JAPAN NEW CAR ASSESSMENT PROGRAM FOR MINOR NECK INJURY PROTECTION IN REAR-END COLLISIONS

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ABSTRACT

The JNCAP intends to introduce a minor neck injury protection performance evaluation test method within the JNCAP program. Our research began with a 4-year project in 2005. In the first year, we conducted rear-end vehicle collision tests using a MDB to ascertain vehicle rear crash characteristics. In the second year, we conducted crash tests to allow changing the test conditions such as braking effect and excluding the influence of the MDB honeycomb. Basic data collected included floor G during a crash and measurement of the dummy injury level. In the third year, we conducted dynamic component sled tests to select an actual vehicle crash test or sled test. As a result, we found that the vehicle seat structure has a greater influence on the results than the vehicle structure. Additionally, in examining the sled acceleration pulse which represents the vehicle crash, we found that the crash characteristics of recent vehicles exhibited a triangular pulse rather than a trapezoidal pulse in the actual rear-end vehicle crash test. Delta-V is determined based on the cumulative figures for the rear-end crash accident speed rate. In the final year, all research results and conclusions were incorporated in our test protocol, and trial tests were conducted using the draft test procedure, which consists of the dynamic component sled test with a generic triangular pulse of delta-V=20 km/h. Effective evaluation indices will be finalized using recent biomechanical information. We will then publish all research results and present our final proposal.

1. Background

Thirty percent of traffic accidents in Japan are rear-end collisions and more than 90% of involved drivers sustain a neck injury[1]. When focusing on long-term injuries resulting from vehicle collisions during the decade from 1992 to 2002, the rear-end collisions were second and the most common were head-on collisions. The number of rear-end collisions increased annually and in 2002 comprised 24% of all accidents resulting in long-term injury[2]. Comparison of traffic accident injuries reveals that rear-end collisions are responsible for 38% of all injuries, resulting in 456,421 victims. This is now the most common type of traffic accident and the human loss has reached 288.8 billion Yen, second only to pedestrian-vehicle accidents. Neck injuries, specifically, account for 76% of rear-end collision injuries[3].

Technical countermeasures, such as the neck injury reduction seat, are gradually becoming more common in the market. The JNCAP will introduce an assessment program for neck injury protection performance in rear-end collisions to reduce neck injuries, popularize protection devices, and promote technological improvement.

2. Prerequisite condition

Dynamic evaluation will be introduced using an improved biomechanical rear-end collision dummy. Based on our study, the BioRID IIg was selected; it has been studied in the global technical regulation No. 7 (gtr-7) and is used by the Euro NCAP and IIHS. Due to budget constraints, we try to avoid overlap with regulations and the NCAP. Static geometric measurements for head restraints, which are based on the gtr-7, will be stipulated in national regulations in the near future. Therefore, we will not include this evaluation. Although it is preferable to use multiple pulses to eliminate pinpoint countermeasure, we intend to select a single pulse for evaluation for economic reasons. Our main goal is the reduction of long-term injuries, as a part of a broader aim to reduce fatal or serious injuries.

3. Considerations in introducing dynamic collision test

At first, the appropriateness of conducting a rear-end collision vehicle crash test was examined

as a part of the program. We initially considered using the frontal collision test car for the rear-end collision test due to budget constraints. However, industry experts strongly opposed using the same vehicle for both frontal collision and rear-end collision tests because damage from the first collision could influence the results of the second collision. This idea was therefore discarded.

The influences of vehicle and seat structures were then examined because Haland et al.[4] reported that seat structure is a greater factor for neck injury from rear-end collisions than vehicle structure. As a first step, we studied the crash pulse of a Moving Deformable Barrier (MDB) crashed into the rear of test vehicles (see Figure 1). Test results are shown in Table 1 and Figure 2-1, 2-2 and 2-3.

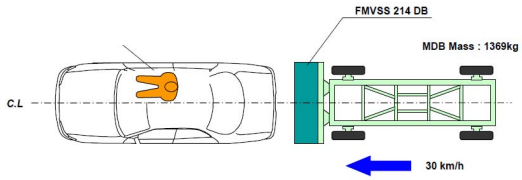

Figure 1. Test car vs. MDB rear-end collision Test

In these tests, Case 1 and 3 showed 2-peak pulses, which were also reported by Avery (2001)[5], but case 2 did not, possibly because the mass of the tested vehicle was much heavier than that of the MDB and this influenced the energy-absorbing characteristic of the MDB. In the MDB barrier test, the crash pulse may have been affected by the barrier characteristics, and may have included tire influences because the brake was applied in the crashed test vehicle.

Conditions were modified to eliminate these influences by conducting the test using a Moving Rigid Barrier (MRB). Figure 3 shows the exterior of the MRB, which has a mass of 1110 kg with plywood.

