

Proposal for an Injury Parameters/Criteria on  
the reduction of neck injury from rear-end  
crashes for the GTR7 (Informal HR-GTR)

based on research collaboration with NHTSA  
(VRTC)

- Injury Risk Curve (IV-NIC (R) ) Accident Reconstruction  
Simulation based on 20 cases -

J-MLIT / JARI

JAPAN

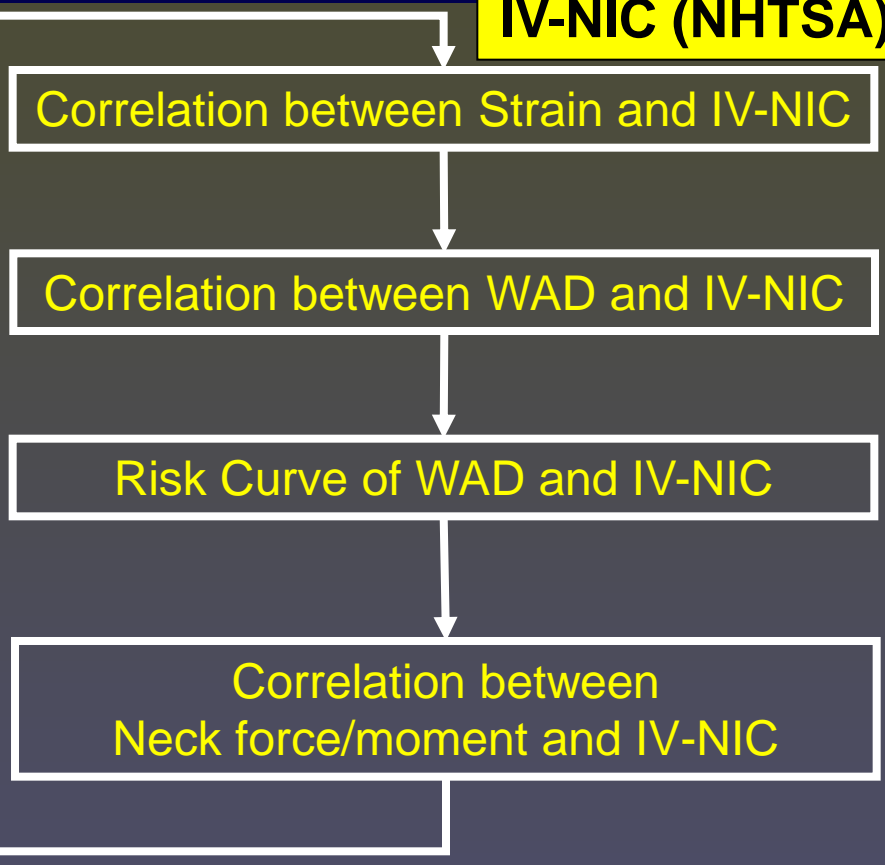
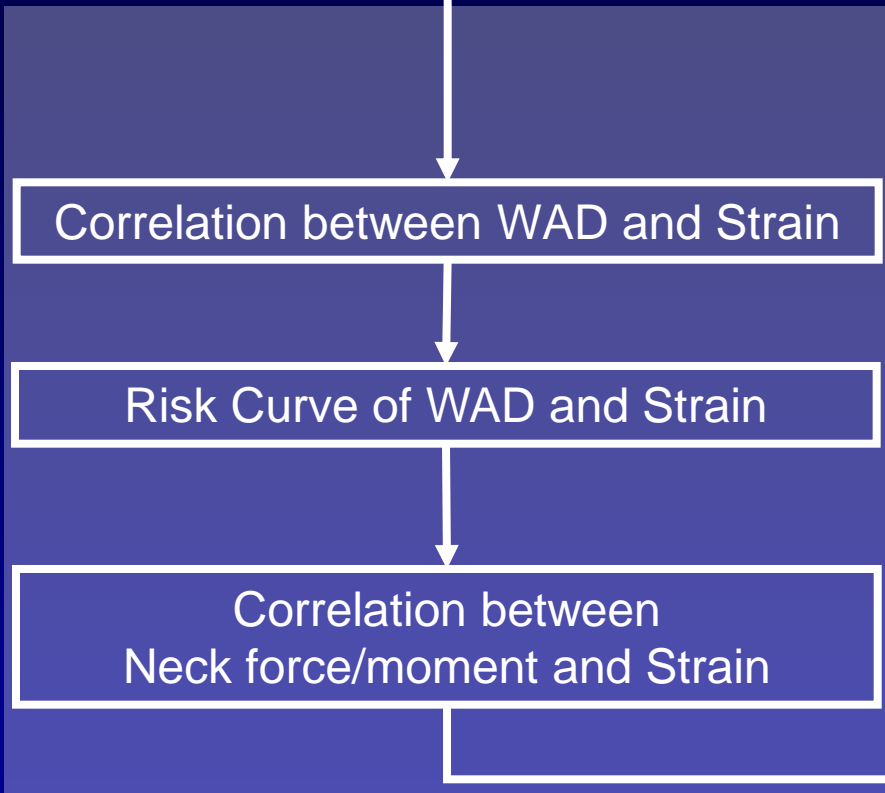
# Contents

1. Research Flow
2. Calculation of IV-NIC(R) for 20 accident cases by FE Simulation
  - 1) 20 accident cases of FE Simulation
  - 2) IV-NIC(R) as calculated from 20 accident cases of FE simulation
3. Correlation between IV-NIC (R) and Strain (Rate)
  - 1) Correlation between Strain (Rate) and IV-NIC(R) at the Extension
  - 2) Correlation between Strain (Rate) and IV-NIC(R) at the Flexion
4. Injury Risk Curve (IV-NIC(R)) based on 20 cases FE Simulation
  - 1) Relationship between IV-NIC(R) and WAD
  - 2) Risk Curve of IV-NIC(R) at Extension and Flexion
  - 3) Risk Curve of IV-NIC(R) in NHTSA
  - 4) WAD and AIS
  - 5) WAD and AIS (continued-1)
  - 6) WAD and AIS (continued-2)
  - 7) WAD and AIS (continued-3)
  - 8) Selection of IV-NIC values at Flexion and Extension
  - 9) Selection of IV-NIC values at Flexion and Extension (continued-1)
  - 10) Selection of IV-NIC values at Flexion and Extension (continued-2)
  - 11) Risk Curve at Flexion
5. Correlation between Neck Force/Moment and IV-NIC (R)
  - 1) Neck Force/Moment and IV-NIC (R)
  - 2) Risk Curve of NIC, Neck Force/Moment and Reference Values
  - 3) WAD2+95% value calculated from the Risk Curve of neck force/moment
6. Summary

