BIOMECHANICAL RESPONSE OF THE HEAD, NECK AND TORSO TO DIRECT IMPACT ON THE BACK OF MALE AND FEMALE VOLUNTEERS

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ABSTRACT

Low-severity impact at T1, T6, and L1 to the back of volunteers were applied using a newly developed thrust piston with pneumatically charged cylinder (simulated whiplash loading device) in order to simulate the whiplash motions during such impacts. Seven male and two female volunteers were subjected. The average age of the volunteers was 25 years old. The impact of 100-400 N with duration of 50-100 ms was applied to the back of these volunteers. The three impact locations for each volunteer were: 1) the close area of the first thoracic vertebra (T1), 2) the close area of the six thoracic vertebra (T6), and 3) the close area of the first lumbar spine (L1). The test results for human volunteers were compared with the cadaver tests reported in the past.

For T1, T6, and L1 impacts, the lower cervical spine showed an initial flexion during early stages of impact. The neck axial force appeared to be in tension in the early stages within 50 ms for T1 and T6 impacts. On the other hand, the neck axial compression force in the early stages became remarkable for L1 impact. Due to the neck muscle tension, the neck moment was observed to be getting small which eventually resulted to a minimal movement of the head. However, the neck axial compression force was not affected due to the muscle tension. It can be argued that the neck muscle tension did not influence the movement of the spine.

For T1 and T6 impacts, the neck shear force increased while the change in the neck axial compression force was negligible due to the increase in the impact load level. The head rotational angle and the localized motion of cervical spine for female were bigger than that of male using the same impact load level.

It is confirmed that it is necessary to take into account the motion of the spine and/or spine flexibility in evaluating the cause of cervical injuries during low speed rear-end impacts. Furthermore, with this experiment, the difference in the loading condition at the back caused by different impact positions to the spine and the impact load levels could be understood more. This study thus recommends that a new design in the dummy spinal structure must be made in order to obtain an accurate prediction of minor neck injury occurrence.

Key words: Dummies, Neck, Low-severity impact, Volunteer, Cervical Spine

IN A REAR-END COLLISION, the spinal column of an occupant will make a straightening as the torso is pushed upward due to its impact against the seat back. It is said (Kaneoka et al., 1998) that this spinal deformation affects the neck push-up motion and increases the neck injury incidence.

It has been recognized widely that the neck deforms into the S-shape (Grauner et al, 1997; Panjabi et al., 1998; Yoganandan et al., 1997) in line with the "whiplash motion" originated from the first thoracic vertebra (T1), and that the bending moment around the occipital condyle (OC) at the top of neck and the head rotation are the factors that cause neck injuries. Hence, subsequent studies (Svensson et al, 1991, 1993; Waltz et al.,1995) conducted for the clarification of neck injury mechanism and the S-shape deformation have been focused on the horizontal component of impact force originated from T1 alone out of various impact forces, while studies taking into account of components in vertical direction and/or rotating motion also are virtually none in existence.

On the other hand, it is reported (Shen et al., 1998) for the first time in 1998 that loads concentrated on the back were different between dummies and humans. This is according to studies on seat/headrest system conducted with measurement of seat back surface pressures using both volunteers and dummies, and aiming at the reduction of severity of neck injuries in rear-end collisions. However, no remarks were made on the relationship between the seat back interaction pressure and deformation of spinal vertebrae (cervical/ thoracic/lumbar vertebrae) - the effect of condition of interaction between the seat back and torso on the cervical spine motions in particular. In order to reduce the severity of neck injuries in rear-end impact by means of enhancement or development of seat system, it is important to determine the torso motion, that is, the cervical spine deformation - and its effect on the spinal column motions.

In this regard, a new head/neck/torso "inertia impact loading device, which is a simulated whiplash motion device" was developed in this study in order to simulate the impact between the occupant torso and the seat back in rear-end collision and to examine the effects on head/neck/torso impact responses and the whole spine motions. Specifically, the effects of different loading locations of impact at the back of occupant on head/neck/torso impact responses and cervical spine motions were also investigated, assuming that the cervical spine deformation would be affected by the dispersion of impact load between the occupant torso and the seat back. This investigation was done by considering the difference in the sex of volunteers and the difference neck muscular responses at the same time.

EXPERIMENTAL METHODS

INERTIA IMPACT TEST EQUIPMENT: A test apparatus was developed anew (Figure 1) in order to simulate the impact between the occupant torso and the seat back in rear-end collision. We also used this apparatus to study the effects of impact on whole spine straightening, neck push-up motion and cervical spine motion. This apparatus consists of an air compressor/accumulator to push out the impacter, coil spring unit, impacter height adjuster and the test subject's seating position adjuster (longitudinal and vertical adjustments). The plate located at the front end of impacter is fixed to the piston through the piston rod. By opening the air fastener located at the rear end, the impacter is ejected and the load is applied to the back of test subject. The coil spring unit is added to control the impacter stroke and the increase of impact load. The impacter stroke and the rise of impact load can be set per experiment.

The analyses of acceleration of the head, the first thoracic vertebra (T1), electromyograph measurement (EMG), neck load (shear force, axial force and moment), head/neck/torso motions, cervical spine motions, etc. during the impact are discussed in previous papers (Ono et al., 2001, 2002).

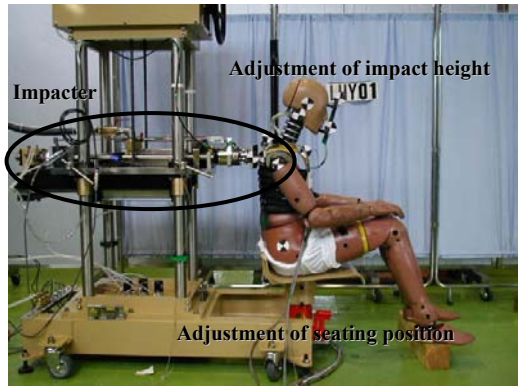

Fig.1 Simulated whiplash loading impacter

SELECTION OF TEST SUBJECTS AND INFORMED CONSENT: Six male and two female healthy adult volunteers without any history of neck injuries were selected as the test subjects. The height, weight, sitting height, estimated head weight, estimated head inertia moment and age of each volunteer are shown in Table 1 for male and Table 2 for female subjects. The cervical spine alignment of each male and female subject taken by means of simple X-rays is shown in Figure 2a and Figure 2b, respectively. The experimental protocol was reviewed and approved by the Ethics Committee of Tsukuba University. All volunteers submitted their informed consent in writing according to the Helsinki Declaration (WHO/CIOMS, 1998) prior to the implementation of the tests.

