EVALUATION OF BIOFIDELITY & REPEATABILITY AND THE INFLUENCE OF DIFFERENT POSITIONING FOR THOR-NT DUMMY

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ABSTRACT

Component tests on the head, neck, thorax, abdomen and face were conducted to evaluate the biofidelity of THOR-NT. HYGE sled tests were also conducted to evaluate repeatability and to investigate the influence of different positioning to dummy responses.
Three frontal HYGE sled tests were conducted under the same conditions with a velocity of 56km/h, acceleration of 270m/s^2, and a designed standard seat position.
Repeatability of dummy responses was evaluated by coefficient of variation (CV) calculated based on the peak values of accelerations, deflections, forces and moments measured. The following three categories were defined as evaluation criteria of repeatability by CV: CV<=5% as good, CV<=10% as acceptable and CV>10% as poor.
The kinematic and dynamic responses of THOR-NT were additionally compared with that of Hybrid-III.
Furthermore, in order to investigate the influence of different positioning to dummy responses, a 56km/h frontal HYGE sled test was conducted on a dummy positioned according to the ATD positioning procedure developed by UMTRI.

In the biofidelity evaluation, only head responses were within the PMHS response corridors.
For repeatability, 10 (32%) out of 31 items in all of the data had an evaluation criteria within CV<=5%. Comparison of dummy responses between UMTRI and standard positioning showed similarity in kinematic responses of the upper body. However, the maximum displacement of ankle in X-direction with respect to the initial position was larger in the UMTRI position compared to the standard position.
In the UMTRI position, the feet which are initially positioned away from the toe board comes in contact with the toe board and slide upward due to the forward movement to the vehicle body during impact. Due to this, difference in dynamic responses of the legs between the UMTRI and standard position was observed.

INTRODUCTION

In October 2003, NHTSA (National Highway Traffic Safety Administration) had released the THOR-NT (Test Device for Human Occupant Restraint - New Technology) as the next generation frontal impact dummy. Almost at the same time, the THOR-FT was also released by the FID (World Frontal Impact Dummy), the European project. Here, FT means "FID Technology."
Although both of these dummies were developed from THOR-alpha, several components of each dummy have been individually improved. Therefore, it is our concern that the responses of these dummies against the impact may differ with each other. If such original development and improvement continue at this pace, two different types will eventually appear as next generation dummies.
Therefore, the harmonization of THOR dummies is now being sought in earnest. From such a background, SAE THOR Evaluation Task Force Group was established in order to harmonize the specifications such as structures and characteristics that are required for dummy. Efforts aimed at the harmonization of two THOR dummies have started.
In order to contribute to the harmonization of THOR dummies, the biofidelity of THOR-NT was evaluated in this study. Furthermore, the repeatability on the responses of THOR-NT in dynamic tests using HYGE sled and the influence on the dummy responses by the different dummy positioning was evaluated.

METHODS

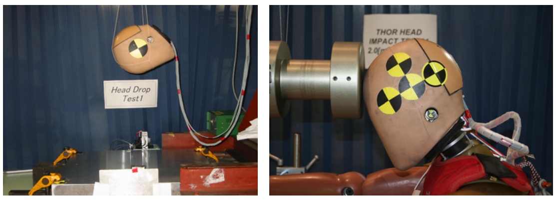
Biofidelity Tests

Biofidelity evaluation tests on the head, neck, thorax, abdomen and face were conducted in accordance with test procedures for THOR determined by NHTSA and GESAC (General Engineering and Systems Analysis Company), Inc. [1], [2], and responses were compared with PMHS (Post Mortem Human Subjects) response corridors.

Head

<u>Head Drop Test</u> - As shown in Figure 1 a), only the head of the dummy was hanged so that the lowest point on the forehead was held 376 mm above the impact plane, and the base of the head-neck mounting platform was inclined at 29 degrees against the vertical line. Then, free fall of the head was performed onto the horizontal rigid plane. The results were evaluated by the peak of 3-axial resultant acceleration of head center of gravity and its occurrence time.

<u>Head Impact Test</u> - The dummy was sat on a flat plane, and the head of the dummy was hit by the impactor with a mass of 23.4 kg and diameter of 152 mm at a speed of 2.0 m/s. The impact point was where the center-line of the impactor is 30 mm above the horizontal marking line at the lowest point of the forehead (Figure 2 b)). The biofidelity evaluation parameters of this head impact test were the peak of the impact force and its occurrence time.



a) Drop test b) Impact test

Figure 1. Setup of biofidelity tests on the head

Neck

<u>Neck Frontal Flexion Test</u> - The head and neck of the dummy are fixed on the HYGE sled by means of fixed attachment as shown in Figure 2, and the dynamic and kinematic responses of the neck at the specified sled pulse were evaluated [3].
With regard to the mini-sled test for the neck in frontal flexion, the correct sled pulse which should be given is the pulse (T1 pulse) as shown in Figure 3. However, since our sled apparatus did not have the ability to generate such complex pulse, the sled pulse (15G) which was used in volunteer testing at the NBDL (Naval Biodynamics Laboratory) as shown in Figure 4 was used in this study.
The evaluation parameters were head rotation angle, resultant acceleration of head center of gravity, back-forth and up-down kinematic displacements and neck moment around Y-axis with respect to the head rotation angle.

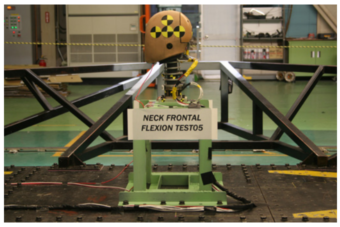


Figure 2. Setup of neck frontal flexion test

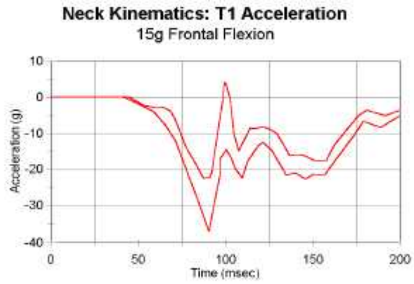


Figure 3. Mini-sled pulse (T1 pulse) in the neck frontal flexion

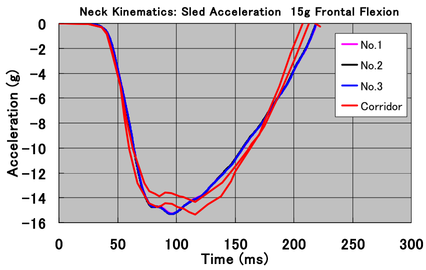


Figure 4. 15G sled pulse in frontal flexion of NBDL

<u>Neck Lateral Flexion Test</u> - Just like the setup of the neck frontal flexion test, the head and neck of the dummy were fixed on the HYGE sled by means of a fixed attachment. The dynamic and kinematic responses of the neck at the specified sled accelerations were evaluated.
With regard to the mini-sled test for the neck in lateral flexion, the correct sled pulse which should be given is the pulse (T1 pulse) as shown in Figure 5. However, since our sled apparatus did not have the ability to generate such complex pulse, the sled pulse (7G) which was used in volunteer testing at the NBDL as shown in Figure 6 was used in this study.
The evaluation parameters were head rotation angle, right-left and up-down kinematic displacements of head center of gravity, and neck moment around X-axis with respect to the head rotation angle.

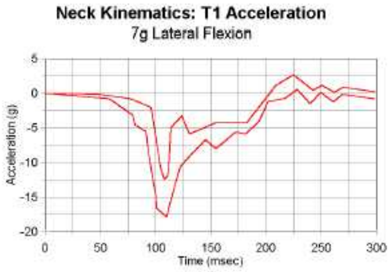


Figure 5. Mini-sled pulse (T1 pulse) in the neck lateral flexion

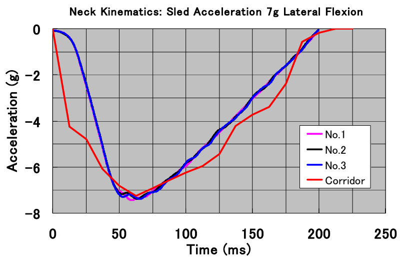


Figure 6. 7G sled pulse in lateral flexion of NBDL

Thorax

Kroell Test - The dummy was sat on a flat plane, and the thorax of the dummy was hit by the impactor with a mass of 23.4 kg and diameter of 152 mm at 4.3m/s and 6.7m/s. The impact point was where the center line of the impactor coincides with the vertical level of the middle of dummy rib #3, and positioned over the mid-line of the sternum (Figure 7). The biofidelity evaluation parameter was the response of impact force versus thorax deflection.