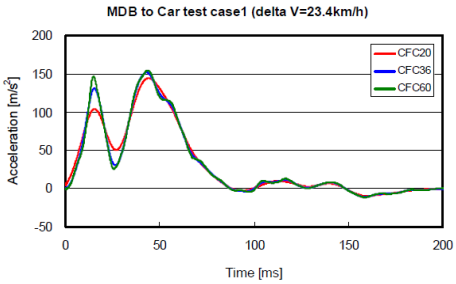

Figure 2-1. Acceleration pulse (MDB to car test, delta-V=23.4 km/h)

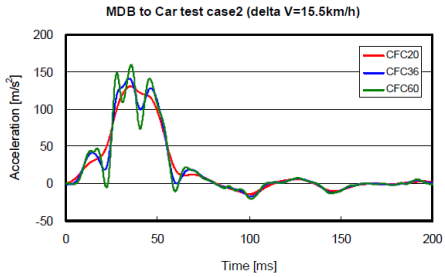

Figure 2-2. Acceleration pulse (MDB to car test, delta-V=15.5 km/h)

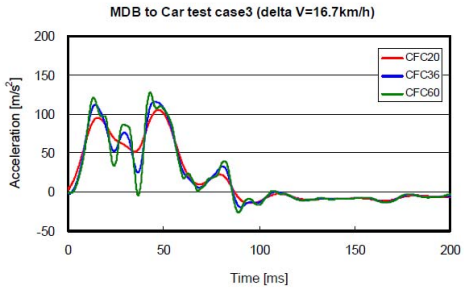

Figure 2-3. Acceleration pulse (MDB to car test, delta-V=16.7 km/h)

Table 1. Acceleration pulse produced by MDB-to-car crash

MDB to Car		Case 1		Case 2		Case 3	
	Filter	Value	Time (m sec)	Value	Time (m sec)	Value	Time (m sec)
Peak Vehicle C.G. Ax (g)	CFC20	14.7	44.1	13.3	35.2	10.8	47.4
Peak Vehicle C.G. Ax (g)	CFC36	15.5	43.0	14.4	34.7	11.8	45.4
Peak Vehicle C.G. Ax (g)	CFC60	15.7	43.6	16.3	35.6	13.1	42.9
Mean Vehicle C.G. Ax G) (Tzero –TP)	-	7.31	87.1 (Tp)	7.18	58.2 (Tp)	5.51	85.9 (Tp)
Vehicle C.G. Vel. Change (km/h)	-	23.4	147.9	15.5	80.9	16.7	85.5
Impact speed (km/h)	-	30.2	-	30.2	-	30.3	-

T_p: Time when acceleration became minus, after more than 90% speed change was recorded.

Figure 3. MRB (Moving Rigid Barrier)

In the MRB test, masses of the three test vehicles were adjusted to the same mass and the brake was not applied to conduct the tests under conditions, which permitted the characteristics of the vehicle structures to be evaluated easily. The MRB test results are shown in Figure 4-1, 4-2 and 4-3. The two-peak characteristic was not observed in the change of vehicle acceleration; case 1 and 3 showed a high peak in the initial stage, but case 2 showed a trapezoidal shape without a clear peak. One reason that case 2 produced a different acceleration pulse may be that the vehicle had a bumper crash box that absorbed energy during the rear-end crash (see Figure 5).

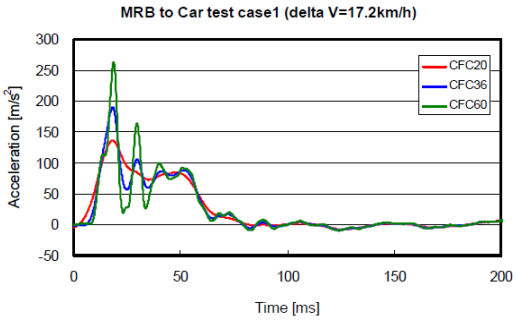

Figure 4-1. MRB-to-car test 1 (delta-V=17.2 km/h)

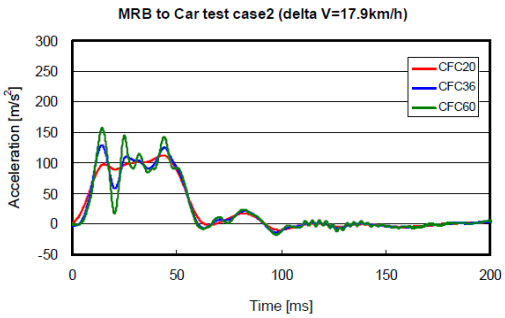

Figure 4-2. MRB-to-car test 2 (delta-V=17.9 km/h)

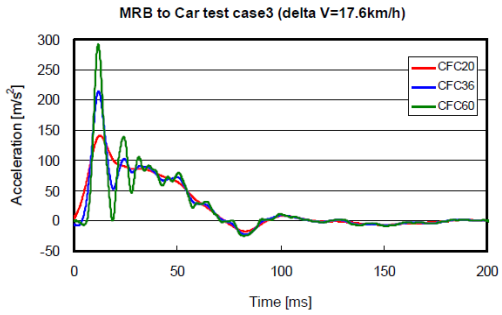

Figure 4-3. MRB-to-car test 3 (delta-V=17.6 km/h)

Figure 5. Photo of bumper crash box

Next, we studied the feasibility of conducting sled test for neck injury protection performance evaluation based on the results of the MRB test. For the sled pulse, the MRB test pulses of case 1 and 2 were used. Five seats were used, including the seats of case 1 (A seat) and case 2 (B seat), as well as three evaluated by the IIHS; two better performing seats (D and E) and one poor performance (C). Figure 6-1 shows comparisons of the Euro NCAP pulses and actual vehicle crash pulses, and Figure 6-2 shows comparisons of the Euro NCAP pulses and the re-produced sled pulses.