Table 1 Male Subjects

		Age	Sex	Height (cm)	Sitting Height (cm)	Weight (kg)	Estimated Head Weight (kg)	Estimated Inertia of Head (10*5 g-cm*2)
1	KW	24	M	168	89	58	3.97	2.04
2	HU	23	M	180	93	67	4.28	2.21
3	KK1	22	M	173	91	70	4.38	2.27
4	TY	26	M	172	92	70	4.38	2.27
5	MO	22	M	173	94	74	4.53	2.35
6	KK	40	M	172	92	73	4.49	2.33

Table 2 Female Subjects

		Age	Sex	Height (cm)	Sitting Height (cm)	Weight (kg)	Estimated Head Weight (kg)	Estimated Inertia of Head (10*5 g-cm*2)
7	FS	23	F	161	82	58	3.98	2.04
8	RO	24	F	152	78	45	3.6	1.83

a) Male b) Female

Fig.2 Typical cervical images of male and female by X-ray pictures

TEST SETUP

This experiment involves a situation subjecting the occupant torso to the impact from the seat back in rear-end collision. The areas close to the first thoracic vertebra (T1), the six thoracic vertebra (T6) and the first lumbar spine (L1) were selected as the impact loading locations (Figure 3). The impact against the area close to L1 was selected considering a situation where a relatively light impact was applied to the lumbar from a relatively hard portion such as the lumbar support. The T1 and T6 impact locations were also set so that the comparison with the direct impact to the back using cadavers could be done properly as described in the following section.

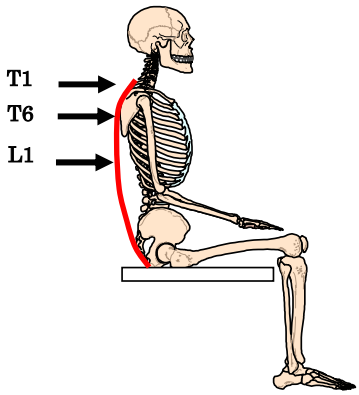

Fig.3 Impact locations

In order to determine the effect of muscle conditions on the neck forces and the head/neck/torso motions, tests were conducted under two separate conditions of neck muscular tension: in one case, the subjects had been informed of the impact timing in advance so that their neck muscles would become tense in anticipation of impact, and in the other case, the subjects had not been informed of the impact timing so that their neck muscles would be relaxed.

In L1 impact tests, the impact loads against L1 were set at three different levels such as 200N, 300N and 400N in order to determine the differences in head/neck/torso impact responses caused by these difference levels of impact load. These impact load levels were set based on the interaction loads between the back and the seat back, which was reported by Ono et al (1999). Also, in this experiment, two female subjects were used as volunteers in order to elucidate how differences in sex could affect head/neck/torso impact responses. Since it was the first time to use volunteers in this kind of test with direct impact to the back, the experiment was conducted with a starting impact load of 200N, that is, without any conceivable risk involved. Then the load was increased gradually to 300N and 400N and this was done by checking first the willingness of each subject and the subject's physical condition carefully. For the female subjects, the impact application was started from a lighter load of 100N on the much safer side, then the load was increased gradually to 200N and 300N. Similarly, this was also by while checking their willingness and their physical condition. As for the seating position in the initial stage, the kyphosis position was selected for the impact against T1 and T6 and this was also based on the studies of Ono et al (1997 and 1999). On the other hand, kyphosis position with the spinal column slightly hunched was selected for the impact against L1 and compared it with the kyposis position selected for the impact against T1 and T6. The instrumentation used in the tests is listed in Table 3.

Table 3 Mesurement Items

Locations		Items	Axis	Model
Event		Trigger	-	Conatct switch
Impact Load		Load	x	LUR-A-1KNSA1 (1kN)
Volunteer	Head - Upper	Acceleration	x, z	Endevco 7264A (20G Cal.)
	- Lower	Acceleration	x, z	Endevco 7264A (20G Cal.)
	T1	Acceleration	x, z	Endevco 7264A (20G Cal.)
	EMG	Control	Skin	
		SCM(L)	Sternoclaidmastoid muscle (Left)	
		PVM(L)	Paravertebral muscles (Left)	
		TZ(L)	Trapezius muscles (Left)	
		SCM(R)	Sternoclaidmastoid muscle (Right)	

TEST MATRIX: The test matrix on the combination of impact load level, impact location and muscle conditions are shown separately for the male subjects (Figure 4a) and female subjects (Figure 4b). The flow of arrow marks in each figure shows the combination of test conditions. As for the male subjects, the parameters used for the tests were the impact locations (T1, T6 and L1) and the muscle conditions and the tests were conducted at the impact load level of 400N. The effect of muscle condition due to the difference in impact load level was investigated at the location of L1. For the female subjects, on the other hand, the same parameters were used but the tests were conducted using an impact load level of 200N. The effect of muscle condition due to the difference in impact load level was investigated at the L1 location, the same as in the case of male subjects.

