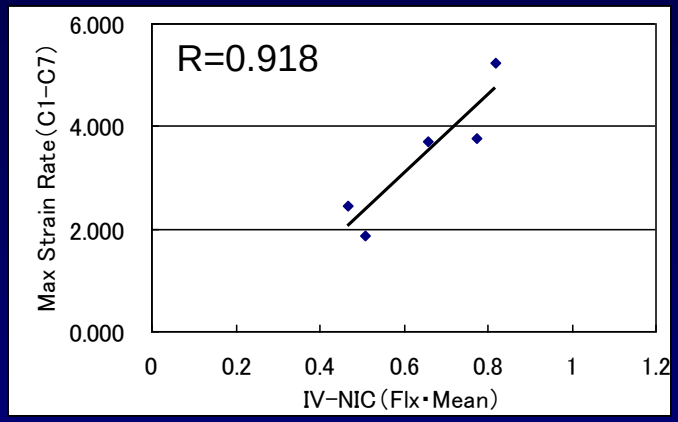
The maximum shear strain has a highest correlation coefficient R of 0.941 with IV-NIC Rotation (Flexion) and IV-NIC Tension.

Correlations between max principal strain rate and IV-NIC(Rotation, Tension and Sliding)

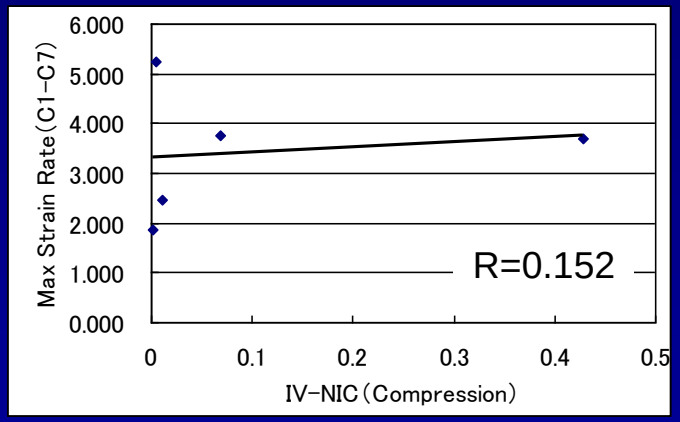
（Rotation: Extension）



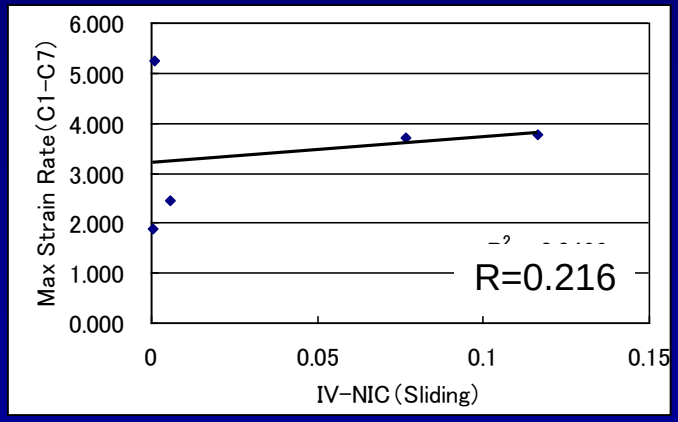
（Rotation: Flexion）



（Tension）



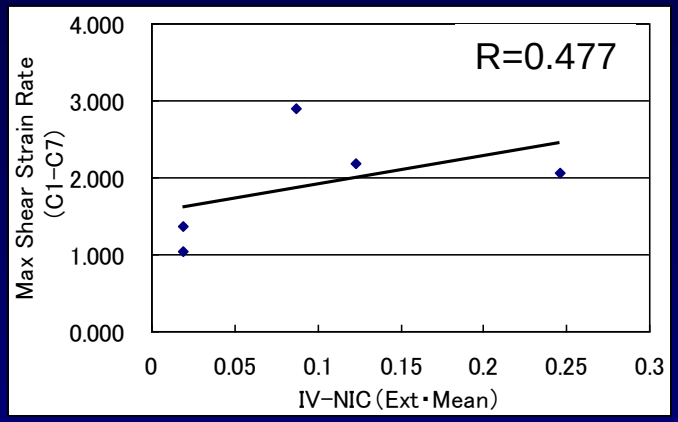
（Sliding：Headforward ）



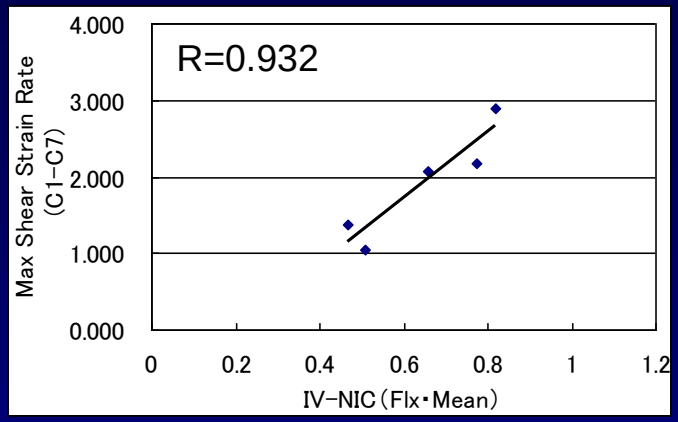
The maximum principal strain rate has a highest correlation coefficient R of 0.918 with IV-NIC Rotation (Flexion).

Correlations between max shear strain rate and IV-NIC(Rotation, Tension and Sliding)

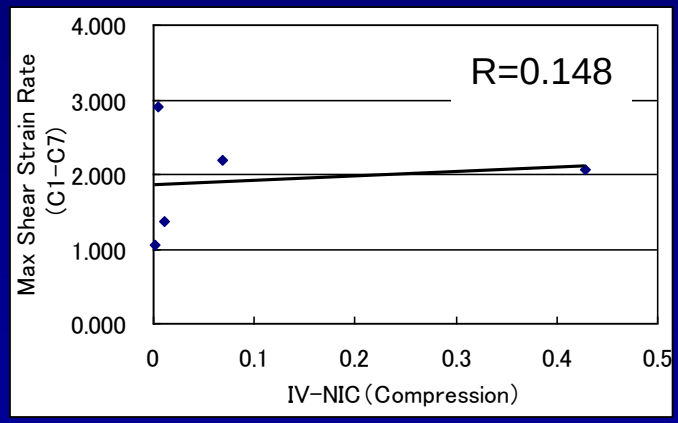
（Rotation: Extension）



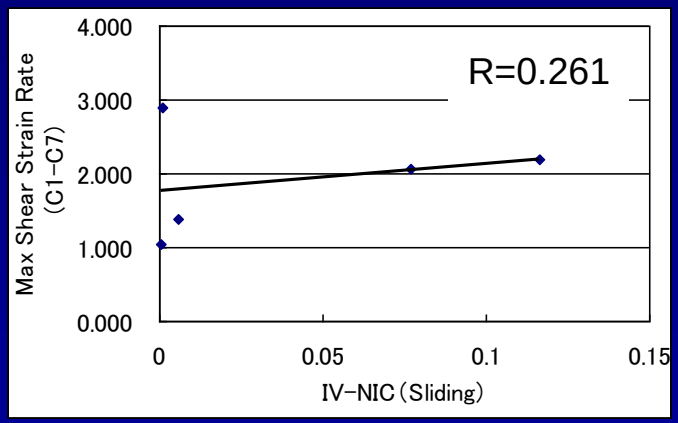
（Rotation: Flexion）



（Tension）



（Sliding：Headforward ）



The maximum shear strain rate has a highest correlation coefficient R of 0.932 with IV-NIC Rotation (Flexion).