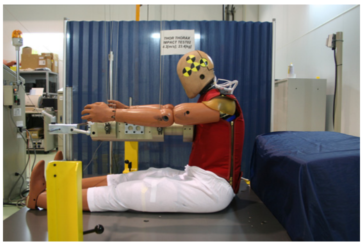
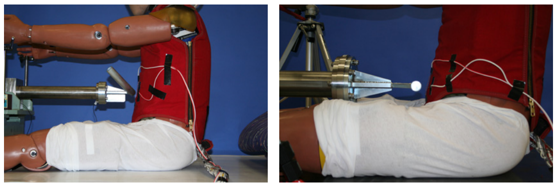


Figure 7. Setup of Kroell test

Abdomen

Upper Abdomen Impact Test - The dummy was sat on a flat plane, and the upper abdomen of the dummy was hit by the rigid steering wheel impactor with a mass of 18 kg and angle against the vertical line of 30 degrees at 8.0m/s. The impact point was where the leading edge of the steering wheel coincides with the center of the seventh rib (Figure 8 a)).

Lower Abdomen Impact Test - The dummy was sat on a flat plane, and the lower abdomen of the dummy was hit by the rigid impactor with a mass of 32 kg, diameter of 25 mm, and length of 300 mm at 6.1m/s. The impact point was where the center line of the impactor coincided with the vertical level of the line joining the centers of the attachment nuts of the right and left DGSPs and aimed at the mid-point of this line (Figure 8 b)).



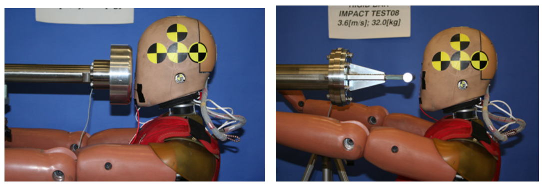
a) Upper abdomen b) Lower abdomen

Figure 8. Setup of biofidelity tests on the abdomen

Face

Disk Impact Test - The dummy was sat on a flat plane, and the face of the dummy was hit by the impactor with a mass of 13 kg and diameter of 152 mm at a speed of 6.7 m/s. The center of the disk was configured to impact at the mid-point of the line joining the two maxilla plates on the face (Figure 9 a)).

Rigid Bar Impact Test - The dummy was sat on a flat plane, and the face of the dummy was hit by the rigid bar impactor with a mass of 32 kg, diameter of 25 mm, and length of 300 mm at a speed of 3.6 m/s. The rod was configured to impact along the mid-line of the left and right maxilla plates on the face (Figure 9 b)).



a) Disk impact b) Rigid bar impact

Figure 9. Setup of biofidelity tests on the face

HYGE Sled Tests

The white-body of a passenger car was fixed on the sled and the white-body which seated the dummy was given an impact at 35 mph (56 km/h). The accelerations and forces, etc of the dummy was measured by each sensor. The motion of the dummy was recorded by high speed video cameras and analyzed. Figure 10 indicates the acceleration curve and the velocity curve of the sled.

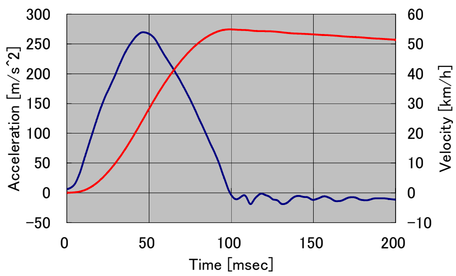


Figure 10. Acceleration and velocity of the sled

Measurements - The accelerations and forces, etc of the dummy were measured. These data were recorded by the data acquisition system attached to the sled and were filtered based on SAE J211 [4]. The behavior of the dummy was recorded by three high speed video cameras from the side view of the sled, and the motion of the target mark of each component of the dummy was analyzed.

Test Conditions

a) Evaluation of Repeatability - In order to evaluate the repeatability of the dynamic responses of THOR-NT, three tests were conducted under the same conditions. The dummy was set according to the positioning procedure for Hybrid-III specified in FMVSS 208 (Federal Motor Vehicle Safety Standard No. 208, Occupant Crash Protection) [5]. The dummy seating position, the seat position, and the restraint devices were as follows:

1) The dummy seating position: driver's seat
2) The seat slide position: at the mid position
3) The seat lifter position: at the lowest position
4) The seat back position: at the designed standard position
5) Restraint devices: airbag, and seatbelt with pretensioner and force limiter

Hereafter, this seat position is called "standard position".

b) Investigation on the influence of different positioning to dummy responses - In order to investigate the influence of different positioning to dummy responses, tests were conducted on a dummy positioned according to the ATD positioning procedure, developed by UMTRI (University of Michigan Transportation Research Institute) [6]. The positioned posture and response of the dummy in this test were compared with those in the tests to evaluate repeatability. The seating position of dummy, the seat position, and the restraint device were as follows:

1) The seating position of dummy: driver's seat
2) The position of the seat slide: 50 mm rearward from the middle position
3) The position of the seat lifter: 18 mm above the lowest position
4) The position of the seat back: a designed standard position
5) Restraint device: a seatbelt with force limiter and pretensioner, and an airbag

Hereafter, this seat position is called "UMTRI position".

Definition for Evaluation of Repeatability - The repeatability of the dynamic responses of the dummy was evaluated by means of coefficients of Variation (CV). As shown in (Equation 1), CV is the percentile of the standard deviation of the peak value of data which measured in three tests divided by the average of those. In addition, it can be considered that CV equal to or less than 5% is "Good", equal to or less than 10% is "Acceptable", and exceeding 10% is "Poor" [7].

$$CV = \left[\frac{S}{\overline{X}}\right] * 100\ (\%) \qquad (1)$$

S : Standard deviation of the measured peak value
$\overline{X}$: Average of the measured peak value

RESULTS

Biofidelity Tests

Biofidelity on the head, neck thorax abdomen and face were compared with PMHS response corridors.

Head

Head Drop Test - Figure 11 indicates the results of the head drop test. The method of biofidelity test and that of certification test are the same [1], [2]. However, since the corridors of these tests were different, both biofidelity corridor and certification corridor are shown in this figure. The responses of the head were within the range of biofidelity corridor in all three tests, indicating good repeatability. However, with regard to certification corridor, the peak occurrence time of the head resultant acceleration was out of the corridor.

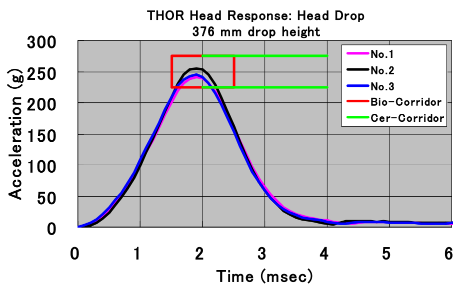


Figure 11. Response on head drop

Head Impact Test - Figure 12 indicates the results of the head impact test. The method of biofidelity test and that of certification test are the same [1], [2]. However, since the corridors of these tests were different, both biofidelity corridor and certification corridor are shown in this figure.

With regard to the repeatability, the results of No. 2 and No. 3 were quite similar, whereas the undulation of No. 1 rose up more gently, and the peak occurrence time of the impact force of No. 1 was slightly late. It can be presumed that this difference stemmed from a little variation of the test setup such as the sitting posture of the dummy and the impact position. However, in all the three tests, responses were within the biofidelity corridor and certification corridor.