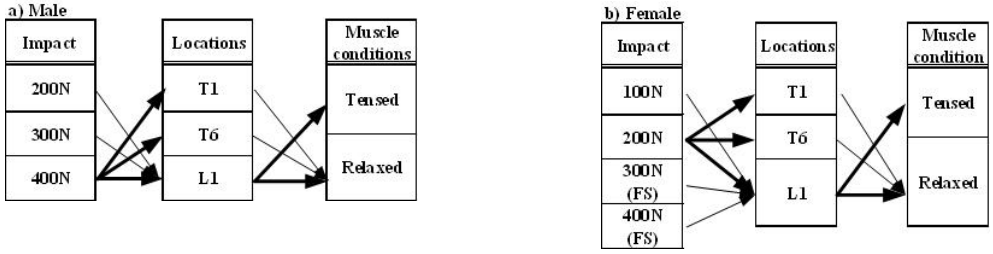

Fig.4 Test matrix

RESULTS

EFFECTS OF DIFFERENCE IN IMPACT LOAD LEVELS ON HEAD/NECK/TORSO RESPONSES: The effects of difference impact loads on the head/neck/torso responses were studied. The tests were conducted using three different impact load levels such as 200N, 300N and 400N under the following test conditions: 1) six male subjects only, 2) with neck muscles relaxed, and 3) impact location of L1. Figure 5 shows the impact load, head rotation angle, head rotation angle with respect to T1, the T1 displacements in X and Z directions, and the neck forces. The data shown for each impact load are mean values of the subjects.

As shown in Figure 5, it is found that the head rotation angle, head rotation angle with respect to T1 and the neck load are observed to be increasing as the impact load increases. The pushed-up displacement of T1 in the direction of Z, however, does not tend to increase in line with the increase in impact load, while the neck axial force tends to increase markedly.

EFFECTS OF DIFFERENCE IN IMPACT LOCATION ON HEAD/NECK/TORSO RESPONSES: The effects of different impact locations on the head/neck/torso responses were investigated. The impacts were applied against three different locations - T1, T6 and L1 – under the following test conditions: 1) six male subjects only, 2) with or without neck muscle tension, 3) the same impact load of 400N. Figure 6 shows the impact load, head rotation angle, head rotation angle with respect to T1, the T1 displacements in X and Z directions, and the neck forces. The data shown for each impact load are the mean values of the subjects. Given the above set-up, the following result is observed:

During impact tests against T1, T6 and L1, the extension of head starts around 30 ms after the impact. The extension starts earlier for the impacts against T1 and T6 than that against L1. The maximum head extension angle is found around 100 ms for both T1 and T6, while around 200 ms for L1 impact location. The head rotation against T1 in the early stages of T1 and T6 impacts is in the form of flexion. This phenomenon becomes most remarkable in T6 impact. Less head Z displacement relative to T1 is observed in T1 and T6 impacts, while the head is pushed upward in L1 impact. No significant differences in neck forces are found between T1 and T6 impacts. In comparison to L1 impact, however, the neck shear force becomes apparent in T1 and T6 impacts. In cases of T1 and T6 impacts, the axial compression force was applied to the neck after impact and this resulted to a more axial force to pull the neck. The neck moment results in the flexion of the neck immediately after the impact, followed by the extension, which is found not only in T1 and T6 impacts but also in L1 impact.

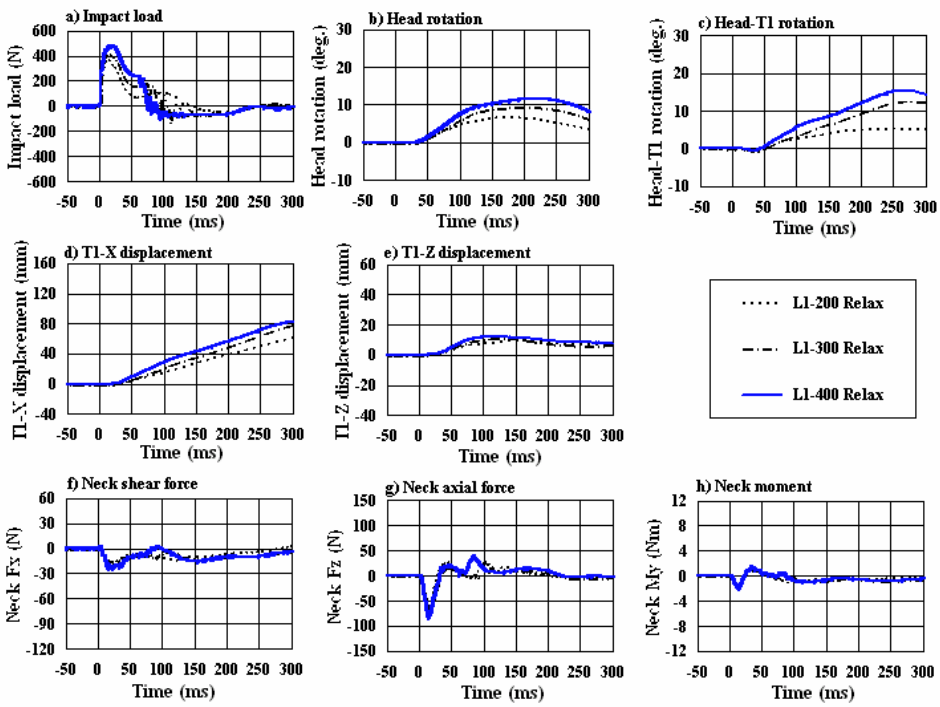

Fig.5 Biomechanical responses for the different impact loadings (200N, 300N, 400N) on the back at L1