20 accident cases of FE Simulation

**Strain (JNCAP)**

**IV-NIC (NHTSA)**



Risk Curve of Neck force and moment (Strain and IV-NIC)

**Injury Criteria and Value for GTR7 (Proposal)**

## 1) 20 accident cases of FE Simulation

CASE		RECORDED CRASH PULSE			REPORTED INJURY			PASSENGER CHARACTERISTICS			
No.	D/P	$\Delta v$ [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	26.0	5.6	12.6	Injured	>6 m	3	M	57	178	100
4	Passenger	26.0	5.6	12.6	Injured	>6 m	3	F	57	168	80
2	Driver	23.3	6.7	14.7	Injured	>6 m	2	F	59	156	60
8	Driver	20.4	5.2	12.8	Injured	<1 m	1	F	22	171	63
8	Passenger	20.4	5.2	12.8	Injured	<1 m	2	M	18	179	80
7	Driver	19.5	4.0	9.2	No injuries	no	0	M	67	167	84
7	Passenger	19.5	4.0	9.2	Injured	<1 m	1	F	72	165	63
10	Driver	17.6	5.0	12.4	Injured	1-6 m	1	M	74	175	62
10	Passenger	17.6	5.0	12.4	Injured	1-6 m	2	F	74	160	57
6	Driver	16.3	4.9	12.1	No injuries	no	0	F	59	165	65
6	Passenger	16.3	4.9	12.1	Injured	<1 m	1	M	88	170	70
11	Driver	16.3	6.5	15.2	No injuries	no	0	M	61	176	77
11	Passenger	16.3	6.5	15.2	No injuries	no	0	F	61	154	69
21	Driver	14.3	4.5	10.6	No injuries	no	0	M	50	171	85
23	Driver	11.1	3.7	8.9	Injured	<1 m	1	F	35	178	65
20	Driver	10.8	3.7	7.1	Injured	<1 m	1	M	65	176	82
20	Passenger	10.8	3.7	7.1	No injuries	no	0	M	68	176	77
24	Driver	8.8	3.5	7.5	Injured	1-6 m	1	F	35	165	55
3	Driver	14.7	5.2	7.5	Injured	>6 m	2	M	35	165	55

2) IV-NIC(R) as calculated from 20 accident cases of FE simulation.

No.	$\Delta v$ [km/h]	Mean Acc. [g]	Peak Acc. [g]	WAD	Extension		Flexion	
					Mean		Mean	
1_D	28.2	5.8	10.6	2	C6/C7	0.478	C5/C6	0.926
4_D	26.0	5.6	12.6	3	C6/C7	0.123	C5/C6	0.775
4_P	26.0	5.6	12.6	3	C6/C7	0.258	C5/C6	0.691
2_D	23.3	6.7	14.7	2	C3/C4	0.181	C5/C6	0.900
8_D	20.4	5.2	12.8	1	C2/C3	0.414	C5/C6	0.922
8_P	20.4	5.2	12.8	2	C2/C3	0.087	C5/C6	0.817
7_D	19.5	4.0	9.2	0	C6/C7	0.343	C5/C6	0.465
7_P	19.5	4.0	9.2	1	C2/C3	0.311	C5/C6	0.614
10_D	17.6	5.0	12.4	1	C2/C3	0.300	C5/C6	0.969
10_P	17.6	5.0	12.4	2	C3/C4	0.169	C5/C6	0.807
6_D	16.3	4.9	12.1	0	C2/C3	0.179	C5/C6	0.639
6_P	16.3	4.9	12.1	1	C2/C3	0.088	C5/C6	0.810
11_D	16.3	6.5	15.2	0	C2/C3	0.122	C6/C7	0.843
11_P	16.3	6.5	15.2	0	C2/C3	0.121	C6/C7	0.402
21_D	14.3	4.5	10.6	0	C2/C3	0.019	C5/C6	0.468
23_D	11.1	3.7	8.9	1	C2/C3	0.382	C5/C6	0.729
20_D	10.8	3.7	7.1	1	C2/C3	0.018	C5/C6	0.507
20_P	10.8	3.7	7.1	0	C2/C3	0.121	C5/C6	0.578
24_D	8.8	3.5	7.5	1	C2/C3	0.252	C5/C6	0.361
3_D	14.7	5.2	7.5	2	C3/C4	0.246	C5/C6	0.659

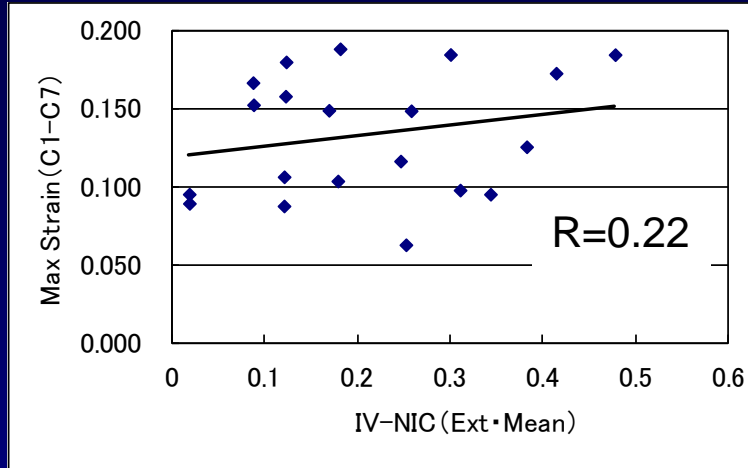
Note) The gray part were from last year.

As for IV-NIC(R) values, Flexion was higher than Extension.