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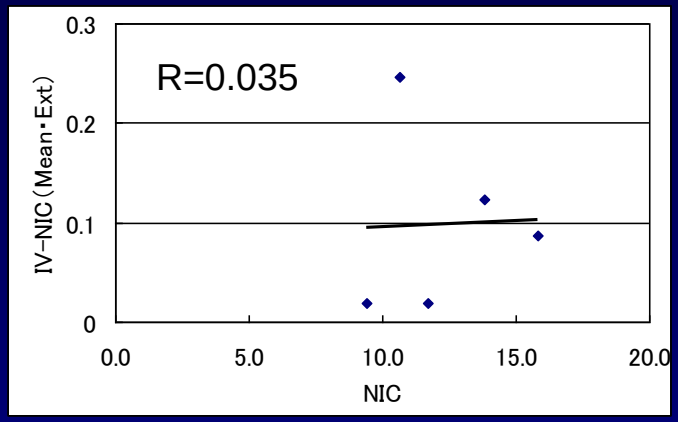
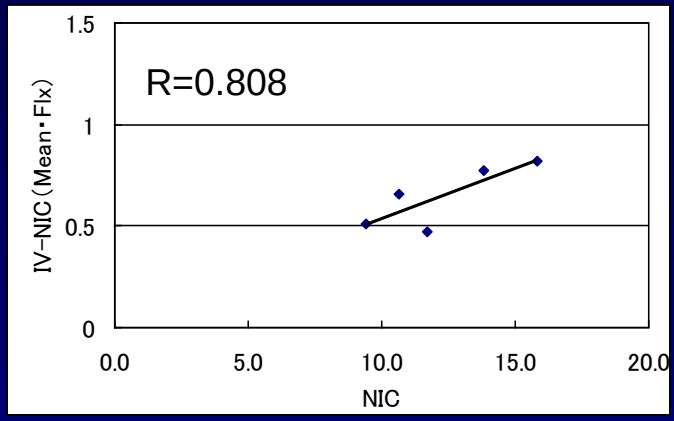
Correlations between IV-NIC（Rotation・Compression・Shear）and NIC

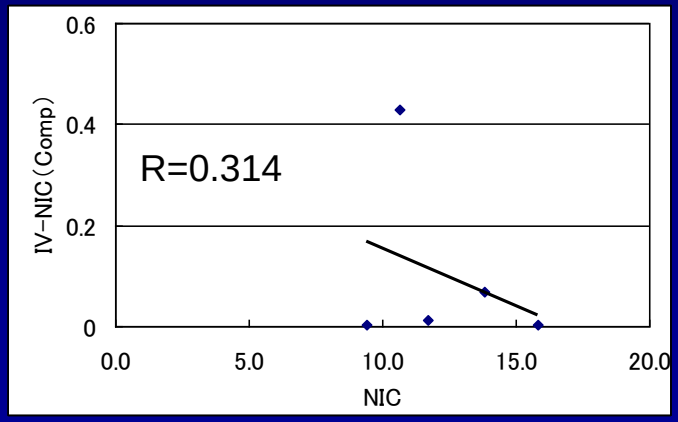
（Rotation：Extension）



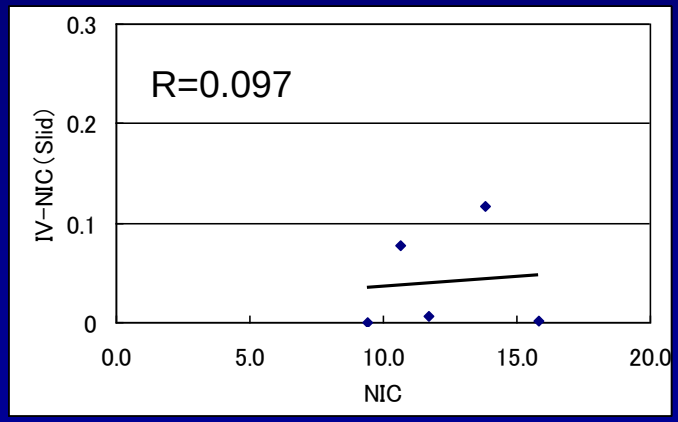
（Rotation：Flexion）



（Compression）



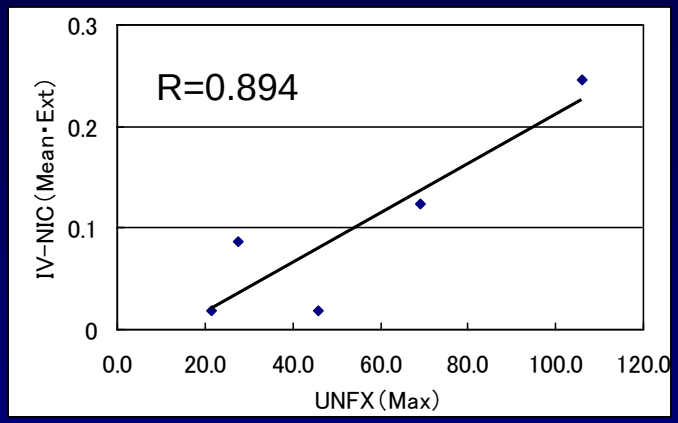
（Sliding）



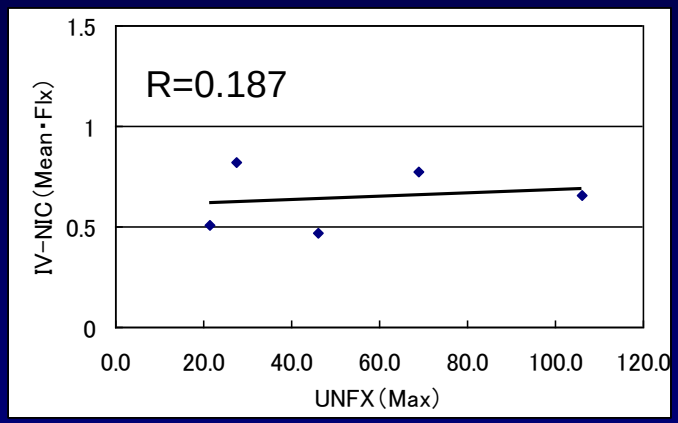
NIC correlates most highly with IV-NIC Rotation (Flexion). In contrast, NIC has a inverse correlation with IV-NIC Compression.