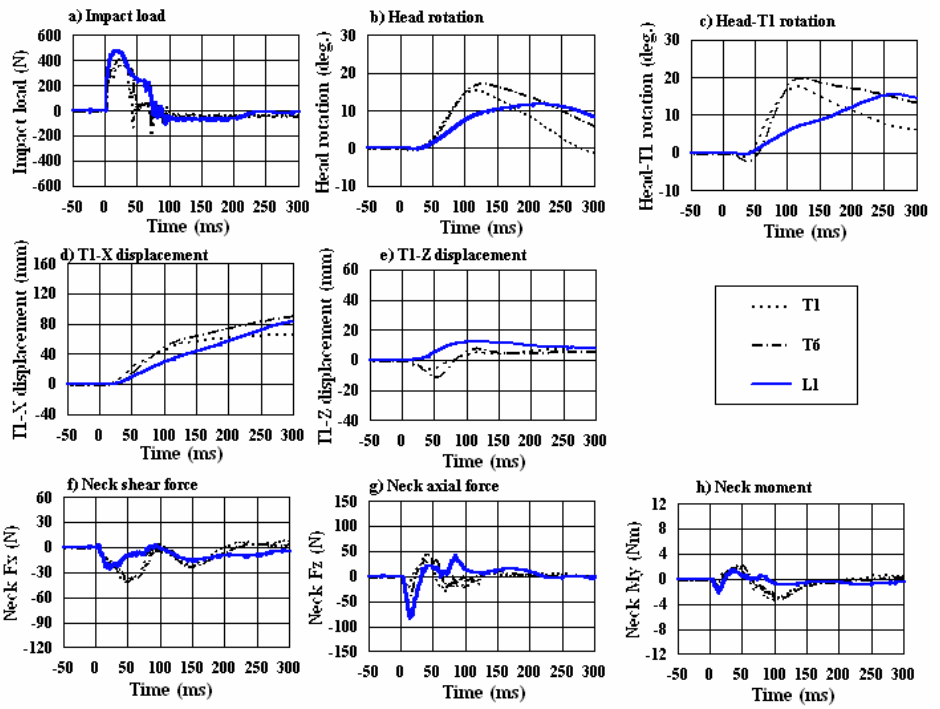

Fig.6 Biomechanical responses for the different impact locations on the back (Impact load: 400N, Relax)

EFFECTS OF NECK MUSCLE CONDITIONS ON HEAD/NECK/TORSO IMPACT RESPONSES: In order to determine the effects of muscle conditions on the neck forces and the head/neck/torso motions, experiments were conducted under two conditions; that is, in terms of neck muscular tension. In one case, the subjects had been informed of the impact timing in advance so that their neck muscles would become tense in anticipation of the impact and in the other case the subjects

had not been informed of impact timing so that their neck muscles would be in the relaxed condition upon impact. The test conditions were set as follows: 1) to conduct the test on the six male subjects only, 2) to set their neck muscles as tensed and relaxed, and 3) to select L1 as the impact location.

Under such test conditions, the impact loads were set at 200 N and 400 N levels, but only the test results for the 400N case are described here. Figure 7 shows the impact load, head rotation angle, head rotation angle with respect to T1, the T1 displacements in X and Z directions, and the neck forces with the impact load of 400N. The data shown in the figure represent mean values of the subjects at each impact load level. The test results obtained given the above conditions are as follows.

The difference in head rotation under the tensed and relaxed conditions of neck muscles is significant. This difference, however, is not so significant if the impact is applied. The X displacements of head and T1 are suppressed markedly, but not in the case of the Z displacements. The neck shear force, axial force and moment also do not show much difference under the tensed and relaxed conditions when the load is applied, though such differences become obvious after the completion of impact. The neck moment in tensed condition is more apparent than that in relaxed condition, though the former yields more head motions.

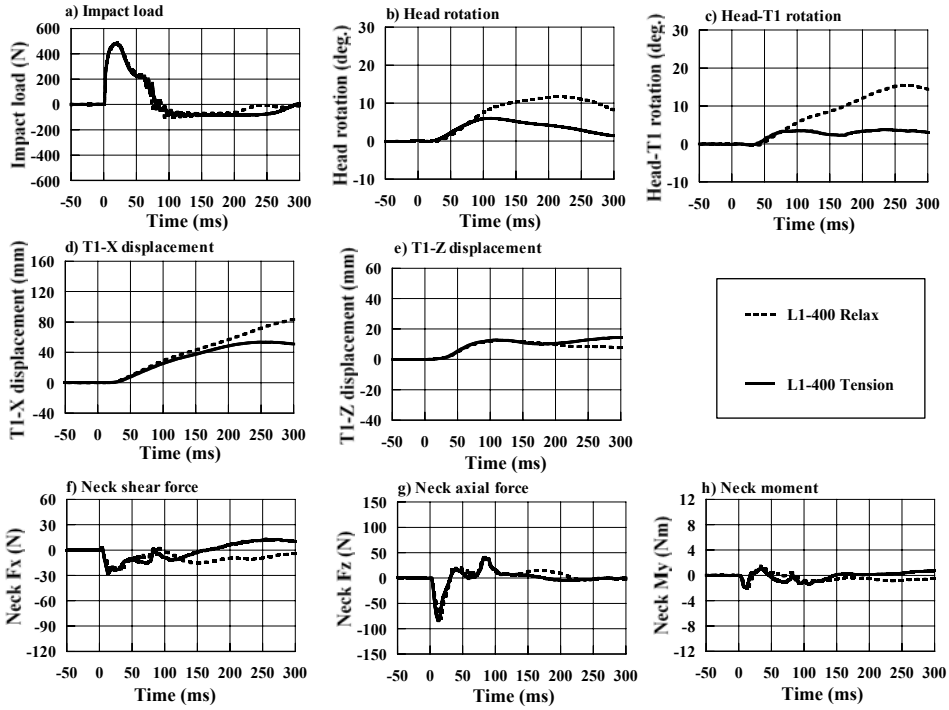

Fig.7 Biomechanical responses for the different muscle conditions (relaxed and tensed) on the back at L1

DISCUSSION

EFFECTS OF DIFFERENCE IMPACT LOADS ON HEAD/NECK/TORSO RESPONSES: Based on the test, it is found that both the head rotation angle and the head rotation angle with respect to T1 at the L1 impact location become more obvious as the impact load is increased. It is also found that the head X displacement occurs in backward direction relative to T1, while generating a relative motion between the head and T1.

The discussion here focuses on the effects of difference impact loads on the head/neck responses. Figure 8 shows the motions of the head and T1. On the other hand, Figure 9 shows the head motion relative to T1.