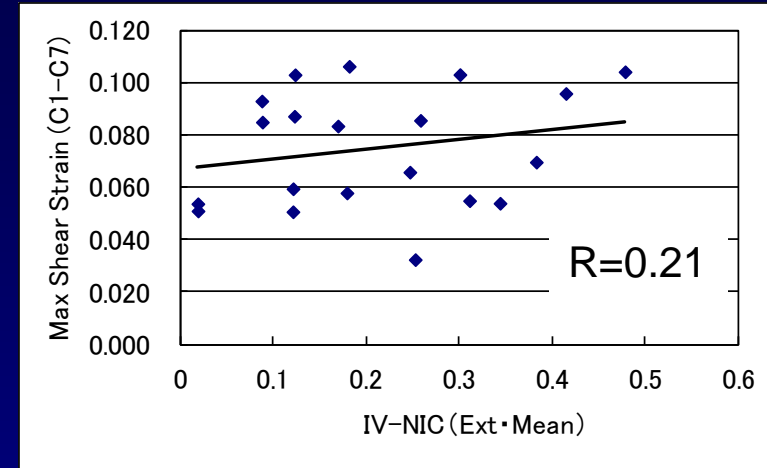
### 3. Correlation between IV-NIC (R) and Strain (Rate)

#### 1) Correlation between Strain (Rate) and IV-NIC(R) at the Extension

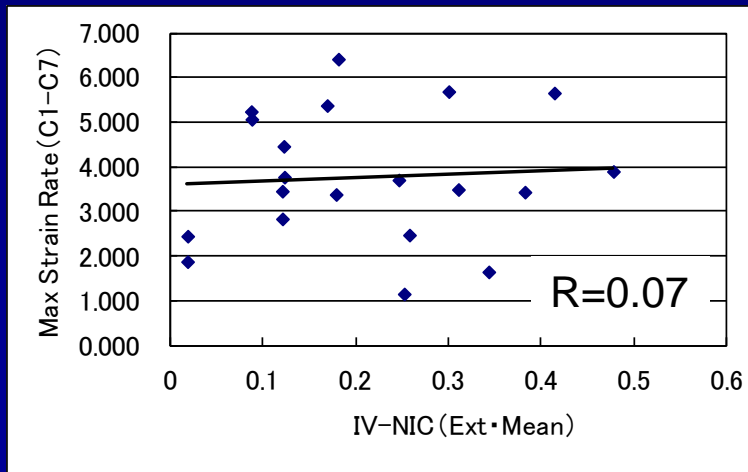
Max. Principal Strain



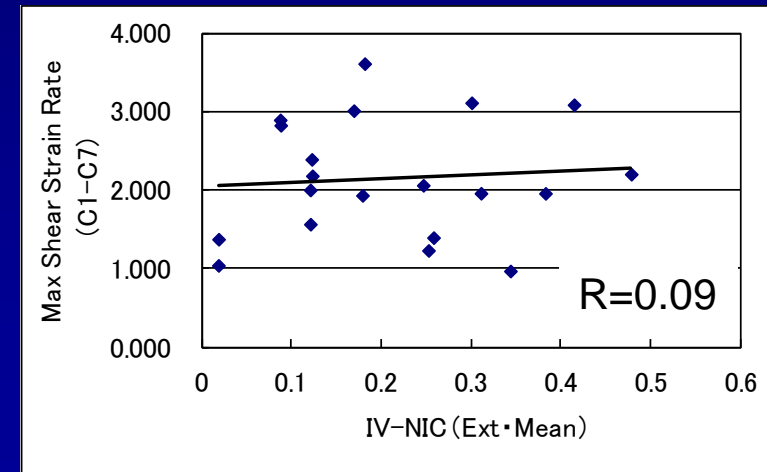
Max. Shear Strain



Max. Principal Strain Rate



Max. Shear Strain Rate

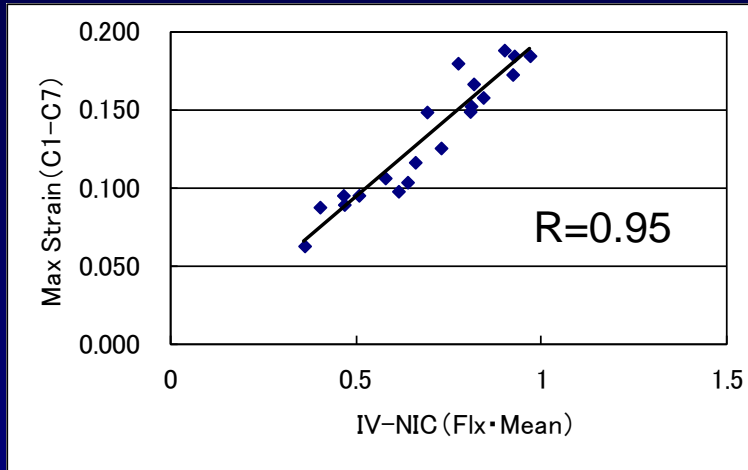


As for the correlation coefficient at the Extension, the strain is around 0.2, the strain rate is 0.05, and doesn't have correlations.

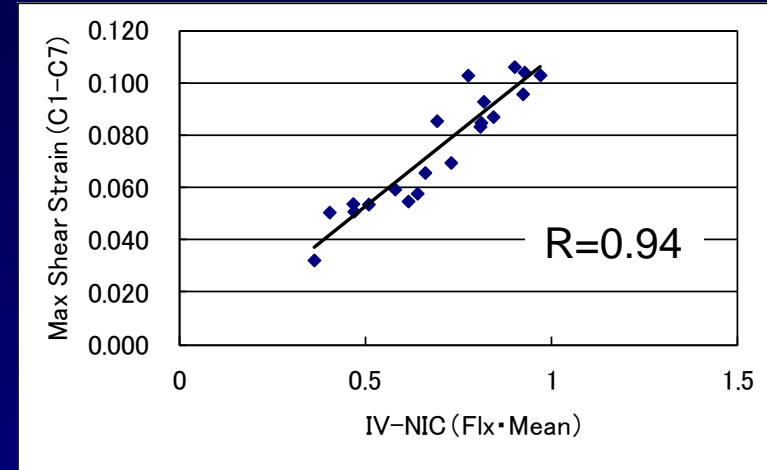
### 3. Correlation between IV-NIC (R) and Strain (Rate)