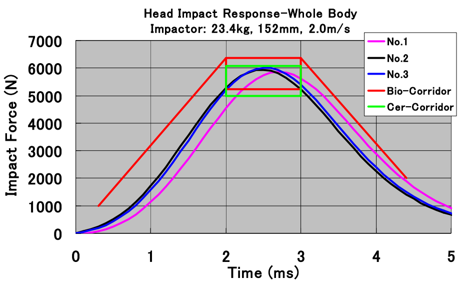


Figure 12. Response on head impact

Neck

Neck Frontal Flexion Test - Figure 13 to Figure 17 respectively indicates the results of the neck frontal flexion tests concerning following evaluation items:

1) Head rotation angle (Figure 13)
2) 3-axial resultant acceleration of head center of gravity (Figure 14)
3) Kinematic displacement of head center of gravity in the X-direction (back-forth) (Figure 15)
4) Kinematic displacement of head center of gravity in the Z-direction (up-down) (Figure 16)
5) Neck moment around Y-axis (My) with respect to the head rotation angle (Figure 17)

The results indicate that the responses were outside the corridors in all the evaluation items. With regard to the sled acceleration corridor, the sled does not accelerate at time 0 and begins to accelerate at around 20 to 30 ms as shown in Figure 4. On the other hand, biofidelity corridors of neck begin to respond at around 50 to 80 ms. Therefore, in the tests conducted in this study, although the sled actually began to accelerate at time 0, the time 0 of the test data was shifted so that it could be synchronized with the sled acceleration corridor. Likewise, time 0 of the dummy data was also shifted in order to synchronize with the time shift of the sled acceleration data. However, the results in all the evaluation items were outside the corridors. Note: These results take notices that were responses where not T1 pulse but 15 G sled pulse of NBDL was used.

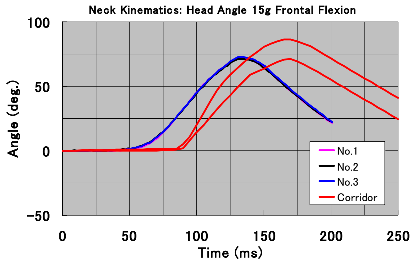


Figure 13. Head rotation angle

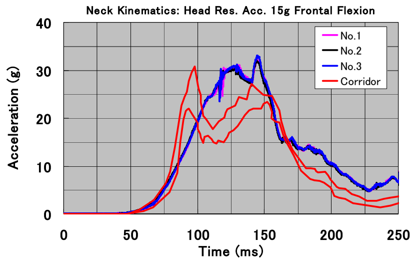


Figure 14. 3-axial res. acceleration of head C.G.

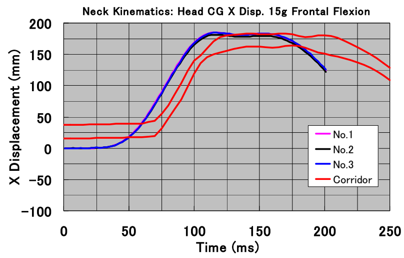


Figure 15. Disp. of head C.G. in the X-direction

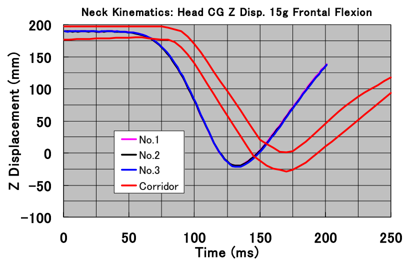


Figure 16. Disp. of head C.G. in the Z-direction

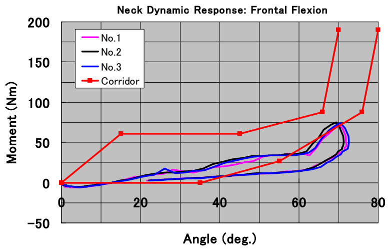


Figure 17. Neck moment around Y-axis (My) w.r.t. the head rotation angle

<u>Neck Lateral Flexion Test</u> - Figure 18 to Figure 21 respectively indicates the results of the neck lateral flexion tests concerning the following evaluation items:

1) Head rotation angle (Figure 18)
2) Kinematic displacement of head center of gravity in the Y-direction (right-left) (Figure 19)
3) Kinematic displacement of head center of gravity in the Z-direction (up-down) (Figure 20)
4) Neck moment around X-axis (Mx) with respect to the head rotation angle (Figure 21)

The results indicate that the responses were outside the corridors in all the evaluation items. In particular, the Y and Z-direction displacements of the head C.G. deviated from these corridors. However, these results take notices that were responses where not T1 pulse but 7 G sled pulse of NBDL was used.

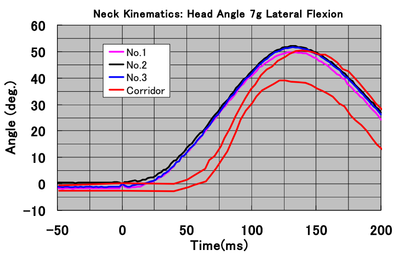


Figure 18. Head rotation angle

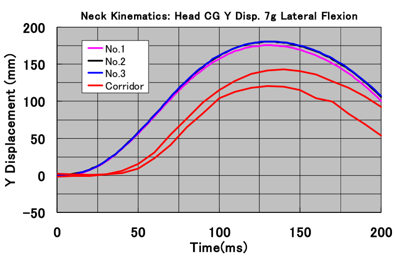


Figure 19. Disp. of head C.G. in Y-direction

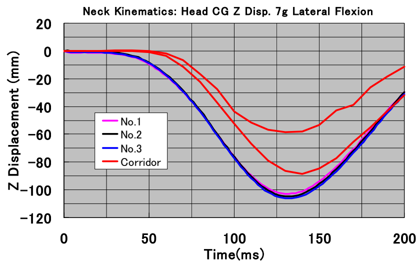


Figure 20. Disp. of head C.G. in Z-direction

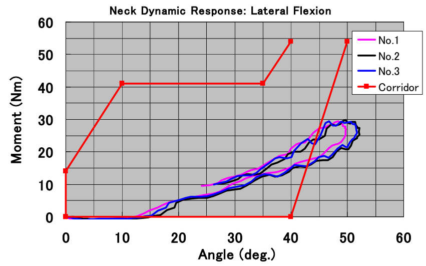


Figure 21. Neck moment around X-axis w.r.t. head rotation angle

Thorax

<u>Kroell Test</u> - Figure 22 indicates the results of the Kroell test at 4.3m/s. In the Kroell test, the method of biofidelity test and that of certification test were the same [1], [2]. However, since the corridors of these tests are different, both biofidelity corridor and certification corridor are shown in this figure.

The repeatability of the three tests was good; however, all of them deviated from both the biofidelity corridor and the certification corridor. It can be presumed that the reason why chest deflection was smaller than that of the corridor was because when the thorax of the dummy was hit, the lowest point of the impactor may have come in contact with its upper abdomen and thereby the intrusion of the impactor may have been restricted.

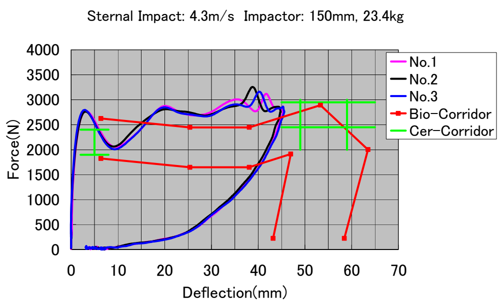


Figure 22. Response of Kroell test at 4.3m/s

Figure 23 indicates the results of the Kroell test at 6.7m/s. The repeatability of the three tests was good. Although the response near the maximum impact force greatly deviated from the biofidelity corridor, the response approximately fell within the corridor at the deflection of 0 to 60 mm. On the other hand, the response fell within both the first and the second certification corridors. However, as shown in this figure, the impact force suddenly increased at approximately 55 mm of the chest deflection. It can be presumed that because there were vestiges that indicate the contact between the mid sternum mass assembly and the spine (Figure 24), the impact force suddenly increased due to the metal contact caused by bottoming out of thorax.