Not much differences in head and T1 motions due to difference impact loads are found in the coordinates of inertia (Figures 8 a and 8 b). The X displacement shown on the head is not affected markedly by the change in impact load, while more Z displacement is noted with impact load of 300 N. In terms of the head motion relative to T1, however, the greatest X displacement is found using impact

load of 400N, though the significant Z displacement is observed with the impact load of 300N. Both the neck shear force and axial forces are increased as the impact load is increased, but the neck moment does not change markedly. Based on the foregoing results, it can be said that the effect of change in impact load on the head/neck/torso responses is significant, since the head motion relative to T1 becomes apparent as the impact load increases. The foregoing results also suggest that it is necessary to take into account not only the level of impact load but also the specific location at the spinal column upon which the impact is imposed.

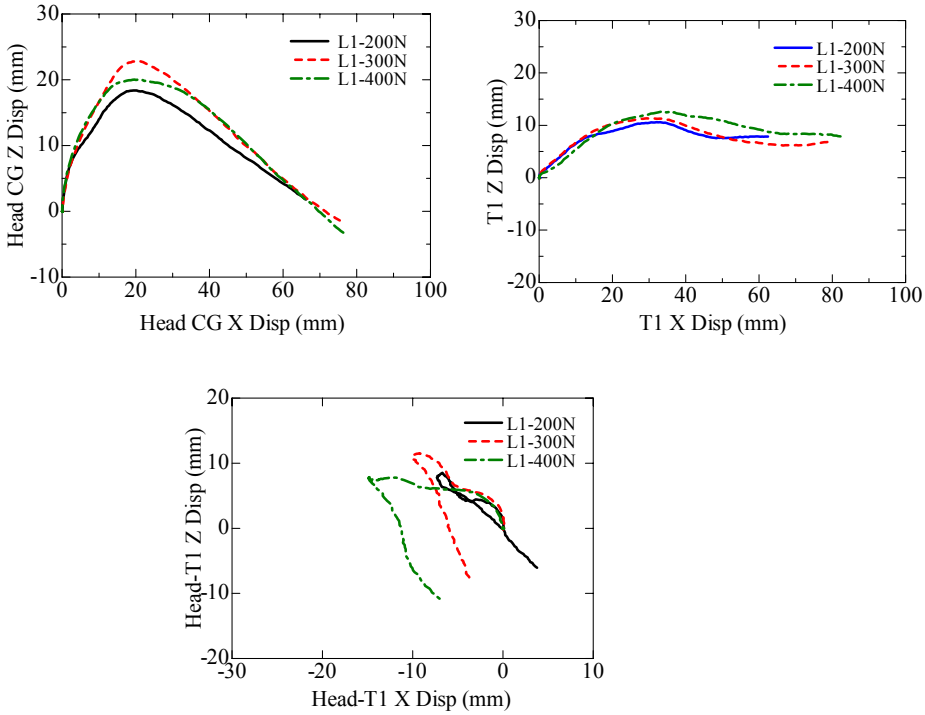

Fig.9 Head trajectories relative T1 for L1 impacts in the different impact load levels (200N, 300N, and

EFFECTS OF DIFFERENCE IMPACT LOCATIONS ON HEAD/NECK RESPONSES: The discussion here dealt with the question on how the difference in impact location - T1, T6 or L1 - affect the head/neck responses. To facilitate comparison of the effects of different impact locations, the head and T1 motions are shown in Figure 10, while the head motion relative to T1 is shown in Figure 11.

It is found that the X displacements of head and T1 are not affected significantly by the three impact locations, but these seems a clear difference in the case of Z displacements. The head Z displacement does not change markedly in T1 and T6 impacts, but the head is pushed upward in L1 impact. Likewise, T1 is pushed upward in L1 impact, but T1 is displaced downward in T1 and T6 impacts. The push-up force is transmitted from the neck lower portion to the upper portion then to the head, causing the neck S-shape during this process.

On the other hand, significant differences in neck shear force, axial force and moment are found among T1, T6 and L1 impacts. The neck shear force is the smallest in L1 impact, becoming greater in T1 and T6 impacts and closer to the lower portion of neck. This indicates that the susceptibility to a direct impact from the impacter is increased as the location of impact against the neck upper portion becomes closer. More neck axial force in noted in L1 impact in comparison to T1 and T6 impacts. This is because the neck is compressed as the impact from the neck lower portion is transmitted to the head in L1 impact, as shown in Figure 10 a). The neck moment causes the S-shape of neck, as the head extends and flexes. Figure 12 shows the relationship between the head rotation angle and the neck moment. It is thus found that the neck flexion/extension moment appears prior to the rotation of head. In L1 impact in particular, the neck moment in the direction of extension becomes more obvious despite the absence of noticeable rotation of the head. In T1 and T6 impacts, the neck

extension/flexion moment becomes more apparent than that in L1, presumably due to the greater relative motion between the head and neck.

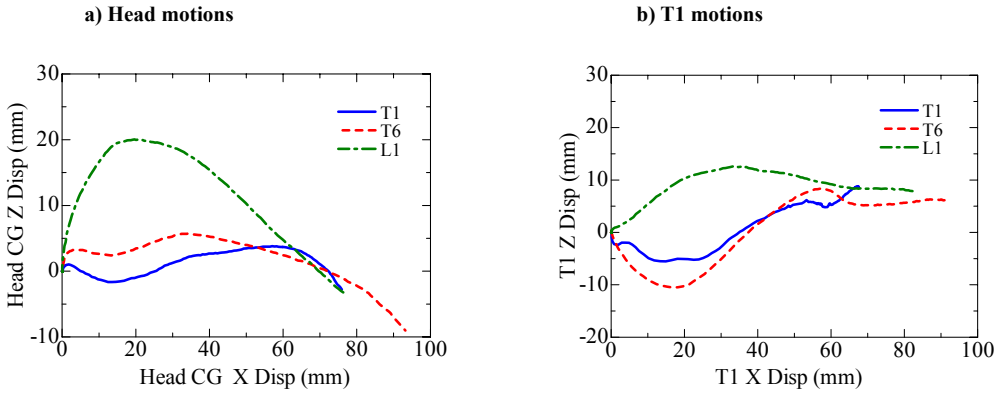

Fig.10 Head and T1 trajectories for the different locations (T1, T6, and L1) at 400N impacts