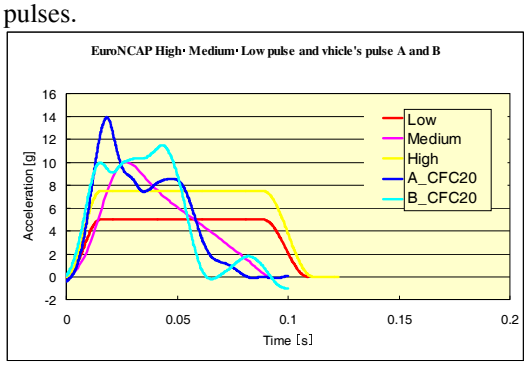

Figure 6-1. Comparisons of Euro NCAP pulses and test vehicle pulses of seat A and seat B

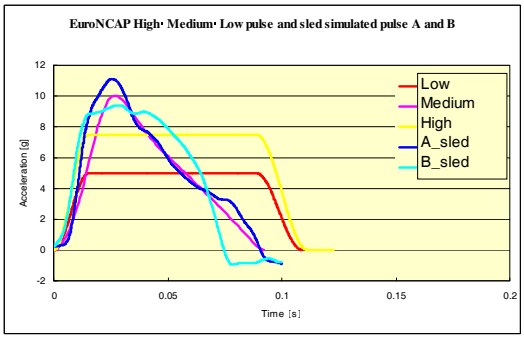

Figure 6-2. Comparisons of Euro NCAP pulses and sled-simulated pulses of seat A and seat B

Table 2. Sled test conditions

Dummy	Pulse	Target speed (km/h)	Test No	Type of seat
BioRID Ⅱg	Triangular Pulse	17.2	2007-A-11	Passive seat
			2007-B-11	Normal seat
			2007-C-11	Normal seat
			2007-D-11	Whips seat
			2007-E-11	Reactive seat
	Trapezoidal Pulse	17.9	2007-A-12	Passive seat
			2007-B-12	Normal seat
			2007-C-12	Normal seat
			2007-D-12	Whips seat
			2007-E-12	Reactive seat

Figure 7. Sled test

Tests were conducted under these conditions using a BioRID Ⅱg dummy, the same as used in the vehicle crash tests (see Figure 7). Sled pulses shown in Figure 8-1 and 8-2 and five different seats were employed under the same condition. Table 2 shows the testing conditions described above.

Figure 9 shows comparison of dummy response using a triangular pulse and the test results of vehicle A. Table 3 shows the dynamic responses of the dummy of the sled test (A seat) and vehicle A test. In the table, MY shows a slightly different behavior, but the sled test reproduced nearly the same results as the vehicle test. Table 4 shows a comparison of the head contact times of the sled test (seat A) and vehicle A test.

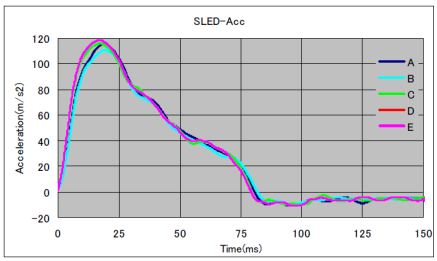

Figure 8-1. Sled acceleration pulse (triangular pulse)

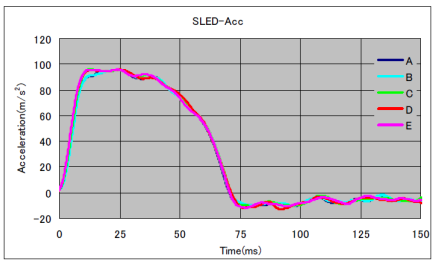

Figure 8-2. Sled acceleration pulse (trapezoidal pulse)

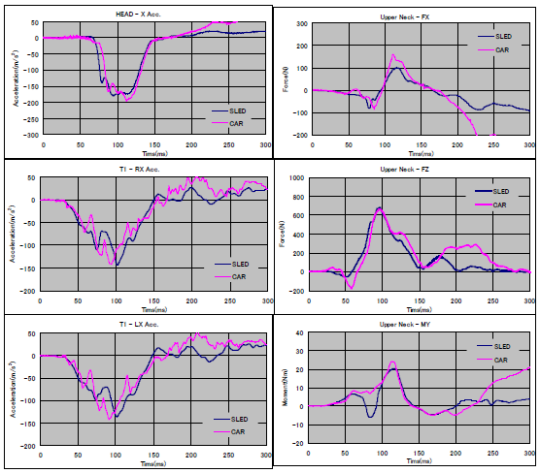

Figure 9. Dynamic responses of main body regions of dummy (Comparison of triangular pulse vs. vehicle test results)

Table 3. Dynamic responses of dummy (comparison of triangular pulse and vehicle test results)

Test No	Hx Acc. (m/s^2)	T1-R Acc. (m/s^2)	T1-L Acc. (m/s^2)	Upper FX (N)	Upper FZ (N)	Upper MY-Flx. (Nm)	Upper MY-Ext. (Nm)	NIC-R (m^2/s^2)	NIC-L (m^2/s^2)
2007-A-11	-180.6	-142.6	-135.8	101.4	683.4	20.3	-6.0	17.4	18.2
Vehicle test	-195.0	-141.7	-142.5	161.8	664.9	24.2	-5.0	21.5	21.6

Table 4. Head contact time for sled test and vehicle test (triangular pulse vs. vehicle test results)

	2007-A-11	Vehicle test
Backset	53.0	50.0
Contact start	64.3	64.0
Contact end	147.0	160.0
Contact Time	82.7	96.0

Unit:msec

Table 5. Dynamic response of dummy (trapezoidal pulse vs. vehicle test)

Test No.	Hx Acc. (m/s^2)	T1-R Acc. (m/s^2)	T1-L Acc. (m/s^2)	Upper FX (N)	Upper FZ (N)	Upper MY-Flx. (Nm)	Upper MY-Ext. (Nm)	NIC-R (m^2/s^2)	NIC-L (m/s^2)
207-B-12	-367.8	-153.5	-148.7	334.7	1653.5	33.7	-8.7	30.8	31.2
Vehicle test	-284.1	-201.3	-198.9	167.3	861.9	22.4	-10.2	40.2	40.3