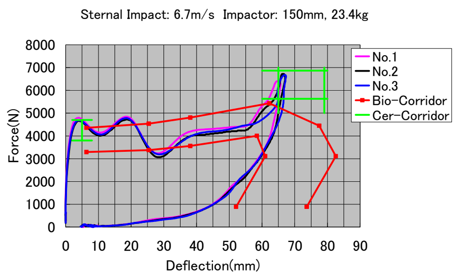


Figure 23. Response of Kroell test at 6.7m/s

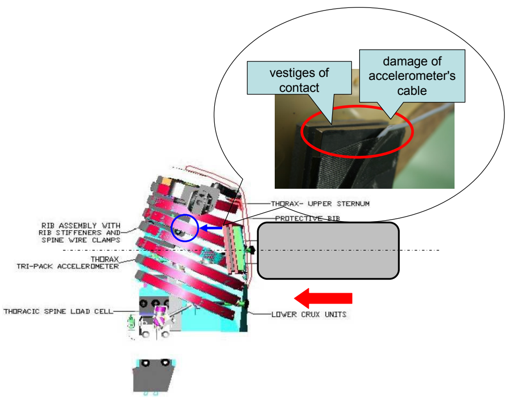


Figure 24. Vestiges of contact between mid sternum mass assembly and spine

Abdomen

Upper Abdomen Impact Test - Figure 25 indicates the results of the upper abdomen impact test. The response on deflection from 50 to 100 mm was within biofidelity corridor, but force on deflection at 120 mm was greater than biofidelity corridor. Therefore, it was found that the upper abdomen of THOR-NT had stiffer characteristics than that of a human body.

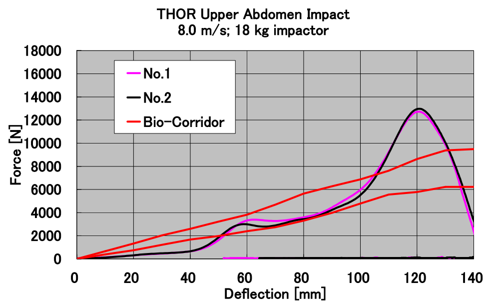


Figure 25. Response of upper abdomen impact

Lower Abdomen Impact Test - Figure 26 indicates the results of the lower abdomen impact test. The response on deflection from 0 to 100 mm was within biofidelity corridor, but force on deflection at 120 mm was far greater than biofidelity corridor. Therefore, it was found that the lower abdomen of THOR-NT had stiffer characteristics than that of a human body.

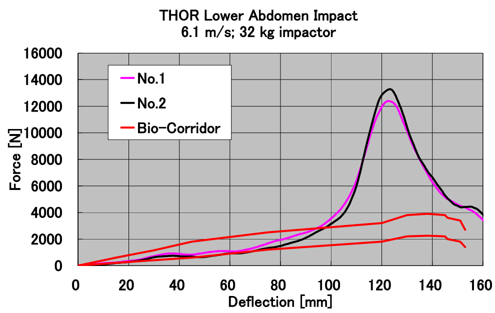


Figure 26. Response of lower abdomen impact

Face

Disk Impact Test - Figure 27 indicates the results of the face disk impact test. In the face disk impact test, the method of biofidelity test and that of certification test were the same [1], [2]. However, since the corridors of these tests are different, both biofidelity corridor and certification corridor are shown in this figure.

Not only the early section of response slightly deviated from the biofidelity corridor, but also the peak impact force was higher than the corridor. In addition, the peak impact force was also higher than certification corridor.

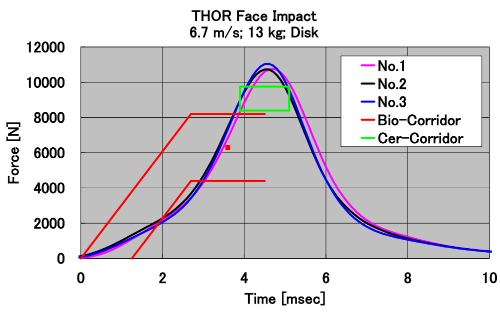


Figure 27. Response of face disk impact

Rigid Bar Impact Test - Figure 28 indicates the results of the face rigid bar impact test. In the face rigid bar impact test, the method of biofidelity test and that of certification test were the same [1], [2]. However, since the corridors of these tests are different, both biofidelity corridor and certification corridor are shown in this figure. The results of all the three tests greatly deviated from biofidelity corridor, and the peak impact force was higher than that of the certification corridor.

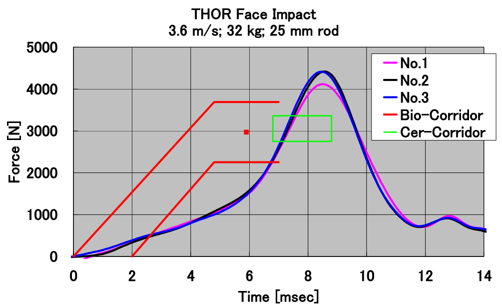


Figure 28. Response of face rigid bar impact

HYGE Sled Tests

In this chapter, it states the results of the evaluation on repeatability of dynamic responses for THOR-NT, and the results of the investigation on influence on responses by the difference of dummy positioning. Furthermore, it states the results of the dynamic and kinematic responses compared between THOR-NT and Hybrid-III.

Positioning of Dummy

Figure 29 indicates the comparison of the positioning of the head, shoulder, hip point (H.P.), knee, and ankle in the three tests on the standard position and one test on the UMTRI position, for THOR-NT. In addition, the positioning in one test on the standard position for Hybrid-III is plotted in this figure.

The repeatability of THOR-NT positioning was good. Even at the maximum, difference in positioning of the head in the vertical direction was only 12 mm.

Comparing the UMTRI position with the average of three tests in the standard position, in the X-direction, the difference of H.P. was the largest, namely, the H.P. in the UMTRI position was positioned 43 mm rearward with respect to that in the standard position. In the Z-direction, the difference of the shoulder was the largest, namely, the shoulder in the UMTRI position was positioned 37 mm above with respect to that in the standard position.

Comparing the positioning of THOR-NT with that of Hybrid-III on the standard position, in the X-direction, the H.P. of THOR-NT was approximately close position to that of Hybrid-III, but the head of THOR-NT was more rearward than that of Hybrid-III while the knee of THOR-NT was more forward than that of Hybrid-III. In the Z-direction, on the whole, each component of THOR-NT was positioned above than that of Hybrid-III.

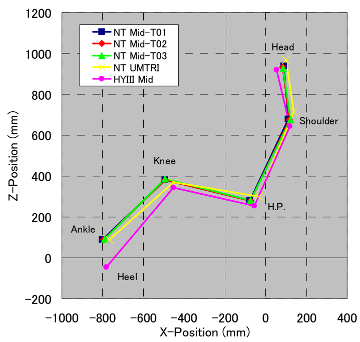


Figure 29. Comparison of the positioning among THOR-NT/Hybrid-III on the standard position, and THOR-NT on the UMTRI position

Kinematic Response

Figure 30 indicates the behavior of each component of the dummy in the three tests on the standard position and one test on the UMTRI position, for THOR-NT. Furthermore, the behavior in one test on the standard position for Hybrid-III is drawn in this figure.

The behavior of THOR-NT was quite similar in the three tests on the standard position. However, as for the head, whose maximum displacement was the most different, the maximum difference in the three tests was 35 mm in both back-forth and up-down directions. As for the other components, the difference in the back-forth direction was 8 to 16 mm, and that in up-down direction was 3 to 6 mm.

The behavior in the UMTRI position and that in the standard position were similar, comparing the kinematics of each part of THOR-NT. However, with regard to the difference in the maximum displacements (X, Z) with respect to the initial position, there were (31mm, 17mm) at the head, (2mm, 3mm) at the shoulder, (2mm, 7mm) at the H.P., (13mm, 10mm) at the knee, and (46mm, 14mm) at the ankle. The difference in the maximum displacement of the ankle in X-direction was the largest.

Comparing the behavior of THOR-NT with that of Hybrid-III on the standard position, both behavior was similar. However, the forward displacements of the head and shoulder for THOR-NT were larger than that of Hybrid-III. Furthermore, since the knee of THOR-NT was initially positioned on the forward and the upward to that of Hybrid-III, the knee of THOR-NT came hard in contact with instrument panel, compared with Hybrid-III.