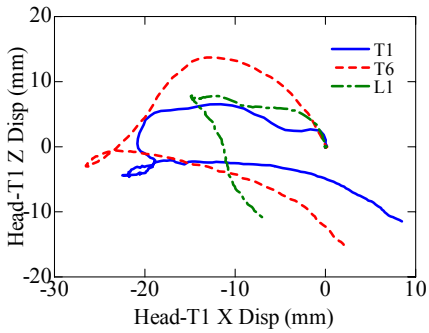

Fig.11 Head trajectories relative to T1 for the different locations (T1, T6, and L1) at 400N impacts

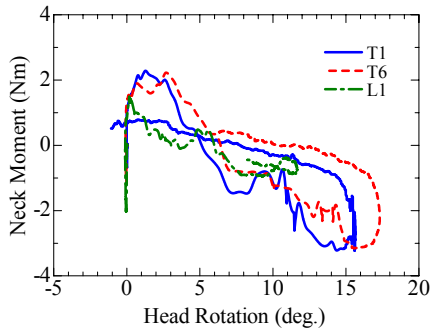

Fig.12 Relationship between head angles and neck moments for the different locations (T1, T6, and L1) at 400N impacts

EFFECTS OF NECK MUSCLE FUNCTIONS ON HEAD/NECK IMPACT RESPONSES:

Marked differences between tensed and relaxed conditions of neck are found in head apparent motions. In the tensed condition, the head rotation is suppressed after 70 ms or so both with the impact loads of 200 N and 400 N. The head rotation relative to T1 is suppressed likewise. The duration of impact is about 80 ms. No significant differences are found between both conditions of neck while the impact is applied. After the removal of impact load, however, obvious differences have been noted. Hence it can be said that the sternoclaidomastoid muscle (SCM) has a strong role in facilitating the flexion that suppresses head motions. This muscular function in tense condition of neck is a function that can be activated consciously by increasing the tension of the neck muscles to suppress the neck motions. Figure 13 shows the responses of SCM in neck tensed and relaxed conditions. These responses are processed with the 20 Hz low pass filter and 500 Hz high pass filter. It is found that the SCM in relaxed condition starts rising around 80 ms, whereas the SCM in tense condition starts rising around 50 ms, and that the occurrence of the paravertebral muscles (PVM) becomes more obvious in tensed condition. This is presumably due to the extension of flexing muscle caused by the marked extension of the head due to the impact, which activates the SCM and in turn facilitates the flexion. With the activation of SCM, the head flexes, and the extension muscle extends further. In the case of neck in tensed condition, on the other hand, the extension muscle does not extend as much as in relaxed condition, and the PVM presumably does not become intense.

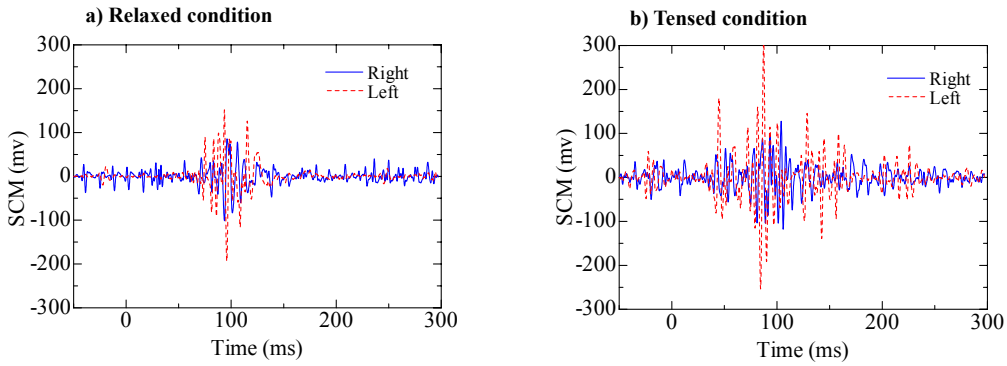

Fig.13 Comparison of SCM discharges between relaxed and tensed muscle conditions

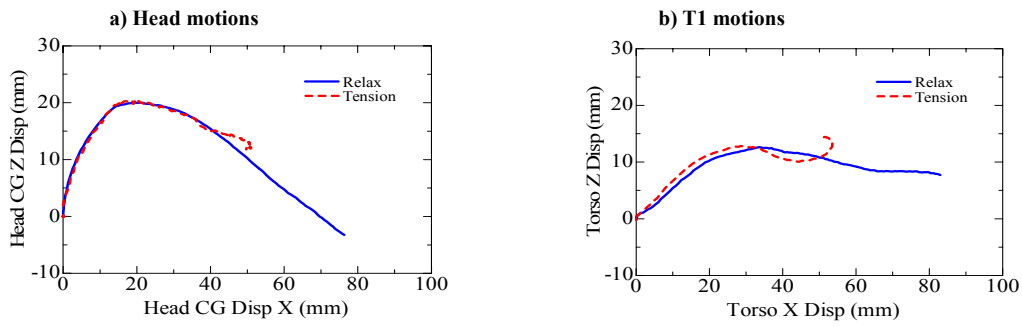

Fig.14 Comparison of head and T1 motions between relaxed and tensed muscle conditions

The motions of head are shown in Figure 14 a), and this reveals the differences between tensed and relaxed conditions. Figure 14 b) shows the motions of T1 for the tensed and relaxed conditions.

By comparing the motions, it is found that the Z displacements of head and T1 in tensed and relaxed conditions do not show much difference, while the X displacements are greatly suppressed in the tensed condition. According to the head relative to T1, it is also found that the head backward displacement is reduced and the head motions relative to T1 are also reduced in the tensed condition. It is deduced from the foregoing findings that the X displacement of head can be suppressed by a proper anatomical positioning of neck muscles, but it would not be so effective for the suppression of the Z displacement.