Correlations between IV-NIC（Rotation・Compression・Shear）and UpperNeck-Fx(Head backward)

（Rotation：Extension）



（Rotation：Flexion）



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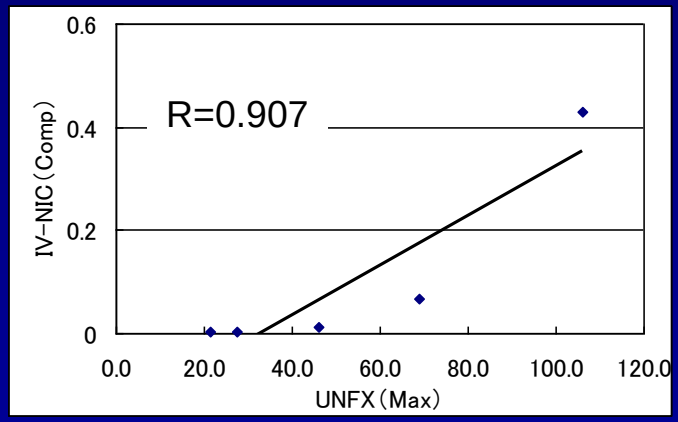

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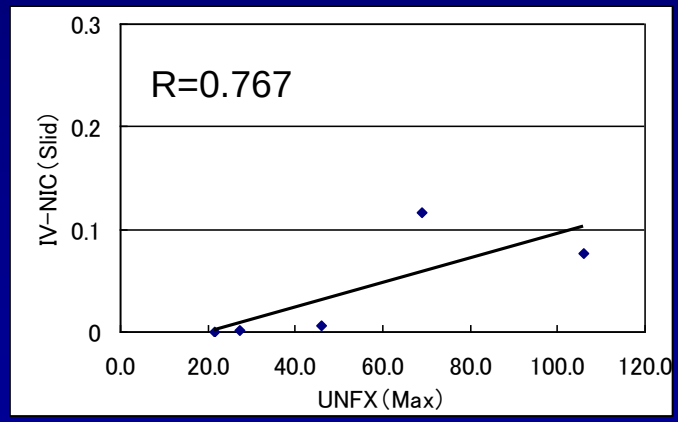
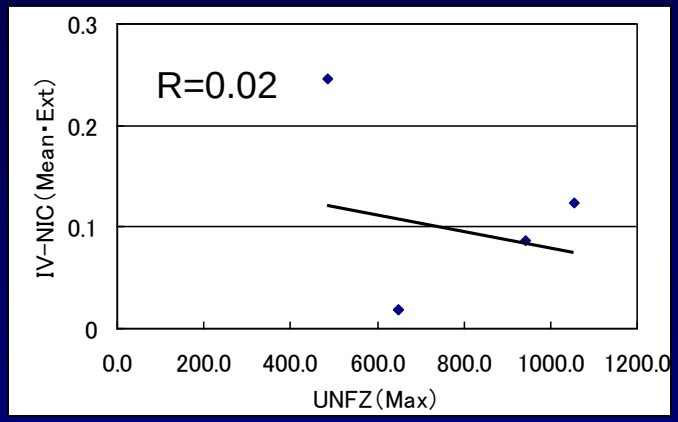


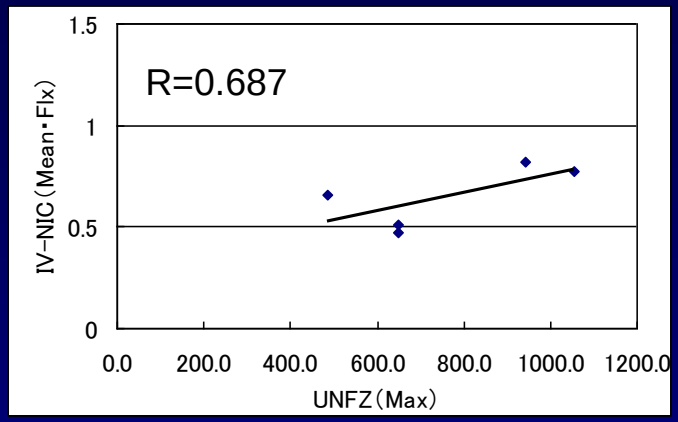
Upper Neck Fx correlates most highly with IV-NIC Compression and also has high correlations with IV-NIC Rotaion (Extension) and Sliding.

Correlations between IV-NIC（Rotation・Compression・Shear）and UpperNeck-Fz(Tension)

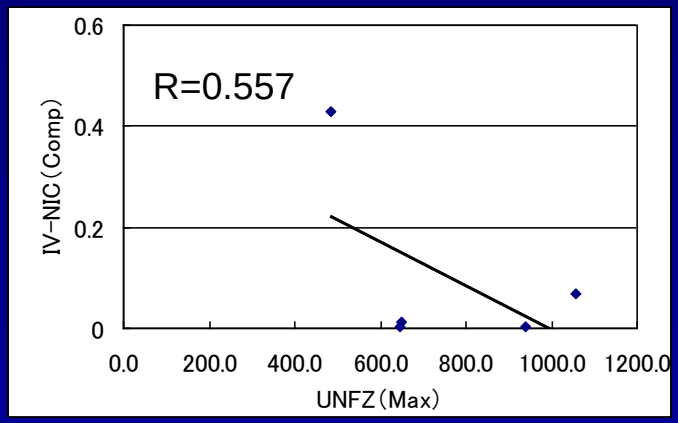
（Rotation：Extension）



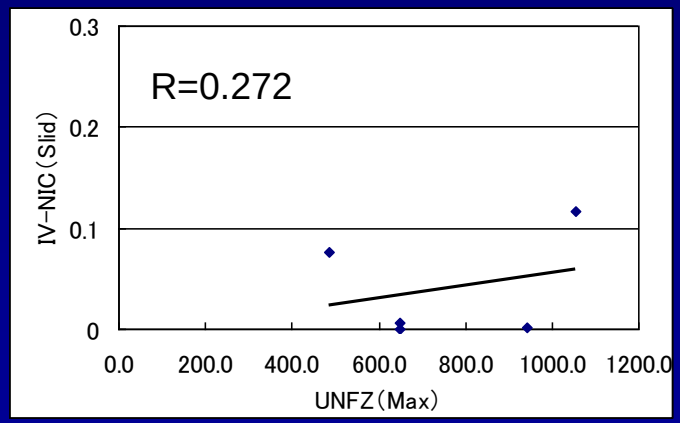
（Rotation：Flexion）



（Compression）



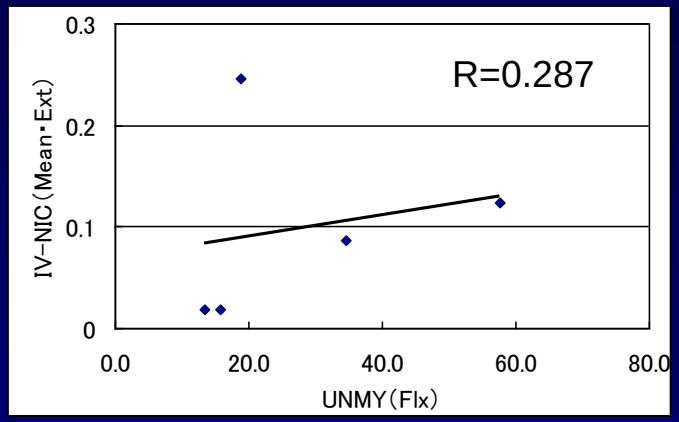
（Sliding）



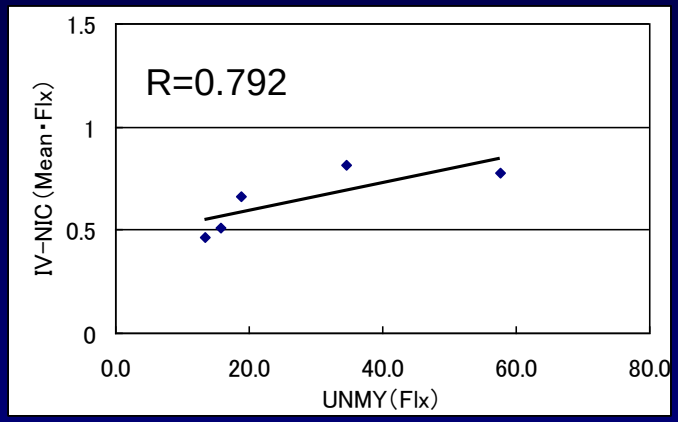
Upper Neck Fz correlates most highly with IV-NIC Rotation (Flexion). In contrast, Upper Neck Fz has inverse correlations with IV-NIC Rotation (Extension) and Compression.