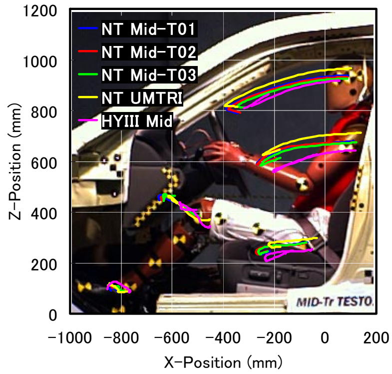
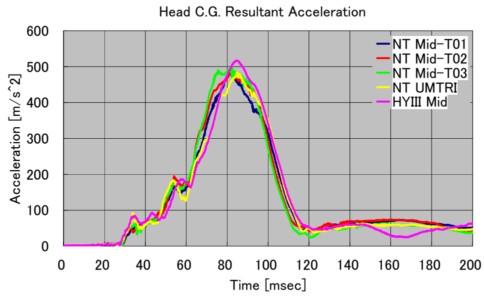


Figure 30. Comparison of the behavior among THOR-NT/Hybrid-III on the standard position, and THOR-NT on the UMTRI position

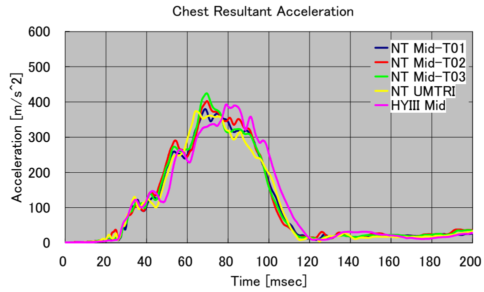
Dynamic Response

__Acceleration Response__ - Figure 31 indicates the acceleration responses of the dummies' head, thorax, and pelvis. In each of these three components, the acceleration appearance, duration, and the peak value were quite similar in the three tests for THOR-NT. The occurrence situation and duration of acceleration were also similar for the standard position and the UMTRI position. Furthermore, the acceleration responses were also similar between THOR-NT and Hybrid-III.

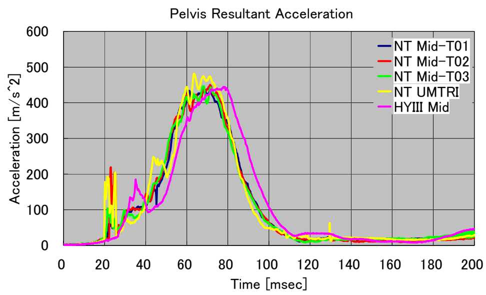
Figure 32 indicates HIC36 ms and clip 3msG on the head acceleration, and Figure 33 indicates clip 3msG on the chest acceleration and maximum 3-axial resultant acceleration of pelvis. The average (Ave.) ± standard deviation (S.D.), and CV of the data of the three tests is also shown in these figures. The clip 3msG of the head (CV=1.7%) and pelvis acceleration (CV=1.9%) were approximately the same in the three tests. On the other hand, HIC36ms (CV=8.7%) and the clip 3msG of the chest (CV=5.8%) increased in repeated tests.



a) Head resultant acceleration

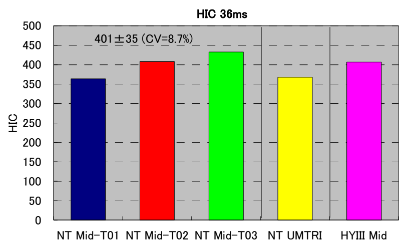


b) Chest resultant acceleration

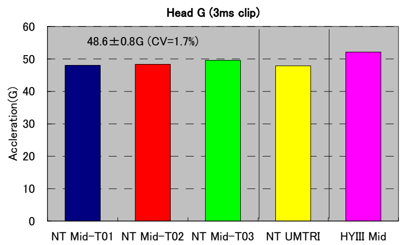


c) Pelvis resultant acceleration

Figure 31. Acceleration responses of the head, thorax, and pelvis

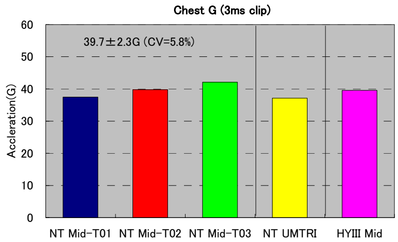


a) HIC36ms

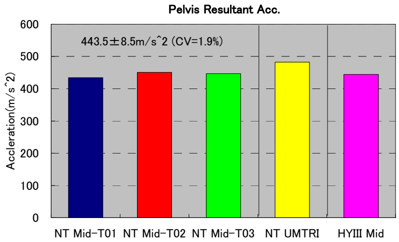


b) Clip 3ms G of head

Figure 32. Injury Criteria of the head, and CV



a) Clip 3ms G of chest



b) Peak acceleration of pelvis

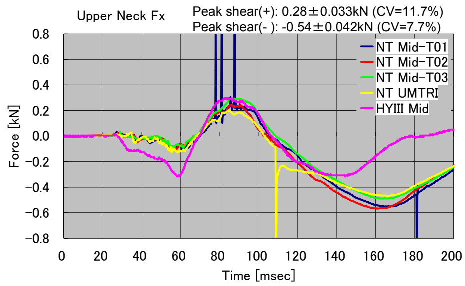
Figure 33. Injury Criteria of the chest, peak acceleration of the pelvis, and CV

Force and Moment Responses of Neck - Figure 34 indicates the neck responses of the shear force (Fx), the tension/compression force (Fz), and the flexion/extension moment around Y-axis (My). With regard to the Fx in the first test (Mid-T01), noises were detected near the peak both in the plus (+) side output (the head backward and the thorax forward) and in the minus (-) side output (the head forward and the thorax backward). The presumed reason is that the cable of the upper neck load cell had already deteriorated. Due to this, even a light touch on the cable caused noise when the functions of the sensor were confirmed after the test. Therefore, the ineffective contact of the wires in the cable caused the noise when the cable was wagged during impact. However, except for the noises of Fx, regarding both Fx and Fz, the responses were similar in the three tests. With regard to My, its appearance was similar in the three tests, but the peak near 90ms in the minus (-) side output (extension) in the first test (Mid-T01) was slightly lower than that in the other two tests. On the other hand, in the plus (+) side output (flexion), the peak in the third test (Mid-T03) was slightly lower than that in the other two tests.

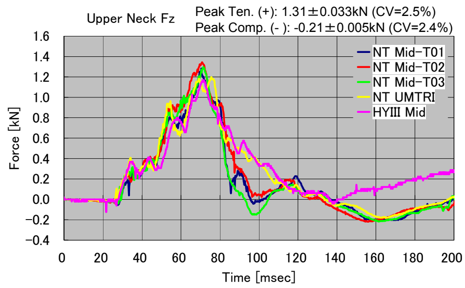
With regard to the repeatability of Fz, both tensile force and compression force were good in the three tests (CV<=2.5%). In the minus (-) side of Fx, repeatability was acceptable (CV=7.7%), but in the plus (+) side, CV exceeded the acceptable criteria (CV=11.7%). In the flexion side of My, repeatability was narrowly acceptable (CV=9.6%). However, in the extension side, the value increased after repeated tests and, as a result, CV greatly exceeded the acceptable criteria (CV=16.8%).

In all the measured points, the occurrence situations of force and moment were similar between the UMTRI position and the standard position. In the response of Fx on the UMTRI position, noise was detected as well as the result in the first test on the standard position.

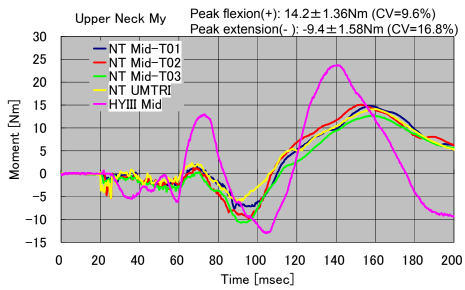
The circumstances in which the neck force and moment were generated were similar between the THOR-NT and Hybrid-III. However, generation level of Fx in the minus side output of THOR-NT from 0 to 60ms was smaller than that of Hybrid-III, while generation level of that from 110 to 160ms was larger than that of Hybrid-III. As for Fz (tension), although the occurrence of the peak force was similar between the THOR-NT and Hybrid-III on the standard position, the circumstance during falling of force was different between them. If anything, the response on UMTIR position was close to that of Hybrid-III. My (flexion) tended to be larger in the Hybrid-III.



a) Neck force Fx



b) Neck force Fz



c) Neck moment My

Figure 34. Force and moment responses of neck

Deflection Responses of the Thorax and Abdomen - Figure 35 indicates responses of the upper thorax deflection in X-direction, and Figure 36 indicates responses of the lower thorax deflection. With regard to repeatability, deflection appearance was similar in the three tests on the standard position, but the maximum values of the right and left side of the chest deflections vary. However, we would like to note that the result of the upper right side in the second test (Mid-T02) was obviously extraordinary. The CV to evaluate repeatability is indicated in this figure. Here, it should be noted that the CV of the upper right deflection was calculated from the results of the first and second tests only. The upper right deflection exhibited the biggest value of the four measuring points, and when compared between the right and the left deflections, the deflections of right side were twice as big as those of the left ones.