EFFECTS OF DIFFERENCE IN SEX ON HEAD/NECK/TORSO IMPACT RESPONSES: The head rotation angle, neck forces, X and Z displacements of T1 of the two female subjects (their mean values) with an impact load of 400 N are shown in Figure 15 for comparison with those of male subjects' corridors. The female head rotation angle keeps on increasing up to 150 ms, then decreasing sharply thereafter. Such motions are scarce in male subjects. The neck shear force of female up to 20 ms is in the lower limit range of male subjects. In terms of neck axial force, the compression that occurs around 20 ms exceeds the male corridor's lower limit range. As for the neck compression, the impact is transmitted from the torso, and pushes up T1 greatly. As for the neck moments, the flexion moment works around 20 ms, then the extension moment works around 40 ms. The values are in the lower/upper limit ranges or exceed the corridors of male subjects.

As described above, more head motions in the case of female subjects are observed than those of male subjects. The neck shear force, axial force and the moment also tend to be more apparent than those of male subjects. The comparison of cervical vertebral images of female subjects as shown in Figure 2 b) with those of male subjects as shown in Figure 2 a) indicates that the size of each vertebra of female subjects is relatively small than that of male subjects. Similarly, it was also reported in other study (Yoganadan et al., 2002) that the size of female cervical vertebra is smaller than that of male, but further efforts should be made to clarify the relationship between the vertebral size and head/neck/torso impact responses.

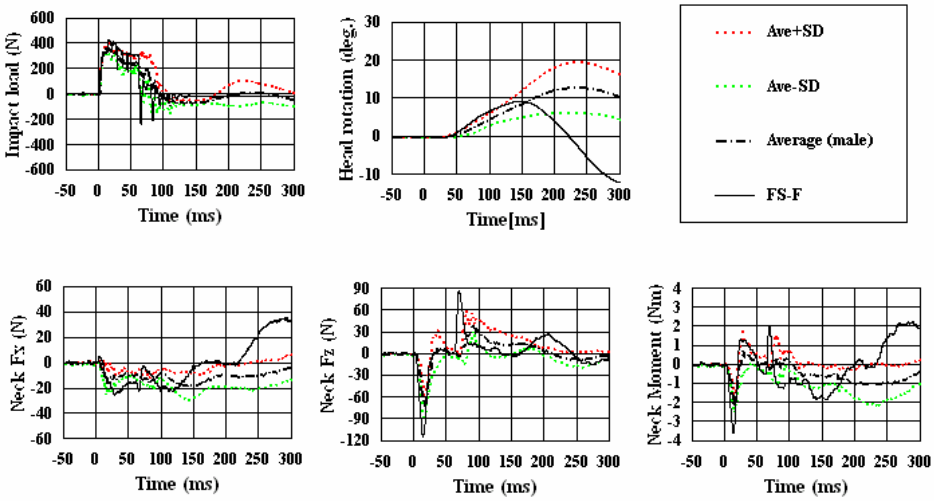

Fig.15 Biomechanical responses for the impact loading (400N) on the back of female volunteer at L1

DIFFERENCES IN IMPACT RESPONSES FOUND IN EXPERIMENTS USING CADAVERS AND VOLUNTEERS: Test results of cadavers and volunteers cannot be compared directly due to marked difference in impact load level. However, it is important to find out what are exactly the differences in impact responses between cadavers and living human-beings, and what are the tendencies of such differences, if there are any. In other words, it is also necessary to study the impact responses inherent to "living subjects" and determine its implication in establishing injury criteria, since the existing injury criteria are based on cadaver data. In this regard, the discussion here focuses on the comparison between cadaver test data reported by Viano et al. (2001) and living human test data, though it should be noted here that the impact responses are different, and there are some elements which are not included in cadaver test data.

Figure 16 a) shows head rotation angles in T1 and T6 impacts while Figure 16 b) shows the head rotation angles relative to T1 for the cadavers. Figure 17 a) shows the head rotation angles of the volunteers in T1 and T6 impacts (with the impact load of 400 N). The head rotation angles relative to T1 of the volunteers are shown in Figure 17 b).

As for the head rotation angles of volunteers, the extension does not start immediately after the impact as in the case of cadavers, but the extension starts around 30 ms. As regards the volunteers' head rotation angles relative to T1, the flexion occurs first, followed by the extension. In case of cadavers, this initial flexion is completely absent, and only the extension is found. Both the head rotation angle and the head rotation angle relative to T1 in the volunteer tests extend first but the extension starts decreasing around 100 ms. In case of cadavers, this decrease is limited. It is presumably because the muscle to facilitate the flexion is activated by the extension for human-beings, which intends to return the head to the original position within the biological limits of extension. In case of cadavers, such muscular responses do not exist due to the absence of neurological reflexes, and the extension may have occurred beyond the biological limits in T1 impact, resulting in the vertebral segment fracture.

Time histories of head rotation relative to T1 and the neck moment in T1 impact cadaver tests are shown in Figure 18 a) for reference. For comparison, the data obtained in the volunteers' tests are shown in Figure 18 b). Both the head rotation and neck moment are found immediately after impact against the volunteers. The pattern of head extension motion is observed to be the same in T1 and T6 impact for both volunteers and cadavers especially approximately before the 80 ms. The pattern however is more apparent for volunteers after 80 ms due to muscle effects. The neck moment also shows the flexion and extension even before the initiation of a slight motion of the head. In case of cadaver tests, on the other hand, the neck moment occurred after the initiation of head extension. It can be said that such differences between cadavers and living humans are caused by muscle conditions, which are biomechanical responses inherent to living human-beings.