## 2) Correlation between Strain (Rate) and IV-NIC(R) at the Flexion

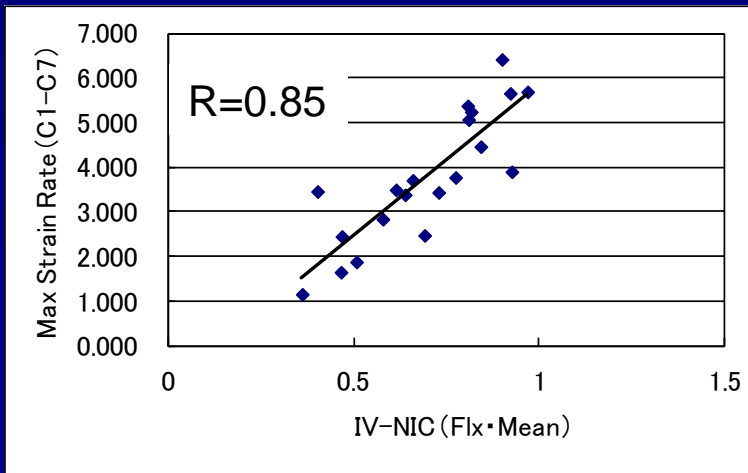
### Max. Principal Strain



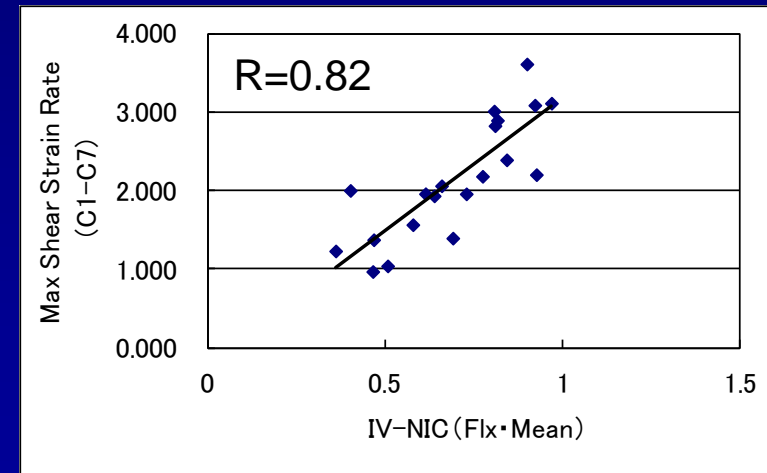
### Max. Shear Strain



### Max. Principal Strain Rate

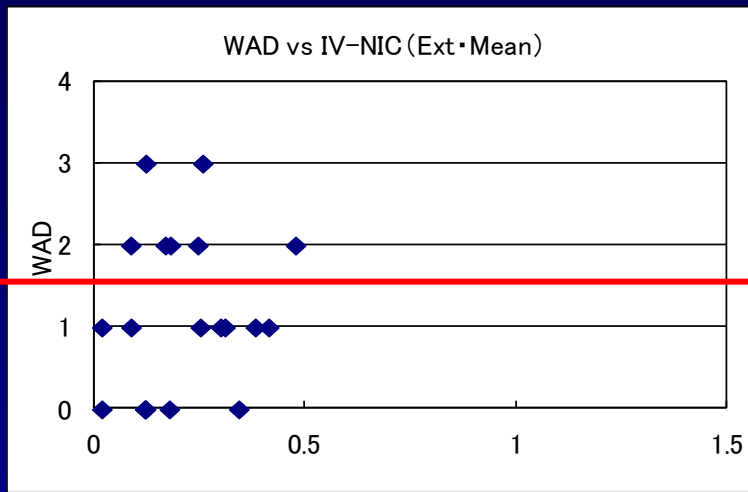


### Max. Shear Strain Rate

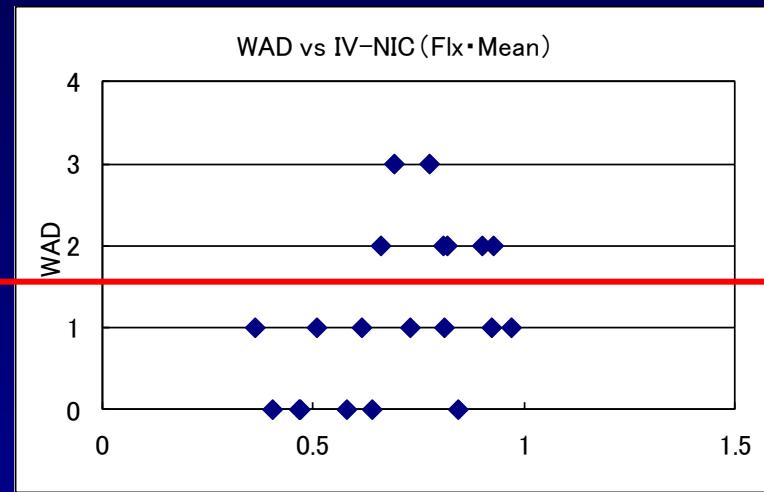


As for the correlation coefficient at the Flexion, the strain is around 0.9, strain rate is 0.8, and has correlation.