As for the repeatability, the CV of the upper right deflection was 0.5% (n=2) and the CV of the lower right deflection was 1.6%, both indicating good results with regard to the right side of the dummy. On the other hand, the CV of the upper left deflection was 19.7% and the CV of the lower left deflection was 17.8%, both indicating that the deflections of the left side of the dummy greatly deviated from the acceptable range.

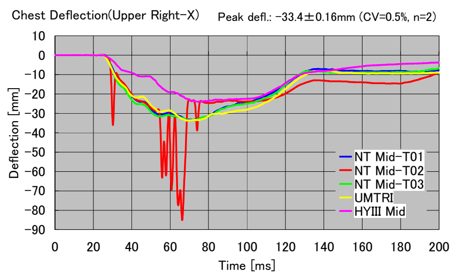
As for the deflections of the upper area on the thorax, both the timing of the deflection occurrence and the maximum deflection were similar between the UMTRI position and the standard position. However, for the two deflections of the lower area on the thorax, although the timing of the deflection occurrence was similar, a difference in the maximum deflection level was observed probably due to the different positioning. With regard to the maximum values of the four measured points, there was a difference of about 2 mm on the upper left. The deflection on the lower left in the UMTRI position was smaller by about 5 mm than that of the standard position, and oppositely, the deflection on the lower right in the UMTRI position was larger by about 5 mm than that of the standard position.

When the right side deflections in THOR-NT are compared with Hybrid-III measurement taken at the center sternum, the deflection of THOR-NT was larger than that of Hybrid-III.

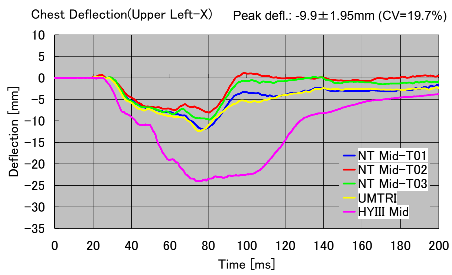
Figure 37 indicates responses of the abdomen deflection. With regard to repeatability, both deflection occurrence situations and the maximum values of the left side of the lower abdomen were quite similar in all the three tests. The deflections of the upper abdomen were quite similar from the start of the undulation to the maximum deflection, but the result of the first test was slightly different from that of the other two tests. In addition, with regard to the deflection of the lower right abdomen, the maximum value of the first test was slightly smaller than that of the other two tests.

The deflection of the left side of the lower abdomen was quite similar in all the three tests, having CV value of 1.1%, indicating very good repeatability. Likewise, the deflection of the right side of the lower abdomen indicated good repeatability with a CV of 4.2%. Even the upper abdomen which indicated the greatest deflection fluctuation had a CV of 5.3%.

From the beginning of deflection occurrence to the peak deflection, the deflection response of the upper abdomen was quite similar between the UMTRI position and the standard position. However, after the peak deflection, the response curve of the UMTRI position decreased slowly compared with that of the standard position. As for the deflection responses of the lower abdomen, from 50 ms to 130 ms, the deflection of the left side in the UMTRI position was slightly lower than that of the standard position. While the responses in other time ranges were approximately the same between the UMTRI position and the standard position. The difference in the maximum deflection level between the UMTRI position and the standard position was larger in the right side than in the left side. The maximum deflection value of the upper abdomen was approximately the same in both seat positions. As for the lower abdomen, the maximum deflection values of the UMTRI position were smaller by 4 mm on the left side and by 10 mm on the right side than those of the standard position.

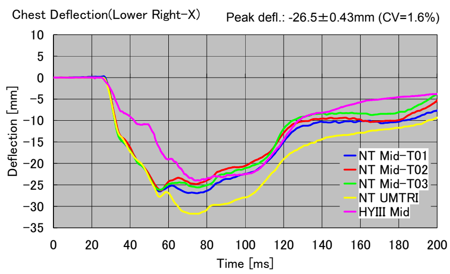


a) Thorax upper right

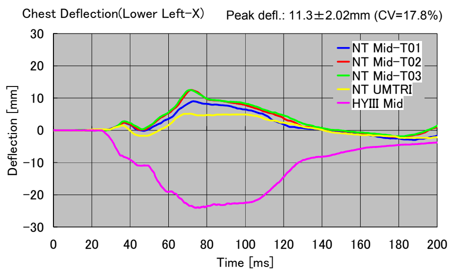


b) Thorax upper left

Figure 35. Deflection responses of upper thorax

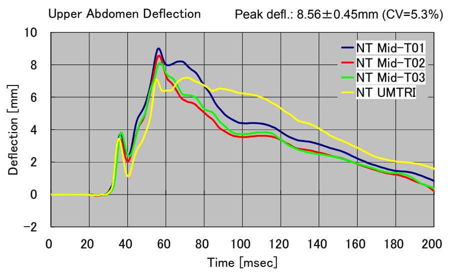


a) Thorax lower right

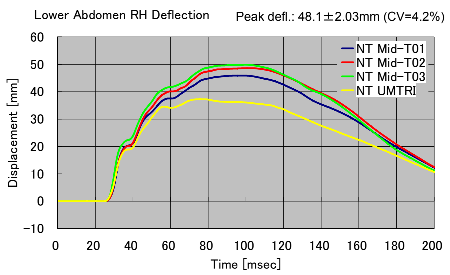


b) Thorax lower left

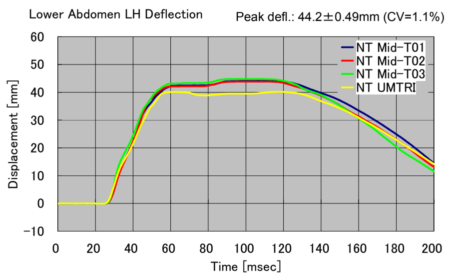
Figure 36. Deflection responses of lower thorax



a) Upper abdemen



b) Lower abdomen right



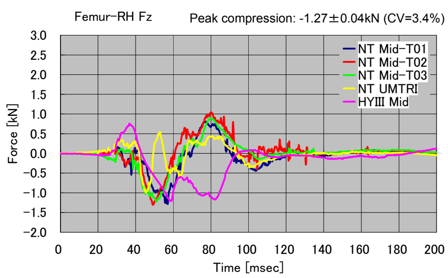
c) Lower abdomen left

Figure 37. Deflection responses of abdomen

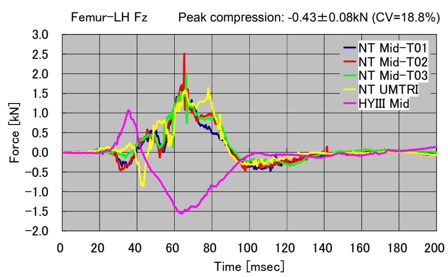
Force and Moment Responses of the Legs - Figure 38 indicates the responses of the tension and compression forces on the femur. The compression force (-) of the left femur of THOR-NT was very low and the tension force (+) was high. The compression and tension forces of the right femur were similar.

With regard to repeatability, the force appearance situation of the right and left femur were similar in all the three tests. The repeatability of the compression force of the right femur was good (CV=3.4%), but the compression force of the left femur greatly deviated from the acceptable range (CV=18.8%).