Correlations between IV-NIC（Rotation・Compression・Shear）and UpperNeck-My(Flexion)

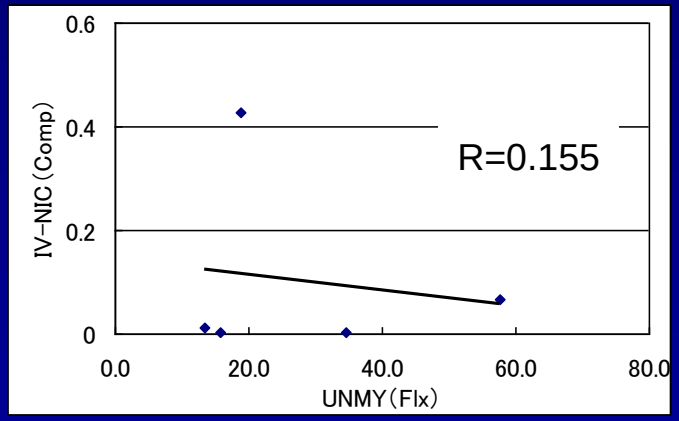
（Rotation：Extension）



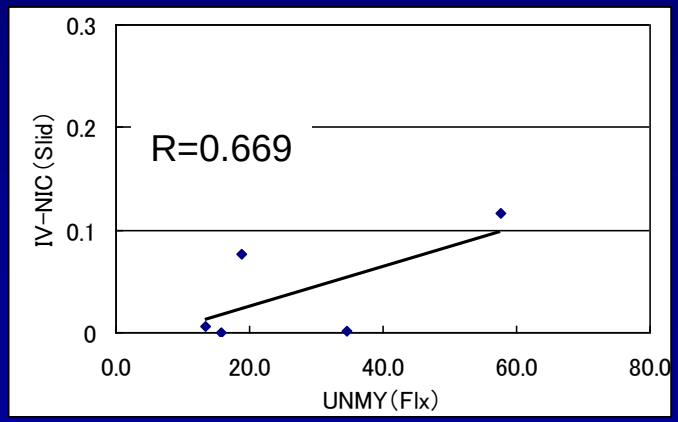
（Rotation：Flexion）



（Compression）



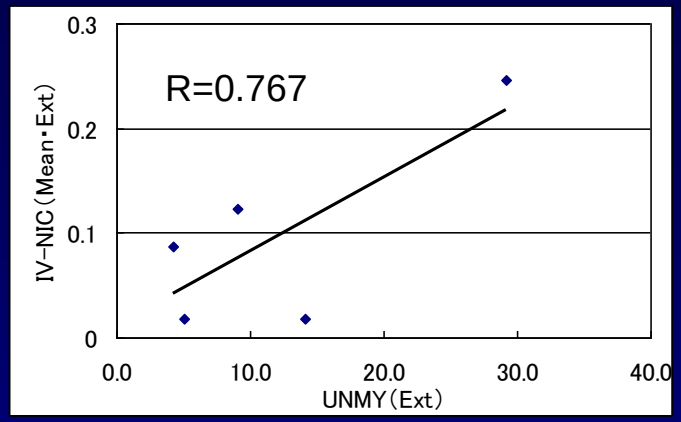
（Sliding）



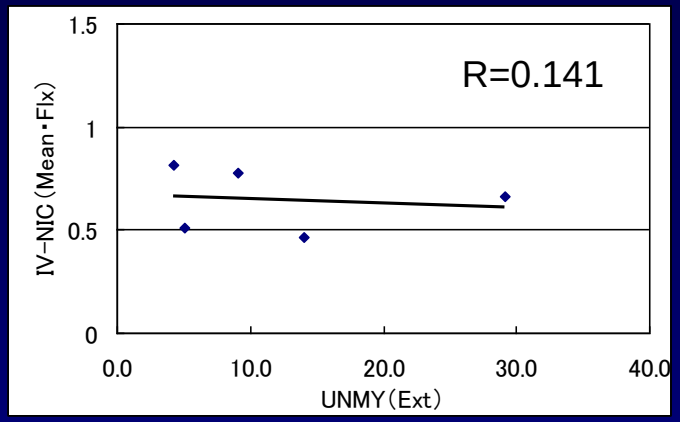
Upper Neck My (Flexion) has good correlations with IV-NIC Rotaion (Flexion) and Sliding.

Correlations between IV-NIC（Rotation・Compression・Shear）and UpperNeck-My(Extension)