## 1) Relationship between IV-NIC(R) and WAD

Extension

WAD2+

Flexion

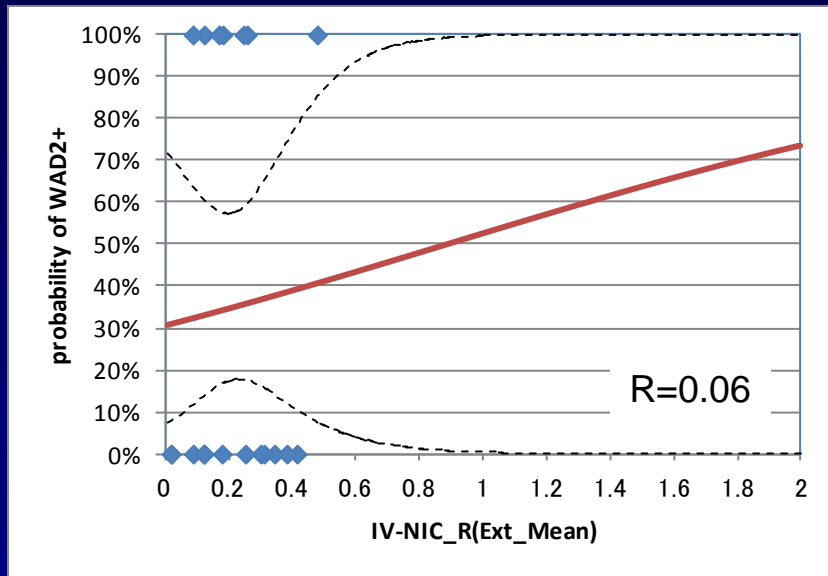
- As for Extension and Flexion, the IV-NIC(R) values tended to increase when the value of WAD increases.
- The tendency to an increase of Flexion is more remarkable than the Extension.

The Risk Curve of IV-NIC is shown in the next pages.

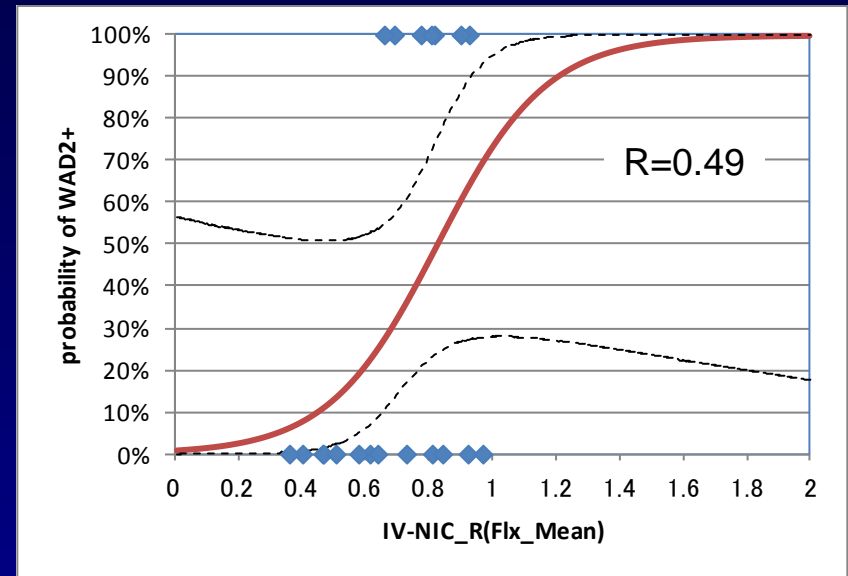


2) Risk Curve of IV-NIC(R) at Extension and Flexion

Extension



Flexion



Extension:

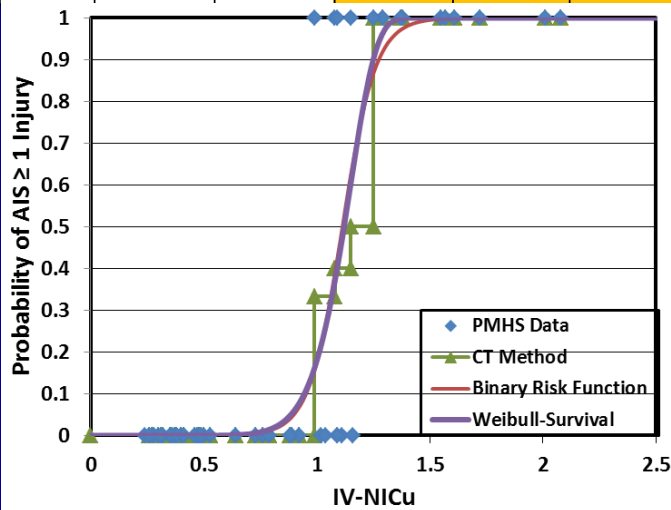
- There is no difference in the IV-NIC(R) value between WAD2+ and less than WAD2.
- The correlation coefficient is low at "0.06".

Flexion:

- The risk curve was established in the injury of WAD2+ and the injury of less than WAD2.
- The correlation coefficient is "0.49".

### 3) Risk Curve of IV-NIC(R) in NHTSA

		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



- Risk Curve was created the data in this table.
- The highest value of either Flexion and Extension were selected as IV-NIC(R), and the Risk Curve of AIS1+ and IV-NIC(R) was created.

#### Difference of Risk Curve in Japan and NHTSA

- 1) WAD (Japan) and AIS (NHTSA)
- 2) Selection of IV-NIC values of either Flexion and Extension

4) WAD and AIS

In most commonly, the symptom of the occupants in the automobile accidents is evaluated at the WAD. On the other hand, neck injury of the PMHS tests in NHTSA, is evaluated at the AIS. Therefore, the relationship between WAD and AIS were as follows.

WAD classification  
(Risk curve of Japan)

AIS classification  
(Risk curve of NHTSA)

WAD	
Grade	Clinical classification
0	The neck has no symptoms, and the physical finding is normal.
1	The neck has pain and stiffness, but the physical finding is normal.
2	In addition to neck symptoms, there is a limit of motion space of the cervical vertebra and a localized tender point, suggesting neck symptoms from the musculoskeletal system.
3	In addition to neck symptoms, there are neurological findings such as the tendon reflex disorder, Adynamia, and perception disorder.
4	Dislocation and fracture of the cervical vertebra.

AIS	
Grade	Clinical classification
0	No Injury
1	<ul style="list-style-type: none"> <li>• Strain, acute with no fracture or dislocation</li> <li>• Inter-spinous ligament laceration</li> </ul>
2	<ul style="list-style-type: none"> <li>• Dislocation (subluxation) without fracture facet unilateral</li> <li>• Disc injury</li> </ul>
3	<ul style="list-style-type: none"> <li>• Dislocation (subluxation) without fracture facet bilateral</li> </ul>



5) WAD and AIS (continued-1)

The cervical spine injuries in the PMHS tests (NHTSA) are as follows.