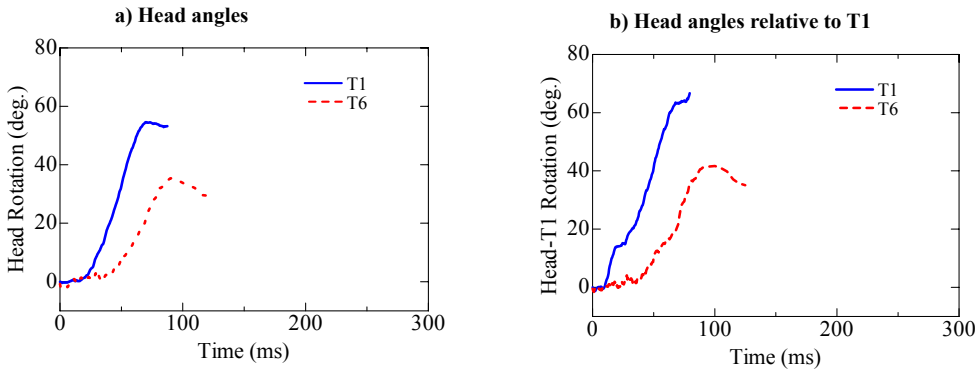

Fig.16 Head angles and head angles relative to T1 rotations on cadavers

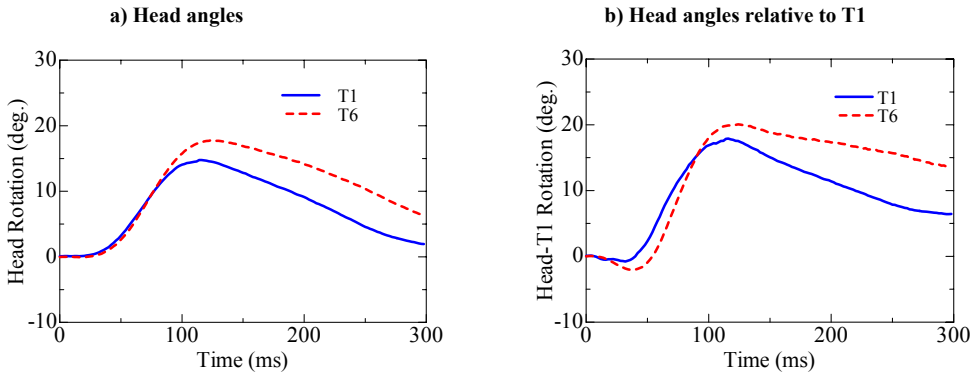

Fig.17 Head angles and head angles relative to T1 rotations on volunteers

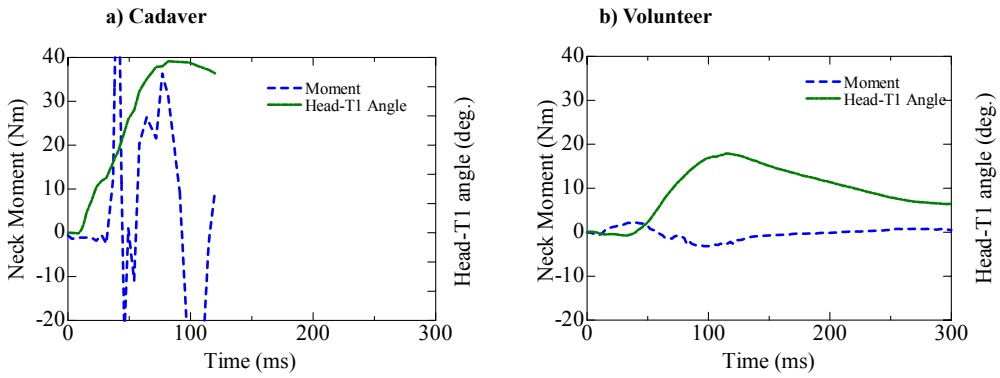

Fig.18 Different responses of Head-T1 angles and neck moments between cadaver and volunteer

CONCLUSIONS

Inertia impact tests using volunteers have been conducted in order to simulate impacts between the occupant torso and seat back in rear-end collision. The distinction of conditions for occupant whole spine deformation is important for impact between the occupant torso and seat back. Assuming here that such a deformation is affected by the dispersion of impact load between the occupant torso and seat back, the effects of difference in impact location on the head/neck/torso responses have been studied. Differences in sex and neck muscular responses have been also studied at the same time. The findings obtained by this study are as follows.

a) Effects of difference impact locations: The initiation of head extension occurs relatively late in L1 impact, whereas the neck moment causes the flexion followed by the extension in every case of T1, T6 and L1, and results in the typical S-shape of the neck. No significant change in the head Z

displacement is found in T1 and T6 impacts, but the head is pushed up markedly in L1 impact.
b) Effects of difference impact loads: Both the head rotation angle and the head rotation angle relative to T1 are becoming more apparent as the impact load increases. Also, the motions of T1 in both X and Z directions also become greater as the impact load increases. The Z-axial push-up motion in particular becomes quite significant by the increase in impact load.
c) Effects of neck muscle conditions on head/neck impact responses: The effect of neck muscle conditions - relaxed or tensed - is particularly significant in terms of head rotation. It is found, however, that the difference is not obvious during the impact loading. It is also found that the X displacements of head and T1 are suppressed markedly according to the neck muscle condition, but not much difference is found in the Z displacements.
d) Effects of difference in sex on head/neck/torso impact responses: The neck shear force, axial force and moment of female subjects are in the lower and upper limit ranges or exceed the corridors of male subjects. Such test results require further studies as the number of female subjects is small, but it is indicated that females tend to be more susceptible to injuries than males.
e) For clearer determination of differences in impact responses between living humans (the volunteers) and cadavers, the data of cadavers tested in similar manner with that for the volunteers have been compared and analyzed. Clear straightening of the whole spine is also found in cadavers, with the head/neck/torso pushed-up relative to T1. It is found, however, that this push-up motion is hardly affected by the level of impact load or the location of impact loading.
f) It is found that the muscular functions of living humans contribute markedly to the differences in impact responses between living humans (the volunteers) and cadavers. The muscular functions also play important roles in clarifying neck injury mechanism.

According to the foregoing results, it is found that the impact between the occupant torso and the seat back in rear-end collision can be simulated by means of "low speed inertia impact experiment". With further pursuit of this experimental method, the causes of neck injuries in rear-end collision can be clearly and possibly determined. Namely, the effects of occupant riding posture, physical structure, sex, human head/neck/torso motions and whole spine straightening, including characteristics of seat cushion can be further clarified.

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