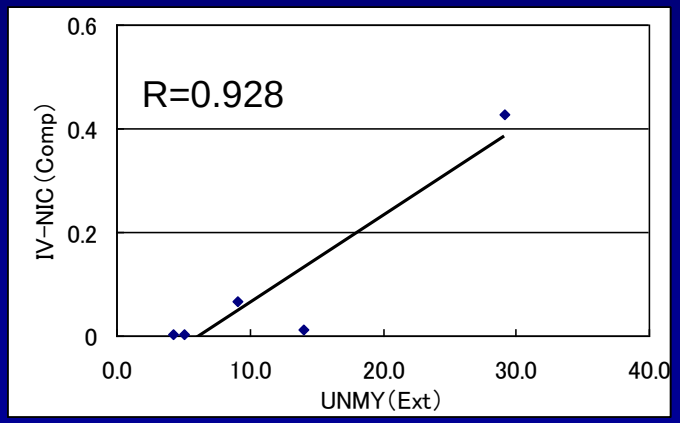
（Rotation：Extension）



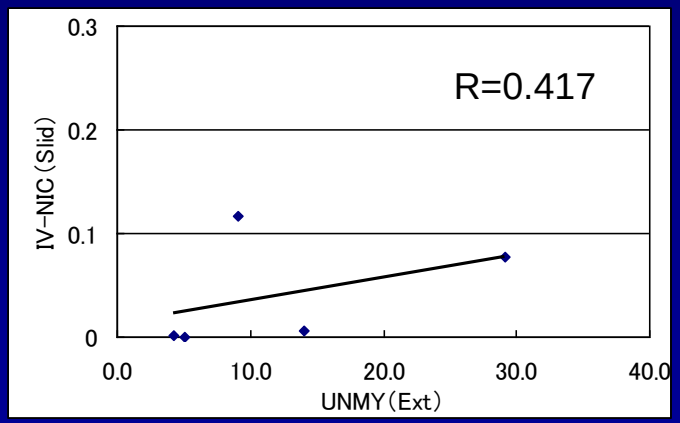
（Rotation：Flexion）



（Compression）



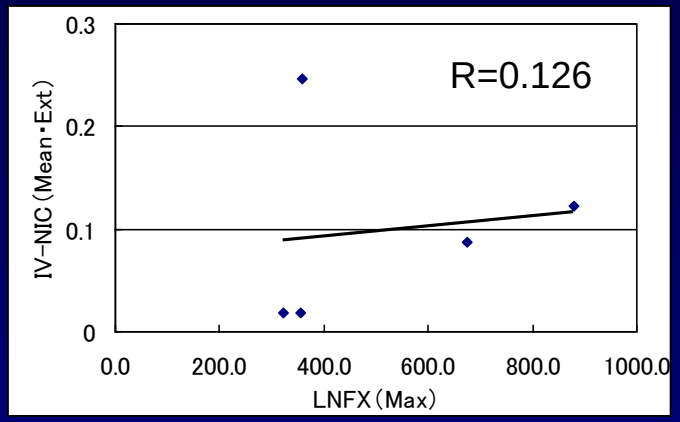
（Sliding）



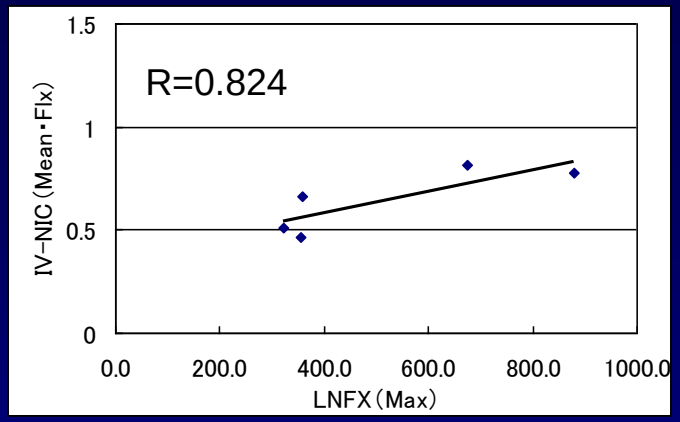
Upper Neck My (Extension) correlates most highly with IV-NIC Compression and also has a good correlation with IV-NIC Rotaion (Extension).

Correlations between IV-NIC（Rotation・Compression・Shear）and LowerNeck-FX(Head backward)

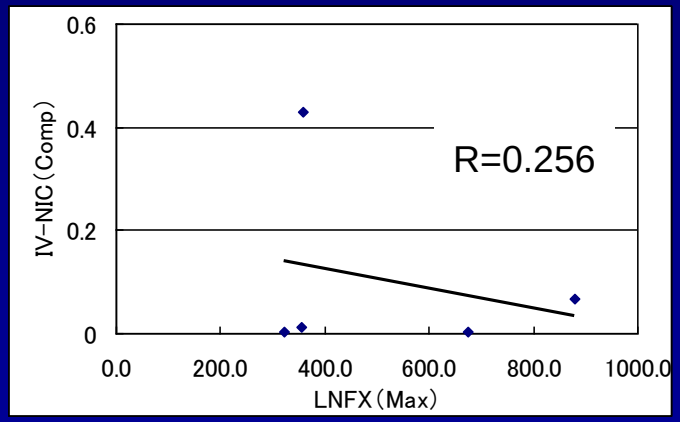
（Rotation：Extension）



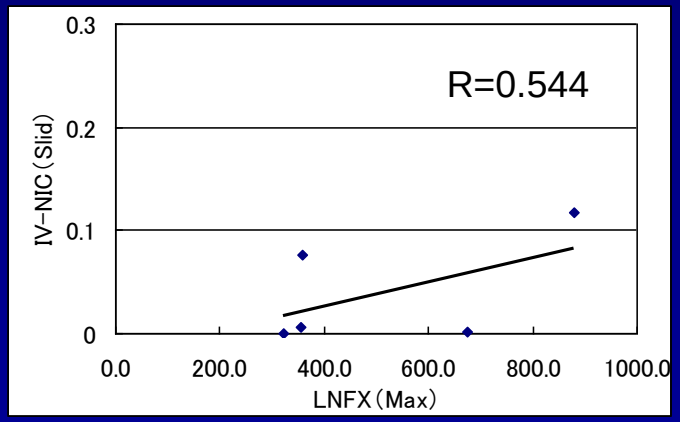
（Rotation：Flexion）



（Compression）



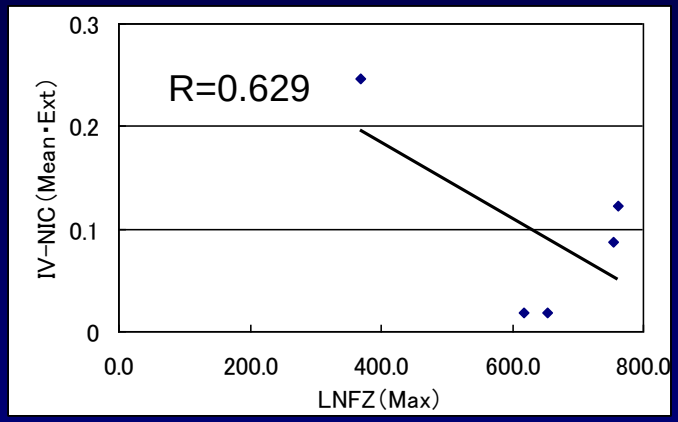
（Sliding）



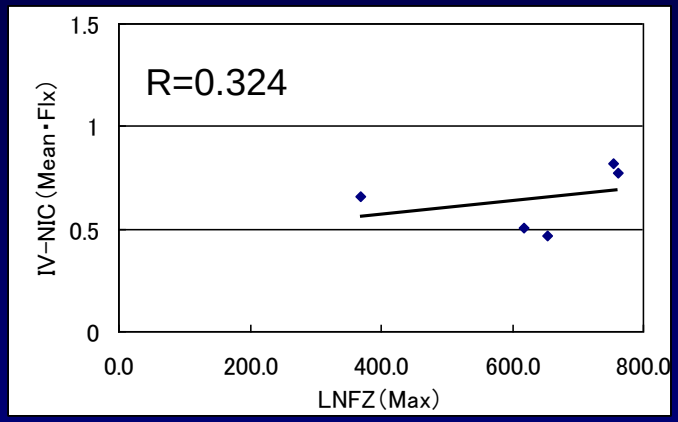
Lower Neck Fx (Head backward) correlates most highly with IV-NIC Rotation (Flexion). In contrast, Lower Neck Fx (Head backward) has a inverse correlation with IV-NIC Compression.

Correlations between IV-NIC（Rotation・Compression・Shear）and LowerNeck-FZ(Tension)