Table 6. Head contact time for sled test and vehicle test (trapezoidal pulse vs. vehicle test results)

	2007-B-12	Vehicle test
Backset	79.0	80.0
Contact start	78.0	72.0
Contact end	143.0	148.0
Contact Time	65.0	76.0

Unit: msec

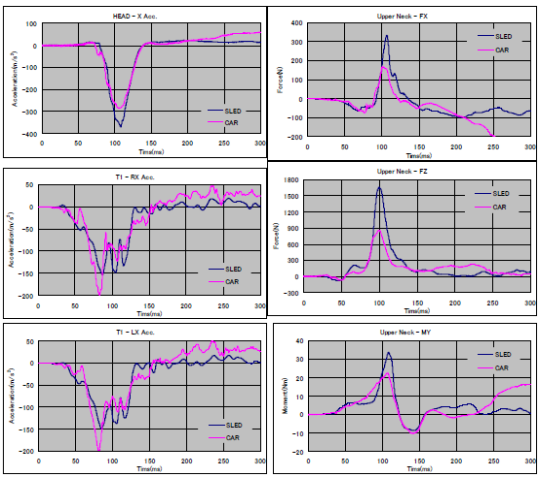

Figure 10. Dynamic response of dummy main regions (comparison of trapezoidal pulse vs. vehicle test results)

Figure 10 shows the dynamic response of the dummy using a trapezoidal pulse and the test results of vehicle B. Comparing sled test to the vehicle test, the maximum values of FX and FZ are markedly different. This means reproducibility of the sled test was insufficient, perhaps because the sled machine did not accurately simulate acceleration of the vehicle crash. Table 5 shows the dynamic response of the dummy of the sled test (B seat) and vehicle B test. Table 6 compares the head contact time for the sled test (B seat) and vehicle B test. Table 7 and Table 8 show the dynamic responses of the dummies in the sled tests using triangular pulse and trapezoidal pulse to compare the five different seats. We compared the seat of vehicle A using a triangular pulse to the seat of vehicle B using a trapezoidal pulse, then compared the seat of vehicle A using a trapezoidal pulse to the seat of vehicle B using a triangular pulse. The test results show that seat A tended to have lower dummy response levels, whereas seat B had higher values. In these tests, we found and confirmed that the influence of the seat dominated the influence of the crash pulse (or vehicle structure). Additionally, the order of the seat performance did not change even when the triangular and trapezoidal crash pulses were exchanged.

Table 7. Dynamic response of dummy (triangular pulse)

Test No.	HX Acc. (m/s^2)	T1-R Acc. (m/s^2)	T1-L Acc. (m/s^2)	Upper FX (N)	Upper FZ (N)	Upper MY-Flx. (Nm)	Upper MY-Ext. (Nm)	NIC-R (m/s^2)	NIC-L (m/s^2)
2007-A-11	-180.6	-142.6	-135.8	101.4	683.4	20.3	-6.0	17.4	18.2
2007-B-11	-316.8	-152.5	-151.0	237.6	1402.4	30.1	-9.0	23.7	24.3
2007-C-11	-341.6	-151.7	-150.7	441.2	1470.6	26.2	-5.3	36.2	36.3
2007-D-11	-188.5	-95.6	-99.1	76.1	520.9	20.5	-5.5	13.4	14.4
2007-E-11	-190.9	-134.5	-134.7	-0.6	504.2	15.6	-4.2	15.6	15.9

Table 8. Dynamic response of dummy (trapezoidal pulse)

Test No.	HX Acc. (m/s^2)	T1-R Acc. (m/s^2)	T1-L Acc. (m/s^2)	Upper FX (N)	Upper FZ (N)	Upper MY-Flx. (Nm)	Upper MY-Ext. (Nm)	NIC-R (m/s^2)	NIC-L (m/s^2)
2007-A-12	-202.1	-175.7	-166.0	253.3	770.8	26.8	-6.6	21.8	22.1
2007-B-12	-367.8	-153.5	-148.7	334.7	1653.5	33.7	-8.7	30.8	31.2
2007-C-12	-360.5	-159.2	-165.9	472.2	1570.4	25.3	-4.0	45.6	45.6
2007-D-12	-194.0	-110.9	-111.1	73.4	484.6	23.6	-6.8	16.3	16.0
2007-E-12	-199.3	-140.3	-136.5	-3.0	578.5	16.5	-3.1	20.1	19.7

As a result, we decided to introduce the sled test method for the evaluation of neck injury protection performance. We also compared injury levels using the triangular pulse and the trapezoidal pulse shapes. We expected test results using the triangular pulse to show a higher level of neck injury than the trapezoidal pulse, but the results were the opposite. The reason may be that not only peak acceleration but also average acceleration has some influence.

4. Study of test crash pulse

Through these vehicle tests, we found that many recent vehicles have a crash pulse characteristic with a triangular pulse or a 2-peak pulse, and the dummy response with a triangular pulse has better reproducibility than an actual rear-end vehicle crash.

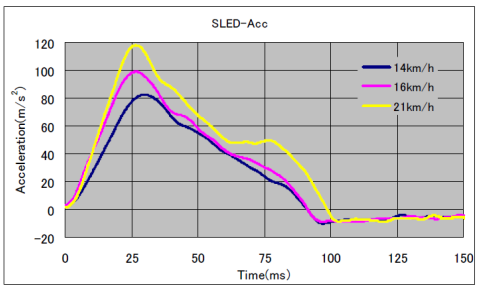

Figure 11. Sled pulses

Based on this finding, we studied maximum acceleration, average acceleration and duration time as shown in Table 9-1, 9-2 and 9-3. Neck injury frequently occurred in rear-end crashes which had delta-V= 10~20 km/h. We conducted vehicle tests using this range of delta-V, and had gained the maximum acceleration of 100~130 m/s^2, average acceleration of 45~70 m/s^2, and duration time of 80~110 ms (see Table 10).

