COMPARISON OF DYNAMIC RESPONSES OF THE THOR-NT AND HYBRID III IN OFFSET FRONTAL CRASH TEST

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ABSTRACT

A 64 km/h offset frontal crash test was conducted with the THOR-NT and Hybrid III to investigate the responses of both dummies under a crash situation that includes both deformation and rotational behavior of a vehicle.

Though the dummies were installed in the driver seat according to the ECE R94 positioning procedure, their postures were slightly different. The head and heels of the THOR-NT were positioned rearward. Similarly, the shoulders and knees were positioned forward compared to the Hybrid-III. Therefore, it is expected that these differences will affect the responses of both dummies.

During the tests, both dummies showed similar kinematics, except for the rotation about Z-axis of the head, and the contact situation to the instrument panel of the arms.

For the injury measures, the chest acceleration of the THOR-NT showed sharp inclination at 100 ms to 120 ms, presumed to be caused by the contact between the arms and instrument panel. The initial time history curve of the lap belt force was approximately the same between both dummies; however, the maximum force of the THOR-NT was less than half of the Hybrid III. For this difference, it was strongly presumed that more kinetic energy was absorbed by the knee bolster for the THOR-NT since its longer femur shortened the initial clearance between the knee and knee bolster. In addition, it was also presumed that the difference of the flesh characteristics around the iliac wing between both dummies affected the results.

The injury measures of both dummies were compared to the injury criteria specified in FMVSS 208 and ECE R94. As for the results, almost equivalent values between the two dummies were observed.

Moreover, as reference, the additional injury measures in the THOR-NT are shown in this paper.

INTRODUCTION

In 1976, the Hybrid III mid-sized male, instrumented test dummy was first released [1]. Subsequently, the Hybrid III has been adopted in the current regulations for frontal impact tests in many countries. The National Highway Traffic Safety Administration (NHTSA) of the U.S. acknowledged the need for improved biofidelity and measurement capabilities of the Hybrid III, consistent with the advancement of vehicle safety devices. Moreover, NHTSA announced plans to develop an advanced crash test dummy with improved biofidelity under frontal impact conditions with expanded injury assessment capabilities [2]. In 1992, the initial advanced ATD known as "Trauma Assessment Device - 50th percentile male (TAD-50M)" was developed by a NHTSA-sponsored consortium of universities and industrial partners [3]. The principal objectives were to review the anthropometry and dynamic biofidelic responses subject to more contemporary occupant seat positionings and restraint systems. In 1994, NHTSA initiated an aggressive effort to integrate existing advanced ATD components. Then, in 1996, the "Test Device for Human Occupant Restraint (THOR)" prototype was introduced [4]. Research organizations in several countries conducted experiments to improve this prototype dummy, leading to the introduction of the THOR-Alpha in 2001 [5]. In 2005, NHTSA released the THOR-NT (New Technology), which was a modified and improved version of the THOR-Alpha [6]. Currently, to improve the THOR-NT further, the discussion regarding the improvement for each body region and the certification and positioning procedures is in progress in SAE THOR Evaluation Task Force Group.

JAMA (Japan Automobile Manufacturers Association) /JARI (Japan Automobile Research Institute) has so far

performed the research activities for contributing to development and improvement of the THOR [7][8][9]. As part of the research activities, in order to investigate the responses of the THOR-NT and Hybrid III under a crash situation that includes both deformation and rotational behavior of a vehicle, authors conducted 64 km/h offset frontal crash tests (ODB tests), and compared the results between the dummies.

64 km/h ODB Tests with the THOR-NT and the Hybrid III

Test Condition

Figure 1 shows the collision configuration of the ODB test. The tests were conducted with 40 % overlap of the vehicle width against the deformable barrier at a impact speed of 64 km/h.

The test vehicles were a compact hatchback type passenger car with 5 doors. The test weights of the two vehicles were both 1090 kg. As shown in Figure 2, the front door of the driver's side was replaced by the steel bar in order to analyze the whole-body behavior of the dummy.

In each of the two ODB tests, the THOR-NT or the Hybrid-III was set on only the driver's seat. The seat positions were subject to the ECE R94 procedure. For the restraint devices, an airbag and a seatbelt with pretensioner and with force-limiter were used.

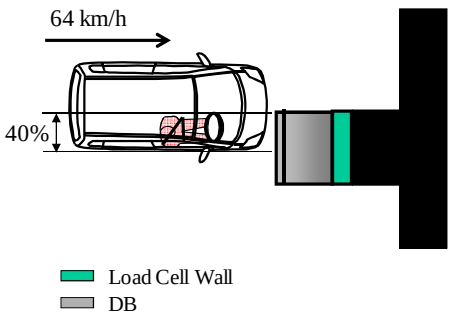

Figure 1. Collision Configuration of the ODB Test

Figure 2. Appearances of the Door Frame of the Driver's Seat Side

Measurements

During the ODB tests, the electrical measurements (e.g. acceleration) of the dummy and vehicle and the optical measurements using a high-speed digital video camera were done. In both pre-test and post-test, the deformation of the test vehicle was measured with the three-dimension measurement device.

For the electrical measurements, the accelerations, deflections and forces of the dummy were measured, and the accelerations at the engine block and the lower of B-pillar of the test vehicle were measured. These data were recorded by a data acquisition system mounted in the luggage room of the test vehicle, and they were filtered compliantly to SAE J211. The detail information of the instrumentations of the THOR-NT and Hybrid III is shown in Appendix.