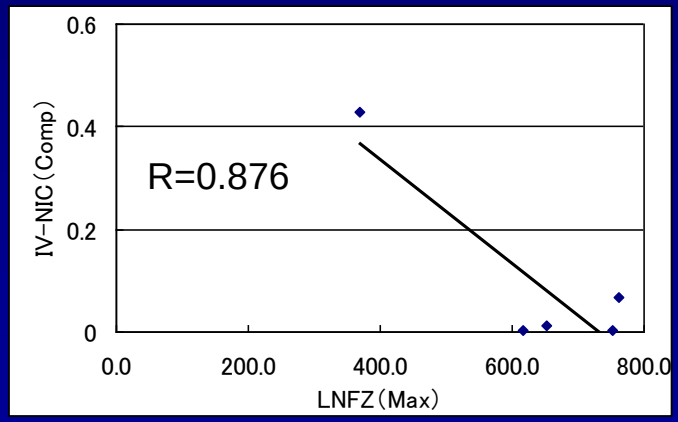
（Rotation：Extension）



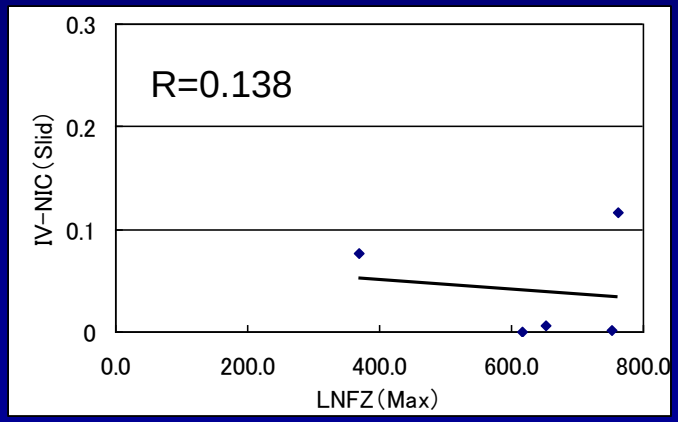
（Rotation：Flexion）



（Compression）



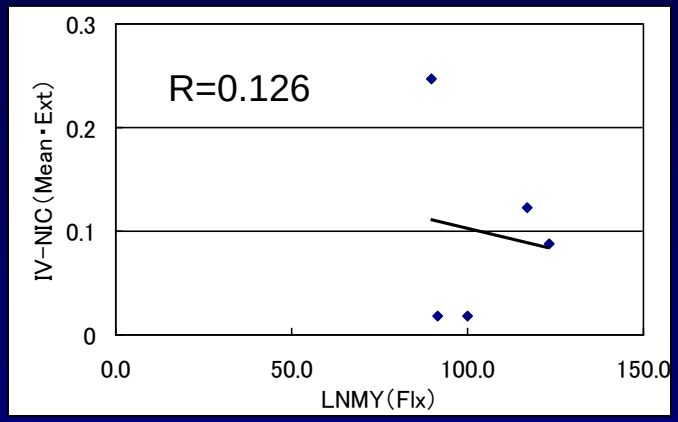
（Sliding）



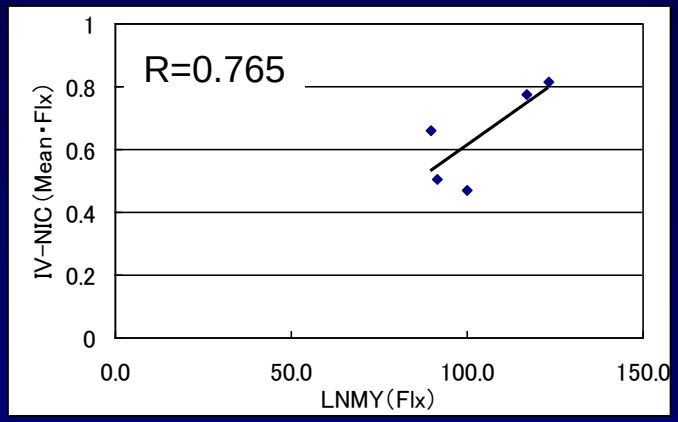
Lower Neck Fz (Tension) correlates slightly with IV-NIC Rotation (Flexion). In contrast, Lower Neck Fx (Head backward) has inverse correlations with the other IV-NIC items.

Correlations between IV-NIC（Rotation・Compression・Shear）and LowerNeck-My(Flexion)

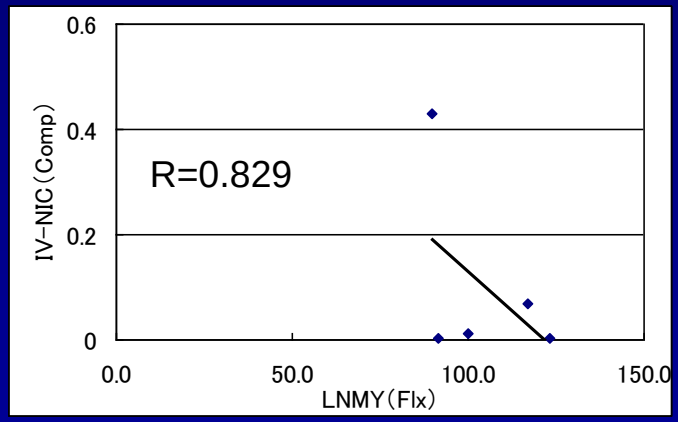
（Rotation：Extension）



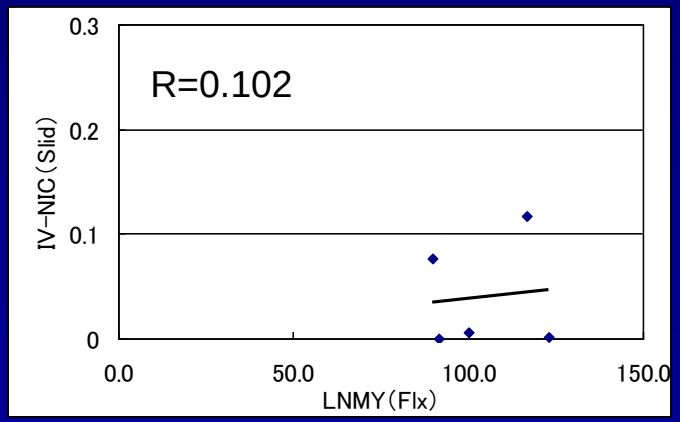
（Rotation：Flexion）



（Compression）



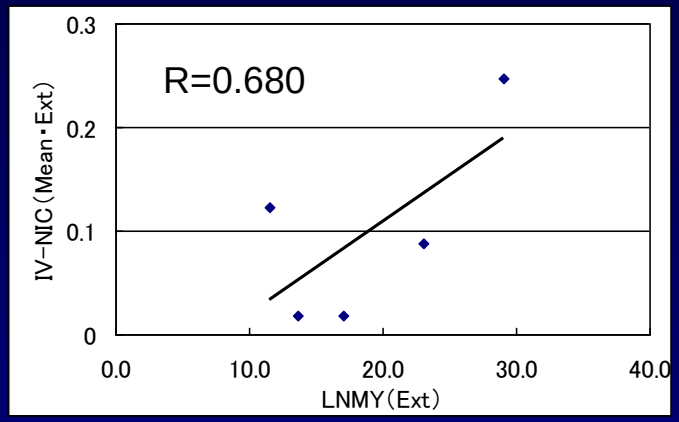
（Sliding）



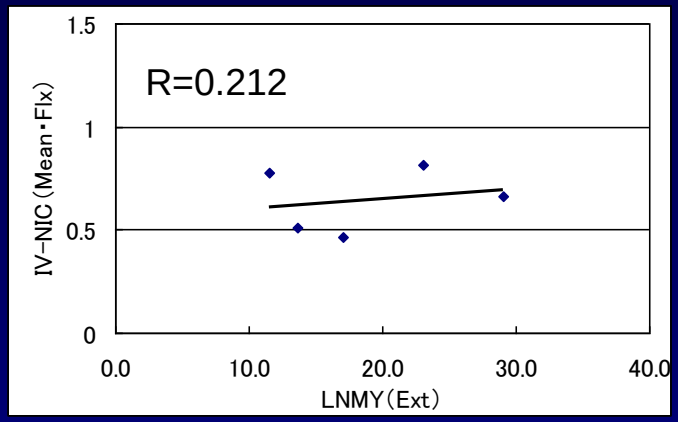
Lower Neck My (Flexion) correlates with IV-NIC Rotation (Flexion). In contrast, Lower Neck My (Flexion) has inverse correlations with IV-NIC Rotation (Extension) Compression.