Next, we studied the influence of delta-V in neck injuries because delta-V is influenced by the mass of crashed vehicle. We found that increasing delta-V tends to provide higher dummy response values (see Figure 11, 12 and Table 11, 12). Figure 11 shows selected sled pulses and Figure 12 presents the dummy dynamic responses of three different delta-V pulses.

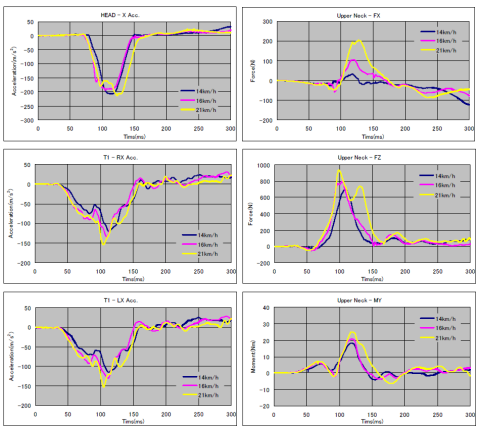

Figure 12. Dynamic response of main region of dummy

Table 9. Maximum acceleration, average acceleration, duration time

Table 9-1. Car-to-Car Test (tested by ITARDA)

Car to Car	Filter	Case 1	Case 2	Case 3	Case 4*
Max. acceleration (m/s^2)	CFC 60	101.9	162.7	162.7	53.9
Ave. acceleration (m/s^2)	-	47.63	80.07	78.60	27.44
Duration (ms)	-	111.6	107.7	105.0	128.5
Delta-V (km/h)	-	19.0	27.7	23.2	12.6
Collision speed (km/h)	-	35.2	49.9	30.1	29.1

* Note: In Case 4, the crashed car was a one-box type vehicle, which possibly nose-dived.

Table 9-2. MDB to Car Test

DB to Car	Filter	Case 1	Case 2	Case 3
Max. acceleration (m/s^2)	CFC 20	144.1	130.3	105.8
Ave. acceleration (m/s^2)	-	71.64	70.36	54.00
Duration (ms)	-	147.9	80.9	85.5
Delta-V (km/h)	-	23.4	15.5	16.7
Collision speed (km/h)	-	30.2	30.2	30.3

Table 9-3. MRB to Car Test

MRB to Car	Filter	Case 1	Case 2	Case 3
Max. acceleration (m/s^2)	CFC 20	136.2	112.7	141.1
Ave. acceleration (m/s^2)	-	60.17	79.16	69.19
Duration (ms)	-	109.9	90.9	70.0
Delta-V (km/h)	-	17.2	17.9	17.6
Collision speed (km/h)	-	35.1	35.4	35.5

Table 10. Proposal

	Proposal
Max. acceleration (m/s^2)	100~130
Ave. acceleration (m/s^2)	45~70
Duration Time (ms)	80~110

Note: Collision tests results which have a delta-V=10 to 20 km/h, were reviewed, and the range of each item was examined. We focused on the car-to-car and MDB crash test results.

Table 11. Dynamic response levels

Test No.	HX Acc. (m/s^2)	T1-R Acc. (m/s^2)	T1-L Acc. (m/s^2)	Upper FX (N)	Upper FZ (N)	Upper MY-Flx. (Nm)	Upper MY-Ext. (Nm)	NIC-R (m/s^2)	NIC-L (m/s^2)
2007-A-21	-207.8	-120.6	-115.6	33.9	704.4	18.3	-4.2	16.2	16.3
2007-A-22	-193.6	-133.9	-130.7	104.4	800.1	20.7	-3.8	17.9	16.7
2007-A-23	-212.8	-154.3	-153.1	205.1	937.2	25.0	-6.4	18.8	19.2

Table 12. Head contact time to head restraint

	2007-A-21	2007-A-22	2007-A-23
Backset	53.0	51.0	51.0
Contact start	78.0	70.6	71.0
Contact end	151.0	148.0	160.0
Contact Time	73.0	77.4	89.0

Unit: ms

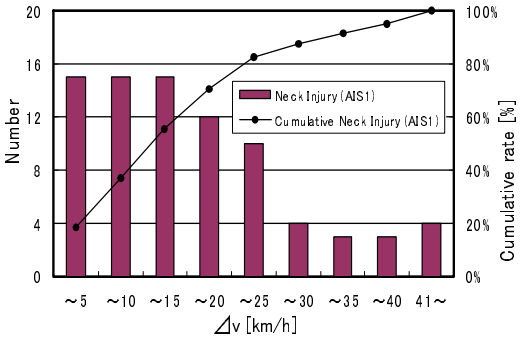

Figure 13. Delta-V of crashed vehicle and driver injury
(Crashed vehicle: passenger cars and mini cars)
(Number of accidents for which delta-V was calculated: passenger cars (89 persons), mini cars (20 persons), from ITARDA Report 2007)