Injury Documentation						
	PMHS03	PMHS04	PMHS05	PMHS06	PMHS07	PMHS08
<b>C2/C3</b>	No injury	No injury	Subluxation bilateral@ FJ (AIS3)	No injury	No injury	No injury
<b>C3/C4</b>	Subluxation bilateral@ FJ (AIS3)	No injury	•Subluxation@ FJ (AIS2) •Subluxation bilateral@ LF	No injury	No injury	No injury
<b>C4/C5</b>	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	Subluxation bilateral@ FJ (AIS3)	No injury	•Subluxation @ FJ (AIS2) •Subluxation bilateral@ LF •Subluxation @ IL	No injury
<b>C5/C6</b>	No injury	•Subluxation bilateral@ FJ (AIS3) •Subluxation bilateral@ LF •Subluxation @ IL	•Subluxation @ FJ (AIS2) •Subluxation bilateral@ LF •Subluxation @ IL	•FJcapsule tear on right side •Mild subluxation due to separation of degenerative disc→Maybe AIS2 or AIS1	No injury	No injury
<b>C6/C7</b>	No injury	•Subluxation bilateral@ LF •Subluxation @ IL →Maybe AIS1	Subluxation @ Interspinous lig →Maybe 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

6) WAD and AIS (continued-2)

The AIS classifications of the cervical spine injuries in the PMHS tests (NHTSA) are as follows.

Injury Documentation						
	PMHS03	PMHS04	PMHS05	PMHS06	PMHS07	PMHS08
C2/C3	No injury	No injury	AIS3	No injury	No injury	No injury
C3/C4	AIS3	No injury	AIS2	No injury	No injury	No injury
C4/C5	AIS3	AIS3	AIS3	No injury	AIS2	No injury
C5/C6	No injury	AIS3	AIS2	AIS2	No injury	No injury
C6/C7	No injury	AIS1	AIS1	No injury	AIS3	AIS1

Note) In the PMHS tests, the evaluation of the inflammation of the soft tissues and the neurologic signs etc. are impossible. Those output might indicate no-injury.

7) WAD and AIS (continued-3)

The table where the AIS codes as the cervical spine injuries of PMHS was replaced at the WAD, is as follows.

Injury Documentation						
	PMHS03	PMHS04	PMHS05	PMHS06	PMHS07	PMHS08
C2/C3	No injury	No injury	WAD4	No injury	No injury	No injury
C3/C4	WAD4	No injury	WAD4	No injury	No injury	No injury
C4/C5	WAD4	WAD4	WAD4	No injury	WAD4	No injury
C5/C6	No injury	WAD4	WAD4	WAD2	No injury	No injury
C6/C7	No injury	WAD2	WAD2	No injury	WAD2	WAD2

Note) In the PMHS tests, the output that cannot be detected by AIS codes might indicate no-injury.

8) Selection of IV-NIC values at Flexion and Extension

- Relationship between Flexion and Extension in IV-NIC(R) -

- The Risk Curve of NHTSA was created by the IV-NIC(R) maximum value of either Flexion or Extension.
- On the other hand, the Risk Curve created by Japan was made separately for Flexion and Extension of IV-NIC(R).
- The Risk Curve was re-created by using the following data (NHTSA) separately for Flexion and Extension.

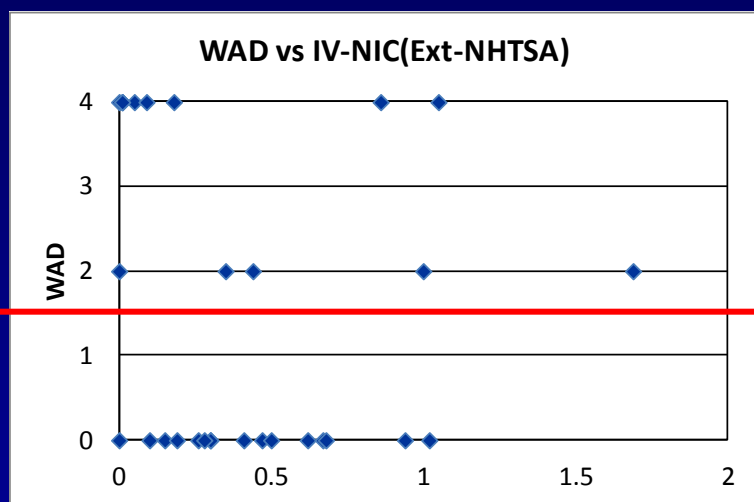
		IV-NIC (Rotation)											
		PMHS03		PMHS04		PMHS05		PMHS06		PMHS07		PMHS08	
		Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate	Low	Moderate
C2/C3		-0.85	-0.79	-1.06**	-0.87	-1.84	-1.52	-0.40	-0.49	-0.90	-0.99	-0.34	-0.45
		+0.26	+0.67	+0.17	+0.26	0.46	0.86	0.23	+0.41	+0.21	+0.30	+0.04	+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

Note) In the table, Flexion is (-), Extension is (+).

9) Selection of IV-NIC values at Flexion and Extension (continued-1)

Relationship between WAD and IV-NIC(R) in NHTSA data is as follows.