Correlations between IV-NIC（Rotation・Compression・Shear）and LowerNeck-My(Extension)

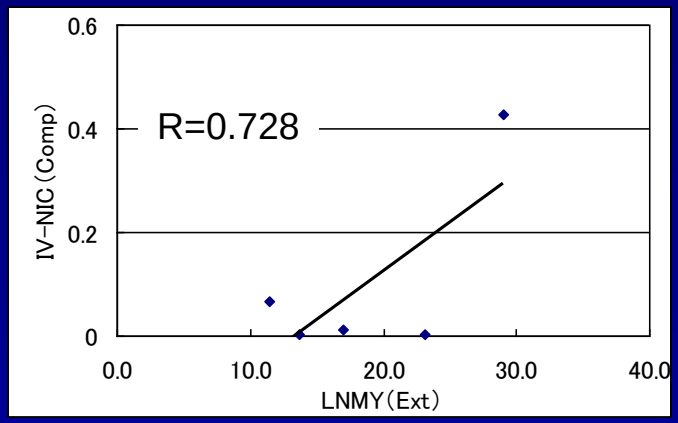
（Rotation：Extension）



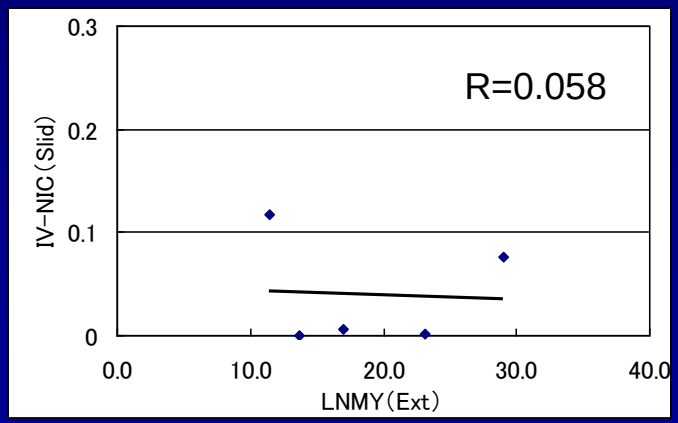
（Rotation：Flexion）



（Compression）



（Sliding）



Lower Neck My (Extension) correlates most highly with IV-NIC Compression and also has a good correlation with IV-NIC Rotaion (Extension).

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Correlations between Strain/Strain rate and IV-NIC（Rotation・Compression・Sliding）

	1.0≦R＜0.7	0.7≦R＜0.4	0.4≦R＜0.2	0.2≦R＜0

Correlation Coefficient（R）	IV-NIC（Rotation）・Extension			IV-NIC（Rotation）・Flexion			IV-NIC Compression	IV-NIC Sliding
	IVANCIC	Panjabi	Mean	IVANCIC	Panjabi	Mean		
Max Principal Strain	0.311	0.312	0.310	0.952	0.952	0.952	0.084	0.524
Max Shear Strain	0.314	0.310	0.311	0.942	0.942	0.942	0.081	0.550
Max Principal Strain Rate	0.450	0.501	0.471	0.918	0.918	0.918	0.152	0.216
Max Shear Strain Rate	0.458	0.505	0.477	0.932	0.932	0.932	0.148	0.261

The correlation coefficient R between Strain/Strain rate and IV-NIC

- Rotation
  - -Flexion: The correlation coefficients with Strain and Strain rate are greater than 0.7. It shows IV-NIC Rotation (Flexion) has good correlations with Strain and Strain rate.
  - -Extension: The correlation coeficients with Strain are around 0.3 and with Strain rate around 0.5.

- Compression
  - The correlation coefficients with Strain and Strain rate are around 0.1. It shows IV-NIC Compression has almost no correlations with Straina and Strain rate.

- Sliding (Head backward)
  - The correlation coeffients with Strain are around 0.5 and with Strain rate around0.2.

Correlations between IV-NIC（Rotation・Compression・Sliding）and other Neck Injury Criterion

1.0≦R＜0.7　0.7≦R＜0.4　0.4≦R＜0.2　0.2≦R＜0　white : Inverse correlation

	Extension			Flexion			Compression	Sliding
	Ivancic	Panjabi	Mean	Ivancic	Panjabi	Mean		
NIC	0.022	0.057	0.035	0.808	0.808	0.808	0.314	0.097
UNFX-HeadRear	0.906	0.873	0.894	0.187	0.187	0.187	0.907	0.767
UNFZ-Tension	0.193	0.205	0.200	0.687	0.687	0.687	0.557	0.272
UNMY-Flexion	0.223	0.189	0.207	0.792	0.792	0.792	0.155	0.669
UNMY-Extension	0.769	0.758	0.767	0.141	0.141	0.141	0.928	0.417
LNFX-HeadRear	0.137	0.117	0.126	0.824	0.824	0.824	0.253	0.544
LNFZ-Tension	0.625	0.628	0.629	0.324	0.324	0.324	0.876	0.138
LNMY-Flexion	0.133	0.112	0.126	0.765	0.765	0.765	0.487	0.102
LNMY-Extension	0.652	0.716	0.681	0.212	0.212	0.212	0.728	0.058

Neck injury criterion with the correlation coefficient greater than 0.7 are as below,

- Rotation
  - -Flexion: UpperNeck-FX, MY（Ext）,
  - -Extension: NIC, UpperNeck-MY（Flx）, LowerNeck-FX, MY（Flx）
- Compression: UpperNeck-FX, MY（Ext）, LowerNeck-MY（Ext）
- Sliding：UpperNeck-FX

Summary of peak response phase for all parameters (5 cases)

		Phase1	Phase2	Phase3	Phase4
Strain Strain Rate	Max Principal Strain		2・3・4・5	1	
	Max Shear Strain		2・3・4・5	1	
	Max Principal Strain Rate		1・2・3・4・5		
	Max Shear Strain Rate		1・2・3・4・5		
IV-NIC	IV-NIC Rotation(Flx)		2・3・4・5	1	
	IV-NIC Rotation(Ext)	3	2	1	4・5
	IV-NIC Compression	1・2・3・4・5			
	IV-NIC Sliding	1・2・4			3・5
Injury Criteria	NIC		2・3・5	1・4	
	UpperNeck-FX(Head-Rear)	1・4	5	3	2
	UpperNeck-FZ(Tension)		2・3・4・5	1	
	UpperNeck-MY(Flexion)		1・3	2・4・5	
	UpperNeck-MY(Extension)		4	1・5	2・3
	LowerNeck-FX(Head-Rear)		2・3・4・5	1	
	LowerNeck-FZ(Tension)		2・3・4・5	1	
	LowerNeck-MY(Flexion)		1・2・3・4・5		
	LowerNeck-MY(Extension)	3	1・2	4・5	

※The number in the Table shows the case No.

The peak response time get into phase 2 for almost all cases. However, the peak response time for IV-NIC Compression and Sliding does not get into any phase.