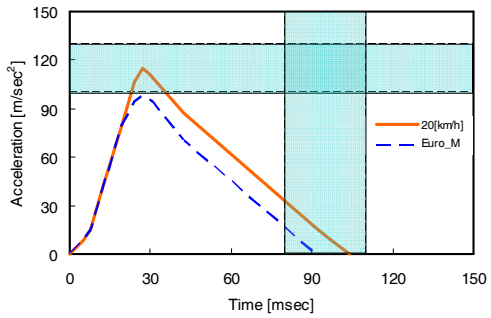

Figure 14. Pulses

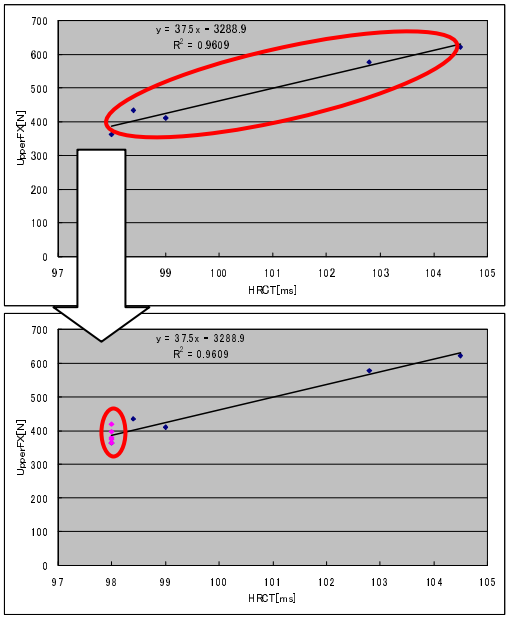

Figure 15. Removal of dispersion of Head Restraint Contact Time

We focused on long-term injury to select the test delta-V because the goal of the JNCAP is the reduction of fatal or serious injuries. In addition, Kullgren[6] recommended the use of delta-V=20 km/h or higher for the evaluation of WAD2+ injury or injury lasting more than one month, and delta-V=20 km/h covers 70% of the neck injuries in Japanese rear-end crash accidents (see Figure 13). Based on these results, we decided to select delta-V=20 km/h. Referring to the Europe and IIHS rear-end crash pulses, we decided to use the triangular pulse for the rear-end crash at delta-V=20 km/h, since it is similar to both the Euro NCAP medium pulse and IIWPG pulse (see Figure 14). Main dispersions are related to the dummies and the seats. We focused on the seat dispersion in an attempt to eliminate their influence. Dispersion of the seats is caused by deformation of the seat backs, and we hypothesize that this dispersion is representative of the dispersion of the head contact time in relation to the head restraint. Since the head restraint contact time (HRCT) and the dummy response values approach a linear relationship, we determined the CV (coefficient of variation) values of the dummy responses after having shifted the relation to an approximate straight line at which HRCT becomes constant (see Figure 15).

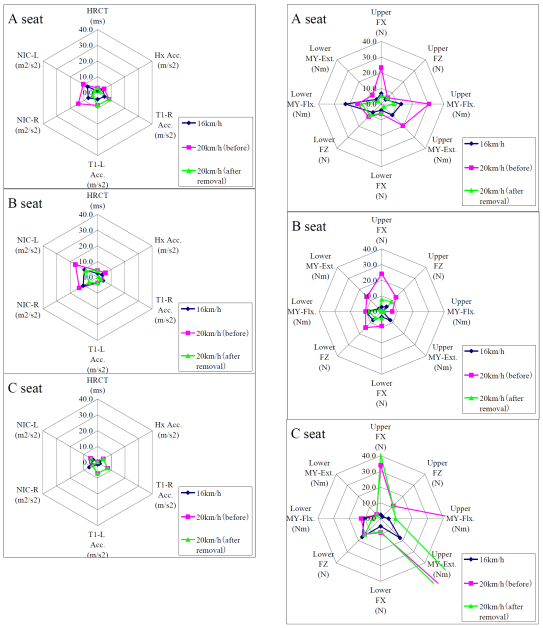

Figure 16. Repeatability test Results (data at 16 km/h are courtesy of JAMA and JASIC.)

Although the repeatability of the BioRID was not considered a problem for the speed range of the test, some seat back deflection was found to enter a range of plastic deformation and broad dispersion at delta-V=20 km/h. This means that some existing seats do not have adequate countermeasure levels in this speed range. Given

these seat performance levels, we cannot objectively evaluate rear-end collision performances for all seats under the delta-V=20 km/h condition (see Figure 16). For this reason, we will start the evaluation tentatively with the delta-V=17.6 km/h, which is 10% higher than the proposed future regulation level.
Delta-V will be increased to 20 km/h after 3 years, when a dynamic test will be required for reactive seats under the regulation, and manufacturers will also have made improved and safer seats commercially available.

5. Study of evaluation guideline

Evaluation guidelines have been developed based on researched injury mechanisms utilizing research papers[8] and volunteers test conducted by Ono et al.
Deng (2000)[9] and Yoganandan (2001)[10] have reported their crash test using cadavers and found that injuries of the intervertebral discs and the facet joint capsule of the lower cervical vertebrae, especially, tearing of the soft tissues, occurred due to shearing and tension. Deng (2000)[9] also reported that dynamic motion and strain rates influence the tearing of soft tissue in the cervical vertebra. Yoganandan (2001)[10], Barnsley (1995)[11] and Lord (1996)[12] reported that neck pain was related to intervertebral discs and facet joint capsule injury resulting from treatment of the disc joint block. Lee (2006)[13] reported that strain of facet joint capsule was related to pain in his test using rats. The volunteer low speed mini-sled test conducted by Ono et al.[8], in which they hypothesized that the strains on the facet joint capsule and the motion of the intervertebral disc were equivalent, measured the motion of the local transformation of the intervertebral disk using sequential cineradiography of the vertebral motion during impact. The maximum principal strain and principal strain rate, and the maximum shear strain and shear strain rate, were determined from these motions. Injury thresholds were defined by the strain value and strain rate at which volunteers felt some discomfort after the test (see Table 13).