In the occurrence of the compression force (in the minus output) in the beginning of the impact, the left femur force at the UMTRI position was slower than that at the standard position and the force indicated higher value. However, for the tension force (in the plus output), the time of the maximum force occurrence and force level were approximately the same in both positions. In the occurrence of the right femur force in the standard position, the compression force occurred at about 50 ms, and then changed into tension force by about 80 ms. On the other hand, the compression force of the right femur in the UMTRI position occurred before 50 ms, and changed into tension force immediately after that. The maximum compression force of the left femur in the UMTRI position was higher than that in the standard position, however, opposite results were obtained in the right femur. Comparing the responses of the THOR-NT and Hybrid-III, the occurrence situation from 0 to 60ms of right femur was similar, whereas left femur became completely different situation.



a) Right femur force



b) Left femur force

Figure 38. Force responses of femur

Figure 39 indicates the axial force responses of the tibia. The axial force was similar in both the right and left tibia. However, the axial force of the upper tibia was larger than that of the lower tibia. In addition, in all the four measuring points, both force occurrence situation and the maximum force were similar in the first and the second tests. But in the third test, the force at the first peak (about 40 ms) was smaller than that of the other two tests. It can be presumed that this difference was due to the slight fluctuation on the setup of the legs in the dummy positioning.

The tibia force was approximately the same at the four measuring points in the tibia (the upper and lower on right tibia and the upper and lower on left tibia). With regard to the repeatability, the lower tibia force on the right leg fell within the acceptable range (CV=7.2%), but the upper tibia force on the right leg, and the upper and lower tibia force on the left leg deviated from the acceptable range, i.e., all of the CVs were higher than 10%.

At the four measured points (upper right, lower right, upper left, and lower left), the occurrence situation of tibia axial force was different between the UMTRI position and the standard position. While the first peak force in the standard position occurred at about 35 ms, the first peak force in the UMTRI position occurred at about 45 ms, and the force level was higher than that of the standard position.

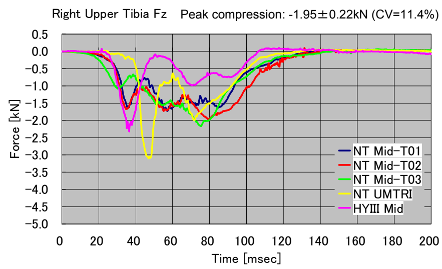
Comparing the responses of the THOR-NT and Hybrid-III on the standard position, the occurrence situation of femur force was similar. However, the peak forces of Hybrid-III were higher than that of THOR-NT.

Figure 40 indicates the moment responses around Y-axis of the tibia. In the three tests of THOR-NT on the standard position, the moment occurrence situations were similar in both the right and left tibia. The maximum moment of the lower tibia was smaller than that of the upper tibia. Also in the three tests, the lower moment of the right tibia tended to indicate smaller values than other three measuring points. Moreover, in all the measuring points on the tibia moments, the values decreased by repeating the test. However, the CVs of the upper and lower tibia moment of the left leg and the lower tibia moment of the right leg were within the range (4% to 6%), while the CV of the upper tibia moment of the right leg was 9.8%. All the CVs fell within the acceptable range of repeatability.

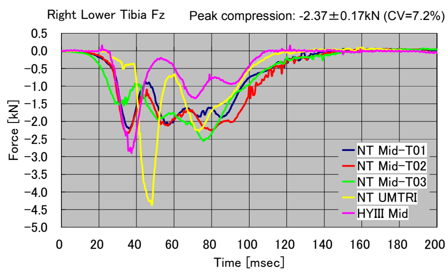
At the four measured points (upper right, lower right, upper left, and lower left), the moment began to appear approximately at the same time in both the UMTRI position and the standard position. However, the undulations from the moment occurrence to the maximum moment were different. In addition, the occurrence time of the maximum moment of the UMTRI position was slightly later than that of the standard position. The maximum tibia moment of the UMTRI position tended to be higher than that of the standard position.

Comparing the responses of the THOR-NT and Hybrid-III on the standard position, in the upper of the right and left tibia, the first peak of Hybrid-III occurred at early timing than THOR-NT.

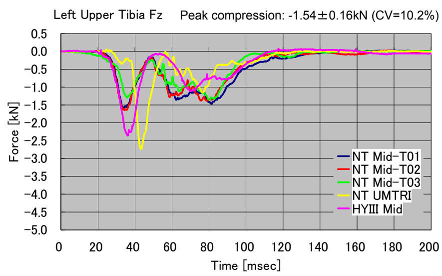
On the other hand, in the lower tibia, Hybrid-III shifted toward minus after it responded toward plus at early timing, and thereby responses between THOR-NT and Hybrid-III were different.



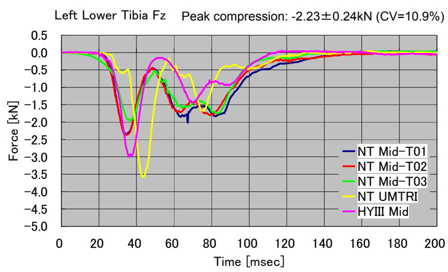
a) Right upper Fz



b) Right lower Fz

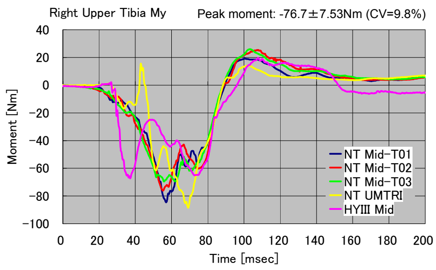


c) Left upper Fz

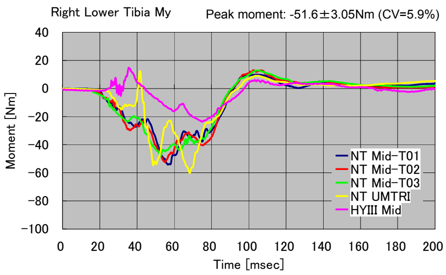


d) Left lower Fz

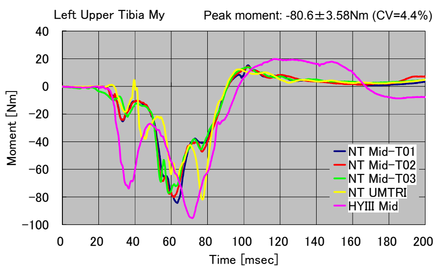
Figure 39. Force responses of tibia



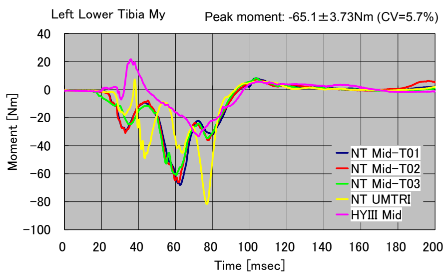
a) Right upper My



b) Right lower My



c) Left upper My



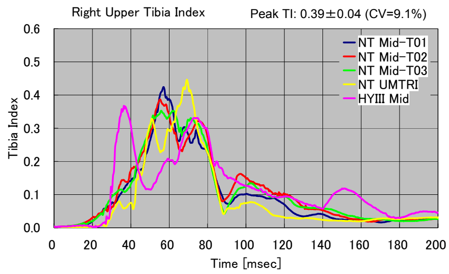
d) Left lower My

Figure 40. Moment responses of tibia

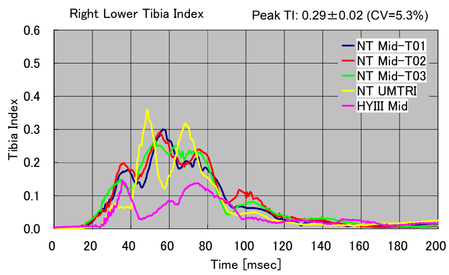
Figure 41 indicates the time history data of the tibia index. In both right and left legs, the curves of the tibia index were similar. As for the maximum values in the tibia index, the value of the upper tibia of the right leg fluctuated larger than that of other three measuring points (CV=9.1%). The CVs of the other three points were from 5.1% to 6.2%.