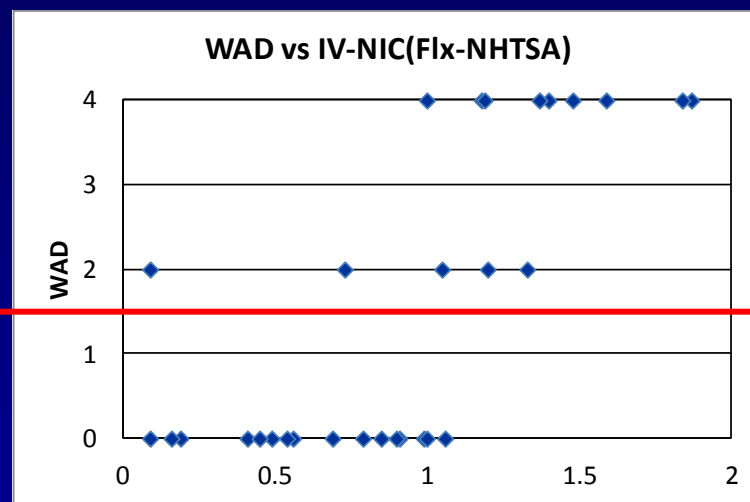
Extension



WAD2+



Flexion

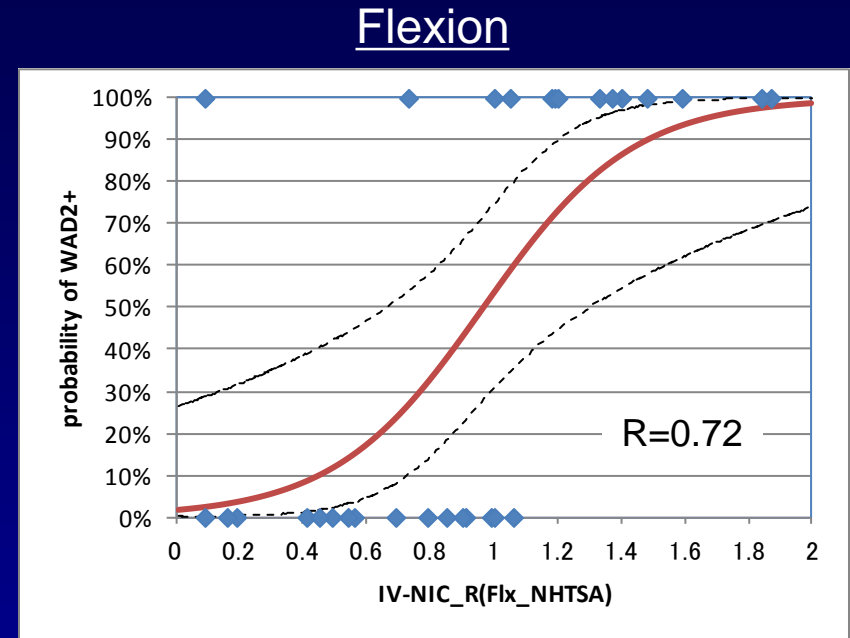
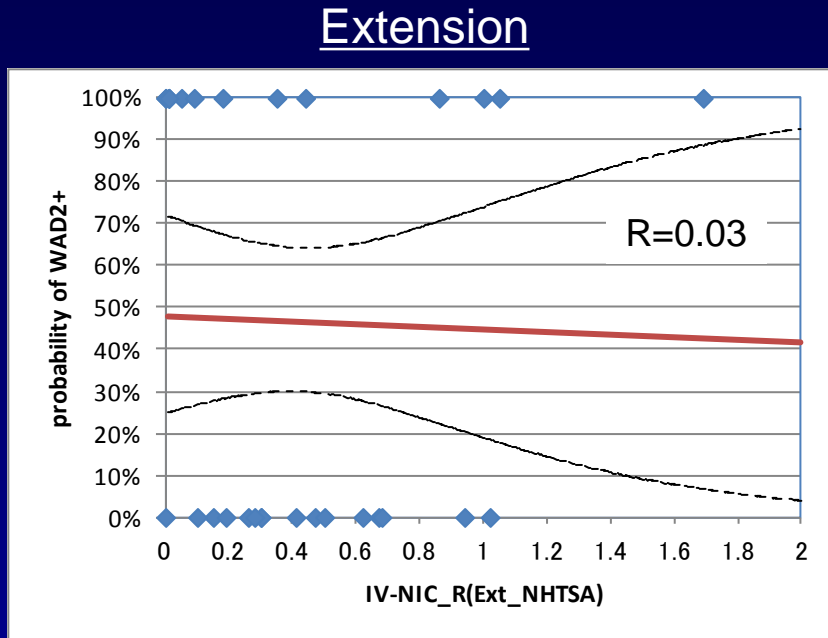


- As for Extension and Flexion, the IV-NIC(R) values tended to increase when the value of WAD increases.
- The tendency to an increase of Flexion is more remarkable than the Extension.



### 10) Selection of IV-NIC values at Flexion and Extension (continued-2)

The Risk Curve was created separately for Flexion and Extension, and the result is as follows.



#### Extension:

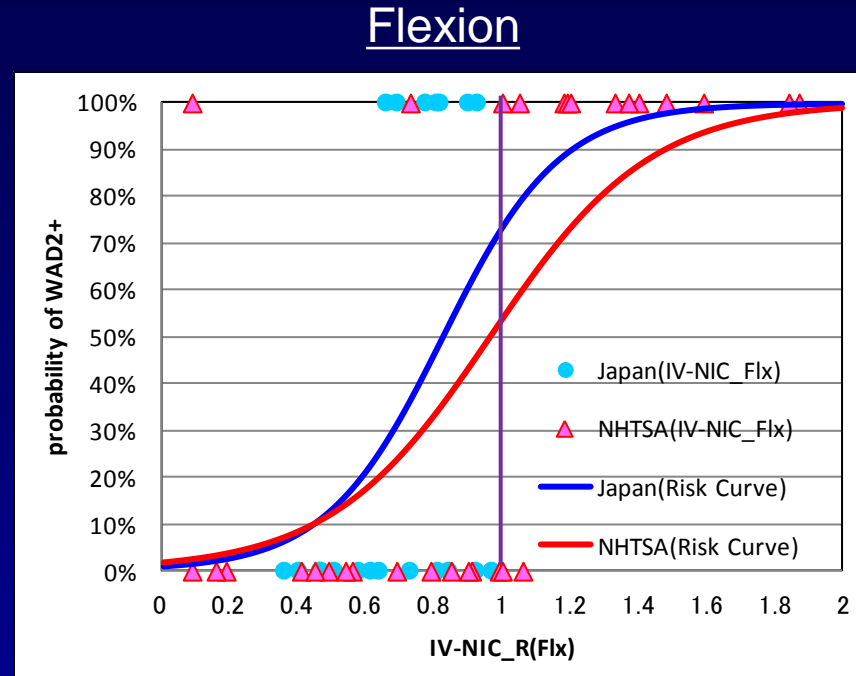
- There is no difference in the IV-NIC(R) value between WAD2+ and less than WAD2.
- The correlation coefficient is low at "0.03".