Table 13. Defined injury thresholds

Principal strain value: 0.06 or more	Principal strain rate: 2.68 or more
Shear strain value: 0.05 or more	Shear strain rate: 1.81 or more

Since actual injuries often occurred in or near the C5~C6 region, the dummy can be used to measure the upper neck Fx, Fz, My, lower neck Fx, Fz, My, head G and T1G (see Figure 17 and 18). We decided to use these factors and evaluate the load applied to the neck during the head contact to head restraint and seatback.

$$NIC(t) = 0.2 \cdot a_{rel}(t) + (V_{rel}(t))^2$$

where $a_{rel} = T1G(t) - HeadG(t)$

$$v_{rel} = \int a_{rel}(t)dt$$

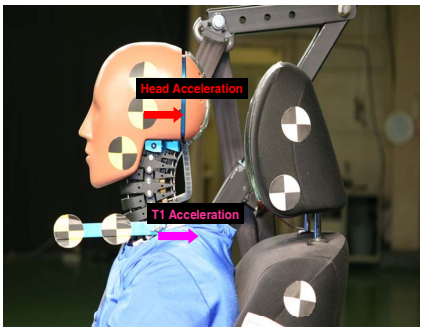

Figure 17. Dummy motion 1)

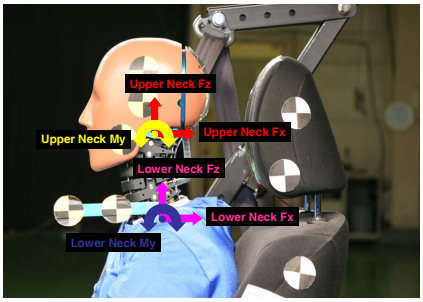

Figure 18. Dummy motion 2)

Neck injury occurred: 1) when the neck became S-shaped through transformation of the cervical vertebrae before the head contacted with the head restraint, and 2) after the head contacted with the head restraint to just before the neck attained maximum backward flexion. Neck injuries were evaluated in phase 1) using the index of NIC_{max} proposed by Bostron et al[7]., and Ono[8] reported NIC_{max} correlated well with the maximum strain rate. Phase 2) was evaluated using the indices of the upper neck Fx, Fz, My, lower neck Fx, Fz and My, proposed by Ono[8]. The reasons for selecting these factors are shown in Table 14.
Simulation analysis was conducted using accident data for the selected injuries indices, and risk curves of these selected indices were made using the analytical results. Due to unavailability of detailed accident data for neck injury, 1) we could not create all of the injury risk curves, and 2) due to the lack of the NIC and lower Fz, we could not identified 0% risk point. However, we specified the discomfort level of volunteers as the 5% risk and made injury risk curves. Additionally, when injury curves were unobtainable, we tentatively used other available injury indices, and made expedient injury risk curves (see Figure 19 and Table 15).

Table 14. Reasons to select following factors

Index of injury		Correlation with strain / strain rate	Comments	Overall decision
Upper Fx	Forward	Marginal	Correlation coefficient is low, dispersion is large	No
	Backward	Good	Correlation of discomfort in volunteer test	Yes
Upper Fz	Tension	Good	Correlation to strain of vertebra, strain rate are high	Yes
	Compression	Marginal	Simulation output is too small to judge the correlation	No
Upper My	Extension	Marginal	Purpose to evaluate control effect of neck upper motion	Yes
	Flexion	Good	Correlations with strain of vertebra and strain rate are high	Yes
Lower Fx	Forward	Marginal	Correlation coefficient is low, dispersion is large	No
	Backward	Good	Correlations with strain of vertebra and strain rate are high	Yes
Lower Fz	Tension	Good	Correlations with strain of vertebra and strain rate are high	Yes
	Compression	Marginal	Simulation output is too small to judge the correlation	No
Lower My	Extension	Marginal	Purpose to evaluate control effect of neck lower motion	Yes
	Flexion	Good	Correlations with strain of vertebra and strain rate are high	Yes
NIC Max.		Good	Correlations with strain of vertebra and strain rate are high before the contact with head restraint	Yes
NIC Min.		Poor	No correlation	No
T1G		Good	Substituted by NIC (NIC included acceleration of T1, NIC can evaluate both head G and T1G)	No
Nkm		Marginal	Substituted by upper Fx, My	No
LNL		Good	Substituted by lower Fx, Fz, My	No
Rebound V		Good	Phase is different of max. strain and strain rate	No
OC-T1		Good	This is displacement, substituted by lower Fx	No
Head-chest rotation angle		Good	This is rotational angle, substituted by lower My	No