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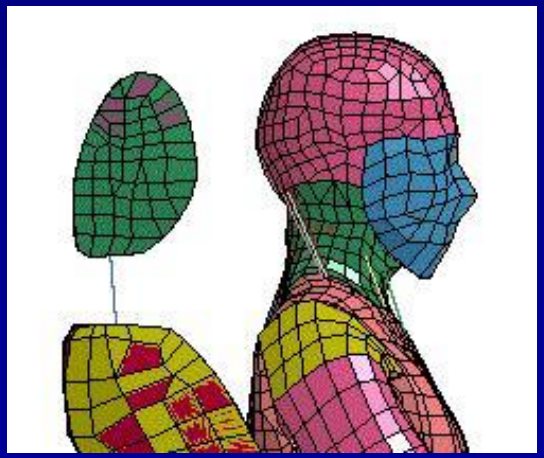
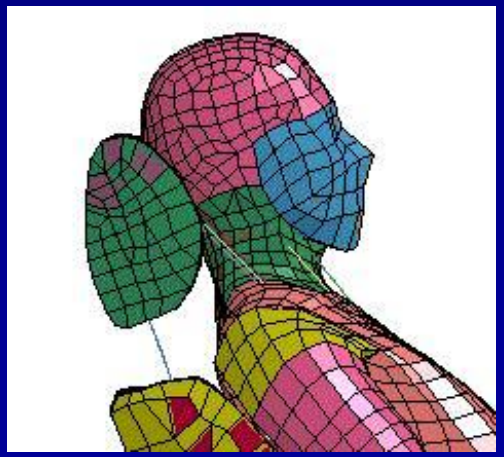
Discussion on IV-NIC (Compression/Sliding) as evaluation parameter

- The axial (compression) motion of cervical vertebrae was not observed in the simulation of accident reconstruction. The motion of the head relative to the neck is shown by the flexion rather than the extension due to the interaction between head and head-restraint such as what was shown in the motion pattern by the simulation (see Figures as below). As a result, the tension force rather than the compression force acts on the cervical vertebrae, and the peak of IV-NIC (compression) does not appear in phase 2.



Initial position



Interaction head/neck and head-restraint

Discussion on IV-NIC (Compression/Sliding) as evaluation parameter (Continued)

- The shear (head backward) motion of cervical vertebrae was not observed in the simulation. This was the same head/neck motion pattern mentioned above. As a result, the head-forward motion rather than the head-backward motion is apparent in the cervical vertebrae, and the peak of IV-NIC (sliding) does not appear in phase 2

- According to the simulation, the peak value of IV-NIC (Compression and Sliding (shear)) does not appear apparently. That is; the IV-NIC (Compression and Sliding (shear)) are not appropriate as an evaluation parameter for the abnormal motion and/or over-stress (over-load) to the cervical vertebrae during a proper interaction impact condition for the standard position of the head/neck relative to the head-restraint (with standard head-restraint seat system).

1. Selection of five cases for accident reconstruction using the FE model in a 2009 IRCOBI paper
2. Relationship between strain and strain rate of cervical vertebrae and IV-NIC
3. Relationship between IV-NIC and NIC, Neck force/Moment
4. Summary of results
5. Discussion of relationship between physical parameters and IV-NIC based on the results of FE simulation
6. Conclusions
7. Further verification of the relationship between “Strain and Strain-rate” and “IV-NIC”

Conclusions

- The cervical vertebral motions with respect to “Strain and Strain-rate”, “Rotation, Sliding (Shear)” and “Axial (Compression/Tension)” including neck forces and moments were analyzed through 5 cases of accident reconstruction simulation. Especially, the peak response times appearing in those parameters (motion) during impacts were also analyzed by the classification of the time phases.

- The peak response time for almost all parameters was getting into phase 2 (the duration from the contact time of the head and head-restraint to the time that the head impact velocity to head-restraint becomes 0 m/s).

Conclusions (Continued)

- From the results of PMHS tests done by NHTSA (VRTC), the IV-NIC (Rotation) will be candidates for evaluation parameters. However, the IV-NIC (Compression/Sliding) are not appropriate as an evaluation parameter for the abnormal motion and/or over-stress (over-load) of the cervical vertebrae during a proper interaction impact conditions for the general position of the head/neck relative to the head-restraint (with general head-restraint seat system) .

- In order to clarify the issues mentioned above, the following verification will be further needed;

1. Selection of five cases for accident reconstruction using the FE model in a 2009 IRCOBI paper
2. Relationship between strain and strain rate of cervical vertebrae and IV-NIC
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Further verification of the relationship between “Strain and Strain-rate” and “IV-NIC”

- In all cases of accident reconstruction simulation, the appearance of the peak response is quite different between “Strain and Strain-rate” and “IV-NIC (Compression and Sliding)”. However, the peak response of “IV-NIC (Rotation)” and “Strain and Strain-rate” were similar.

- Further verification is needed to identify the relationship between “Strain and Strain-rate” and “IV-NIC.”

- There is also a need to validate the interference mode with head and HR in the PMHS experiment.

- In the PMHS experiment, the torso ramping-up of the PMHS subject due to backward recline of the seatback during impact occurs, and then, the lower neck region directly collides with the headrest. This phenomenon is not the proper interaction impact condition for the standard position of the head/neck relative to the headrest.

Further verification of the relationship between “Strain and Strain-rate” and “IV-NIC” (Continued)

- On the other hand, due to less backward recline of the seatback during impact, there is little torso ramping-up of the occupant in the accident simulation, the head relative to the headrest is supported at an appropriate position.

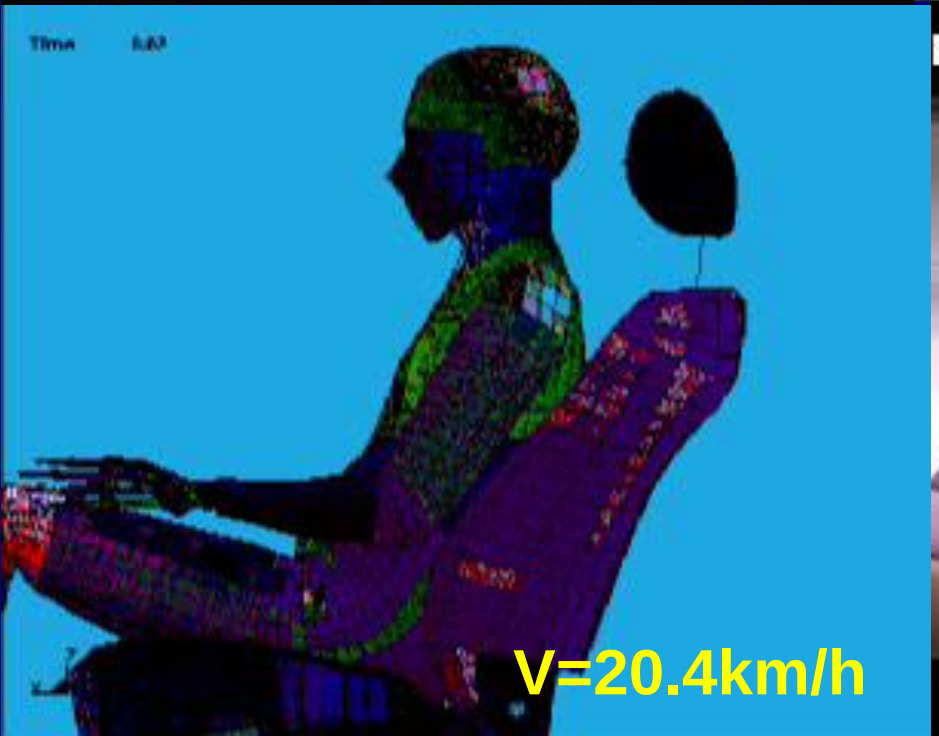
- The occupant motion by the simulation is almost similar to the case of TRL dummy experiment.

- It is pointed out that the difference between the PMHS experiment and the motion by the simulation occurred with such influences as: the difference of impact velocity (higher impact velocity for the PMHS tests, middle velocity for accident reconstruction) or the different seat performance, and the height of the headrest.

- In order to clarify the influence parameters mentioned above, there will be a need to do further research on those issues.

V=24.0km/h

bast
V=17.6km/h


V=20.4km/h

-20.0 ms
V=16.7km/h