#### Flexion:

- The risk curve was established, because there was difference in the IV-NIC value in the injury of WAD2+ and the injury of less than WAD2.
- The correlation coefficient is "0.72".

## 11) Risk Curve at Flexion

- The correlation occurred in Flexion of the Risk Curve of NHTSA (previous page).
- The Risk Curves in Japan (Accident simulation) and NHTSA (PMHS tests) are shown as follows.



<Comparison of WAD2+ probabilities at the IV-NIC"1">

- Risk Curve of Japan (blue line) is "73%".
- Risk Curve of NHTSA (red line) is "53%".

<Different definition between AIS and WAD>

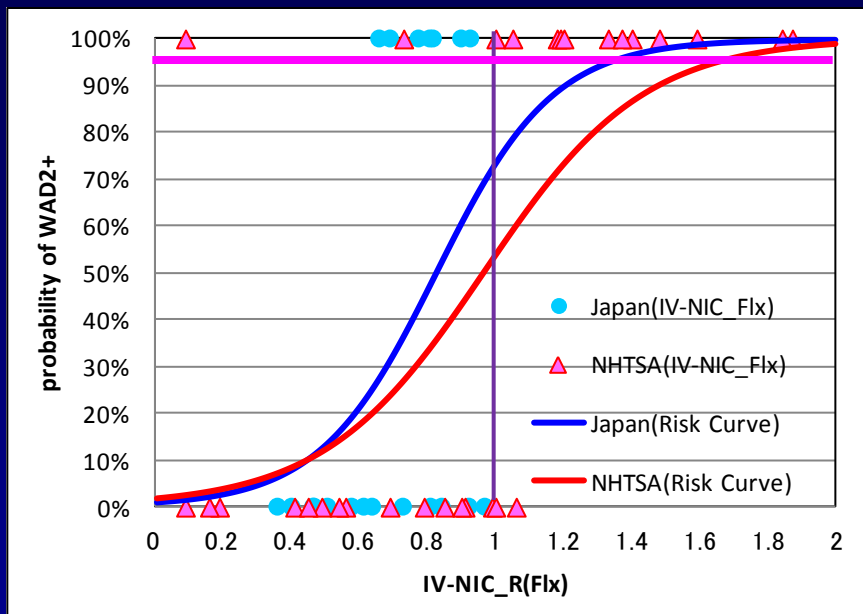
AIS was replaced with WAD and the Risk Curve was created. However, slight injury AIS1 that is a neurological symptom, a strain etc. of the neck cannot be evaluated from the PMHS tests. Therefore, such slight injury that will be evaluated as WAD2 is not counted. As a result, it will be assumed that the data of WAD2+ increased.

### 1) Neck Force/Moment and IV-NIC (R)

- The correlation between IV-NIC(R) and Strain(rate) were almost "1".
- The Risk Curves of IV-NIC(R) were obtained by the accident simulation and the PMHS test, as follows.
  - 1) The Risk Curve from accident simulation (Japan)
  - 2) The Risk Curve from PMHS tests(NHTSA)
- However, because neither the neck force nor neck moment were measured in the PMHS tests, the Risk Curve of NIC and neck force/moment from PMHS tests cannot be obtained.
- Then, the Risk Curve of NIC and neck force/moment were examined from the ratio of the WAD2+95%ile values of IV-NIC(R·Flx) based on two Risk Curves.
- Two Risk Curves and WAD2+95% values of IV-NIC(R,Flx) calculated from Risk Curve are shown in next page.

2) Risk Curve of NIC, Neck Force/Moment and Reference Values

Flexion



WAD2+  
95% Value

Injury Criteria		WAD2+	
		95% Value	
		Japan	NHTSA
IV-NIC Rotation Flexion		1.34	1.66
NIC Max		30	
Upper Neck	FX	730	Calculation from the value of left table.
	FZ	1130	
	MY(Flx)	40	
	MY(Ext)	40	
Lower Neck	FX	730	
	FZ	1480	
	MY(Flx)	40	
	MY(Ext)	40	

The method of calculating neck force/moment was calculated from the ratio in the WAD2+95%ile value of IV-NIC(R·Flx). For example, in NHTSA, it is a ratio of values in the red frame to the value in the blue frame in the table on the right.

3) WAD2+95% value calculated from the Risk Curve of neck force/moment

Injury Criteria		WAD2+	
		95% Value	
		Japan	NHTSA
IV-NIC R Flx		1.34	1.66
NIC Max		30	37
Upper Neck	FX	730	907
	FZ	1130	1404
	MY(Flx)	40	50
	MY(Ext)	40	50
Lower Neck	FX	730	907
	FZ	1480	1839
	MY(Flx)	40	50
	MY(Ext)	40	50

- The result of WAD2+95%ile value in NHTSA was shown in the table.
- The NHTSA's WAD2+95%ile value of IV-NIC was higher, the WAD2+95%ile value of NIC and neck force/moment was also higher.

### 1. Calculation of IV-NIC(R)

- Relationship between IV-NIC(R) and WAD were analyzed from accident simulation.

### 2. Correlation between IV-NIC (R) and Strain (Rate)

- As for the correlation coefficient at the Flexion, the strain is around 0.9, strain rate is 0.8, and has correlations.

### 3. Risk Curve of IV-NIC(R)

- The Risk Curves of IV-NIC(R) for Flexion were obtained by the accident simulation and the PMHS test, as follows.
  - 1) The Risk Curve ( $R=0.49$ ) from 20 cases accident simulation
  - 2) The Risk Curve ( $R=0.72$ ) from PMHS tests (17km/h and 24km/h)

### 4. Injury Parameters and Injury Criteria

- Two Risk Curves and WAD2+95% values of IV-NIC(R,Flx) calculated from Risk Curve are proposed as Injury Parameters and Injury Criteria.
- The comparison with the new Risk Curve based on new PMHS tests in the near future and the Risk Curve currently will be needed.