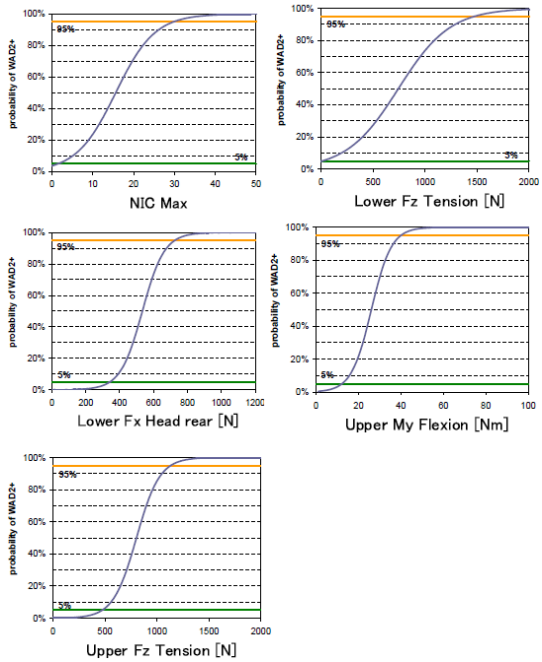

Figure 19. Risk curves of neck injuries

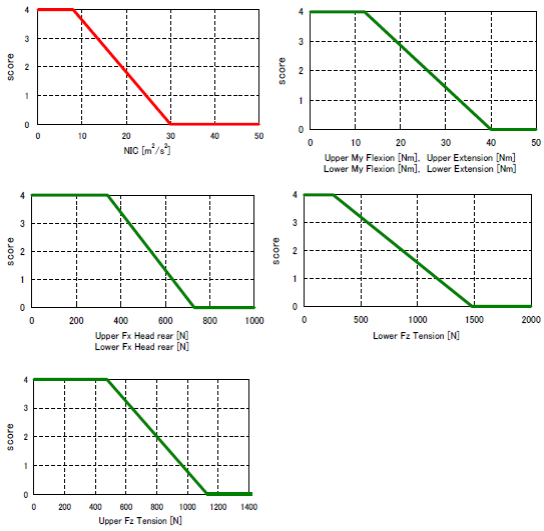

Figure 20. Sliding scale of injury indices and their scores

Based on these injury risk curves, we developed a scoring method to evaluate the injury index using a sliding scale method (see Figure 20 and Table 16).

Table 15. Neck injury indices

Index of injury		Before correction (WAD2+)		After correction (WAD2+)		Remarks
		5% value	95% value	5% value	95% value	
Max. principal strain		0.08	0.24	0.08	0.24	
Max. shear strain		0.05	0.13	0.05	0.13	
Max. principal strain rate		-	10.8	2.68	10.8	5%: refer volunteer data
Max. shear strain rate		-	5.8	1.81	5.8	5%: refer volunteer data
NIC Max.		-	30	8	30	5%: refer volunteer data 95%: from Risk curve
Upper Fx	Backward	-	-	340	730	Substitute for Lower Fx
Upper Fz	Tension	475	1130	475	1130	From risk curve
Upper My	Extension	-	-	12	40	Substitute for Upper My
	Flexion	12	40	12	40	From risk curve
Lower Fx	Backward	340	730	340	730	From risk curve
Lower Fz	Tension	-	1480	257	1480	5%: refer volunteer data 95%: from risk curve
Lower My	Extension	-	-	12	40	Substitute for Upper My
	Flexion	-	-	12	40	Substitute for Upper My

Table 16. 5%/95% values of WAD2+ injury of injury evaluation items

Neck injury evaluation items for rear-end collision			WAD2+	
			5% Value	95% Value
NIC (m^2/s^2)			8	30
Neck force, moment	Upper Fx(N)	Backward	340	730
	Upper Fz(N)	Tension	475	1130
	Upper My (Nm)	Flexion	12	40
		Extension	12	40
	Lower Fx(N)	Backward	340	730
	Lower Fz(N)	Tension	257	1480
	Lower My (Nm)	Flexion	12	40
		Extension	12	40

Before finalizing the evaluation method, we studied weighting factors between NIC and the neck force/ moment. Using simulation results based on accidents data, we compared the points of the NIC and the points of the neck force/moment. We found that the neck force/moment scored only half the points of NIC (see Figure 21). This means that the neck force/moment has twice the influence of the NIC. Therefore, we determined the weighting factor as follows.

NIC : neck force / moment =1:2

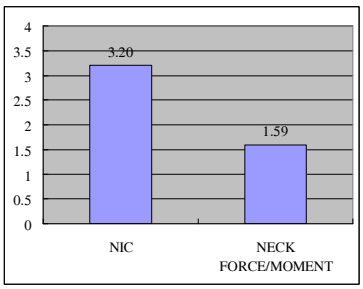

Figure 21. Comparison of NIC points and neck force/moment points in simulation

Evaluation methods for 1) injury before contact with the head restraint evaluated by the NIC (full score of 4 points), and 2) injury during contact with the head restraint evaluated by Upper Fx (Head backward direction, Shear), Upper Fz (Tension direction), Upper My (Flexion), Upper My (Extension), Lower Fx (Head backward direction, Shear), Lower Fz (Tension direction), Lower My (Flexion) and Lower My (Extension) (full score of 4 points); in case 2) worst points will be selected from the eight indices. Then, we added the NIC points and doubled the weighted neck force/moment points. Finally, we evaluated the total points, which included 12 points in all.

6. Conclusion

The JNCAP developed a rear-end collision neck injury assessment testing method, which will reduce long-term neck injuries in Japan, by including the selection of delta-V=20 km/h with triangular pulse after studying accident data and research, and based on available overseas studies. Due to the performance levels of some existing seats, it was difficult to conduct properly evaluations with delta-V=20 km/h in all cases due

to the dispersion of the test results caused by plastic deformation of the seat structure. We will tentatively start with delta-V=17.6 km/h, but will return to delta-V=20 km/h after 3 years. Regarding injury indices, we used volunteer test results and accident reconstruction simulation on the supposition that intervertebral disc motion and strain of the facet joint capsule are equivalent. We selected injury indices NICmax, Upper Fx (Head backward direction, Shear), Upper Fz (Tension direction), Upper My (Flexion), Upper My (Extension), Lower Fx (Head backward direction, Shear), Lower Fz (Tension direction), Lower My (Flexion) and Lower My (Extension).

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