At the four measured points (upper right, lower right, upper left, and lower left), both the undulation of the UMTRI position and that of the standard position began to appear approximately at the same time, however, the undulations from the starting point to the maximum point of tibia index curves were different. Furthermore, the occurrence time of the maximum tibia index of the UMTRI position was slightly later than that of the standard position. The maximum tibia index of the UMTRI position tended to be slightly higher than that of the standard position.

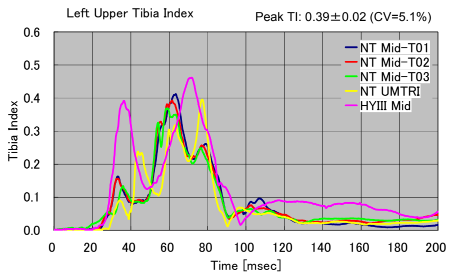
Comparing the responses of the THOR-NT and Hybrid-III on the standard position, in the upper of the right and left tibia, the first peak of Hybrid-III occurred at early timing than THOR-NT. However, with regard to the maximum values of tibia index, THOR-NT and Hybrid-III were similar. On the other hand, in the lower tibia, tibia index of THOR-NT was higher than that of Hybrid-III.



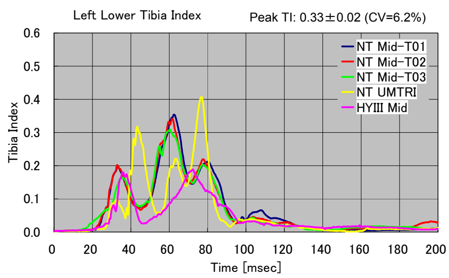
a) Right upper



b) Right lower



c) Left upper



d) Left lower

Figure 41. Tibia Index

DISCUSSIONS

Difference between Biofidelity and Certification Corridors

With regard to the head, thorax and face, the method of biofidelity test and that of certification test are the same. However, the corridors of these tests are different. Therefore, even if the response falls within the one corridor, the response will deviate from another corridor.
It is required how it arranges corridor based on PMHS data.

Suggestion to Improve the Obscure Test Procedures on the Biofidelity and Certification Tests

In biofidelity tests, if it was only the description of the test procedures in the THOR biofidelity/certification test manuals, there was the difficult case of set-up of the test conditions. For instance, as for the head impact test, the test procedure is described in certification manual following as: "The head of the dummy is placed, such that the axis of the impactor is aimed at a point on the forehead on the midsagittal plane and 30 mm above the horizontal line marking the division with the face skin" [2]. However, authors could not correctly judge "the horizontal line marking the division with the face skin". Therefore, authors conducted test assuming that 30 mm above the horizontal line to be approximate point.
Also, as for the rigid bar impact test on the face, the test procedure is described in certification manual following as: "The rod is configured to impact along the mid-line of the left and right maxilla plates on face" [2]. Likewise, as for the disk impact test on the face, the test procedure is described in certification manual following as: "The center of the disk is configured to impact between the cheek and chin plates on the face" [2]. However, authors could not correctly judge "the mid-line of the left and right maxilla plates on face" and "the point between the cheek and chin plates on the face". Therefore, authors conducted these tests, judging the impact point from photographs in the certification manual.
It can be presumed that the slight differences in the test set-up appeared as slightly different result between authors and GESAC. Note: The results of tests which were conducted by GESAC are indicated in the publication of reference [1].
It could be pointed out that it is necessary to arrange the manual such that it is possible to duplicate more faithfully test procedures.

Influence of Different Positioning to Dummy Responses on HYGE Sled Test

With regard to the seat of the white-body of a passenger car used in this test, the seat-slide position in accordance with the ATD positioning procedure of UMTRI was positioned 50 mm rearward with respect to the seat-slide position of the standard position. Therefore, the positioning of the dummy in the UMTRI position was positioned rearward than that in the standard position. The behavior of the dummy was basically similar in both the UMTRI position and the standard position. However, the moving distance of the dummy before coming in contact with the airbag and/or the instrument panel was longer in the UMTRI position than that of the standard position. The clearance between the body of the dummy and the steering wheel/ instrument panel at the initial positioning of the dummy was wider in the UMTRI position compared to the standard position. Therefore, the maximum displacements of each body-part with respect to the initial positioning of the dummy in the UMTRI position were larger relative to the standard position. In particular, there was a difference of about 31 mm at the head and 46 mm at the ankle in the back-forth direction.
With regard to the dynamic responses of the upper body of the dummy, there were little differences observed between the UMTRI position and the standard position. On the other hand, the occurrence situations of force and moment at the femur and the tibia were different relative to those at the upper body probably due to the difference in the behavior of the ankle as stated above.
When the behavior of the dummy in the UMTRI position was checked by means of a video camera, it showed that the ankles moved forward during 0ms to about 40ms and the heels came in contact with the toe board (at the initial position the heels were away from the toe board), and then the feet slide on the toe board at about 40ms to 80ms. On the other hand, in the standard position, the heels were on the toe board at the initial position, and the feet did not slide on the toe board. Instead, the feet appeared to brace against the toe board.
However, the toe board used in the HYGE sled tests series was not the toe board of a real vehicle but a jig-attachment which imitated the real toe board and its surface was covered by a floor carpet of a real vehicle. Therefore, it can be considered that the behavior of the lower legs in these tests did not necessarily reproduce the one in the real driver seat where the lower legs were positioned on the accelerator and the brake pedals.
In addition, the white-body of a passenger car used in

these tests had a rather spacious interior space, and thereby even in the standard position, the clearance between the dummy's knees and the instrument panel was relatively wide. Therefore, it is presumed that this is the reason why conspicuous differences of dummy responses did not appear between the standard position and the UMTRI position.

CONCLUSIONS

The biofidelity of the head, neck, thorax and abdomen of the THOR-NT was evaluated according to the biofidelity test procedures of THOR.

- Only the head responses of the Thor-NT were within the PMHS corridors.
- It was found that the thorax characteristic of Thor-NT dummy was stiffer than the human body. In the test at 6.7m/s, it can be presumed that the maximum force became higher due to the metal contact inside thorax bottomed out.
- With regard to the abdomen, the responses of both upper and lower deviated from each corridor, namely, it was found that the abdomen characteristics of the dummy are stiffer than that of the human body.
- In the head, thorax and face, the test procedures of the biofidelity and certification test are quite same. However, corridors for evaluation in both tests do not overlap with each other. This would cause the result that even if the dummy response is within the corridor of either test, it is outside the corridor of another test. It is required how it arranges corridor based on PMHS data.

In order to obtain the impact response properties of the full assembly of the dummy, four HYGE sled tests were conducted. Evaluation of the repeatability of dynamic response and investigation of the influence on the dummy response by different positioning was performed. In order to evaluate repeatability, three tests were conducted under the same conditions.

- The kinematic responses of the dummy were similar in the three tests.
- As for the dynamic responses of the dummy, coefficient of variation (CV) was used as the evaluation criteria of the repeatability, which was calculated by dividing the standard deviation (SD) of the maximum value of the measured data by the average value. In this study, repeatability was evaluated in the measured data and injury criteria of 31 items. As a result, 10 items (32%) in all the measured data and the injury criteria (31 items) indicated the result that CV is less than 5% as good for repeatability. 23 items (74%) in 31 items indicated the result that CV is less than 10% as acceptable. Thus, the remaining 8 items (26%) indicated that CV is larger than 10% as poor.
- In order to investigate the influence of different positioning to dummy responses, a test was conducted on a dummy positioned according to the ATD positioning procedure developed by UMTRI, and then repeatability was evaluated. When comparing the dummy positioning in the standard and UMTRI position, the dummy in the UMTRI was positioned 50 mm rearward and 18 mm above with respect to the standard seat position. In the back-forth direction, the difference of the H.P. was the largest, namely, the H.P. in the UMTRI position was 43 mm rearward compared with the standard position. In the up-down direction, the difference of the shoulder was the largest, namely, the shoulder in the UMTRI seat position was approximately 37 mm upward compared with the standard seat position.
- The behavior of the dummy was basically similar in both seat positions, but the maximum displacement with respect to the initial position differed in the head and the ankle. The difference in the dummy response due to different positioning was small in the upper body, but large in the femur, legs, and ankles. This is presumed to be due to the difference in the behavior of the ankles.

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