For the optical measurements, a high-speed video camera was used to take the behaviors of the dummy and vehicle during the impact. The behavior of the dummy was observed as follows: The motions of the marks attached to some parts on the dummy were recorded by the video camera, then these were converted into the numerical movements using the video analyzer.

In both the pre-test and post-test, the some coordinate values on the vehicle were measured with the three-dimension measurement device, and the vehicle deformation amounts were calculated from the pre- and post-data. Note: the coordinate system of the vehicle was defined as follows: An origin point was on the trunk lid striker; the X-axis was the fore-aft direction; Y-axis was the lateral direction; and the Z-axis was the vertical direction.

Dummy Positioning

The THOR-NT and the Hybrid III were respectively set in the vehicle in accordance with the positioning procedure described in the ECE R94. Table 1 indicates the X and Z coordinate values of the head, shoulder, hip point (H.P.), knee and heel of the dummies respectively. Figure 3

compares the positions of each component of the dummies in the X-Z coordinate system.

When the H.P. of each dummy was set at the approximately same positions in the fore-aft direction (X-axis), the head and heels of the THOR-NT were positioned rearward, and its shoulders and knees were positioned forward, compared with those of the Hybrid III. In the vertical direction (Z-axis), the H.P., head, shoulders and knees of the THOR-NT were positioned above, compared with those of the Hybrid III. It was presumed that the knees of the THOR-NT were positioned more forward and upward than those of the Hybrid III, because the legs of the THOR-NT are longer than those of the Hybrid III.

Table 1. Coordinate Values of Each Component of the THOR-NT and the Hybrid III

	THOR		HYIII	
	X	Z	X	Z
Head	−77.6	448.6	−107.0	424.1
Shoulder	−78.0	189.9	−50.5	147.1
H.P.	−228.5	−223.5	−227.1	−233.7
Knee	−631.2	−91.1	−600.7	−118.3
Heel	−876.4	−563.5	−898.0	−560.2

Origin: Door Striker Bolt Unit: mm

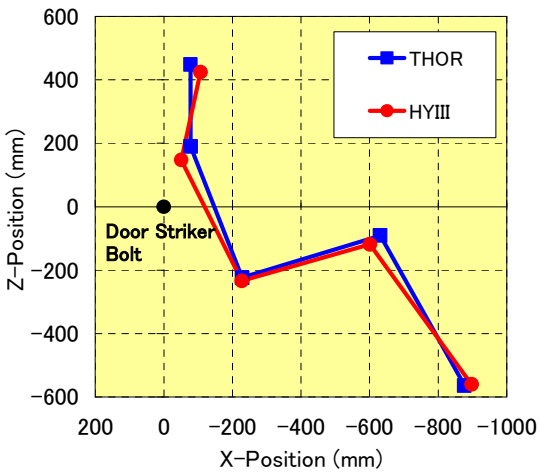

Figure 3. Comparison of Positionings of the THOR-NT and the Hybrid III

Test Results

(1) Vehicle Acceleration

Figure 4 indicates the comparison of the vehicle accelerations in the 64 km/h ODB tests. The acceleration responses between the test vehicles with the THOR-NT and Hybrid III were approximately similar.

(2) Vehicle Deformation

Figure 5 indicates the appearance of the vehicle deformation after the tests. The vehicle deformations in the two tests was similar each other.

(3) Vehicle Behavior

As shown in Figure 6, the behaviors of two vehicles during the impact were similar. The vehicles moved almost straightly until 80 ms, then these began to rotate greatly after 120 ms.

(4) Kinematics of the Dummies

In Figure 7 and Figure 8, the behaviors of the THOR-NT and Hybrid III were compared based on the track of each body part from the impact to just before the vehicle started rotating (120ms). It seems that the forward displacements of each body part of the dummies reached to the maximum at about 120 ms, and these behaviors were approximately similar, except for the rotation about Z-axis of the head, and the contact situation to the instrument panel of the arms. However, the maximum displacements relative to the initial positions of each body part between the dummies were different as shown in Table 2. With regard to the fore-aft direction, the head of the THOR-NT moved forward 28 mm than that of the Hybrid III, and the shoulder of the THOR-NT moved forward 12 mm than that of the Hybrid III. Oppositely, the H.P., knee, and ankle of the Hybrid III moved forward 19 mm, 13 mm, and 24 mm respectively than those of the THOR-NT. With regard to the vertical direction, the head and ankle of the Hybrid III moved downward 31 mm and 17 mm respectively than those of the THOR-NT. The shoulder of the THOR-NT moved downward than that of the Hybrid III, while the knee of the Hybrid III moved upward than that of the THOR-NT. The displacements of the H.P. were approximately same between the two dummies.

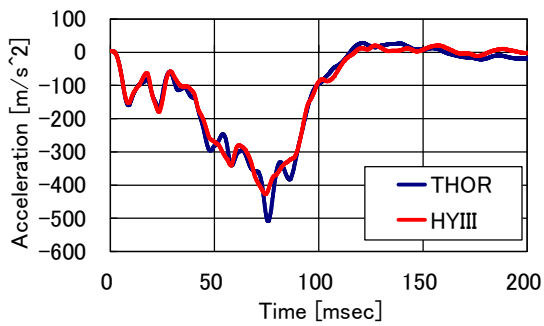

Figure 4. Vehicle Accelerations in 64 km/h ODB Tests

Figure 5. Appearance of the Vehicle Deformations in the Post-Tests

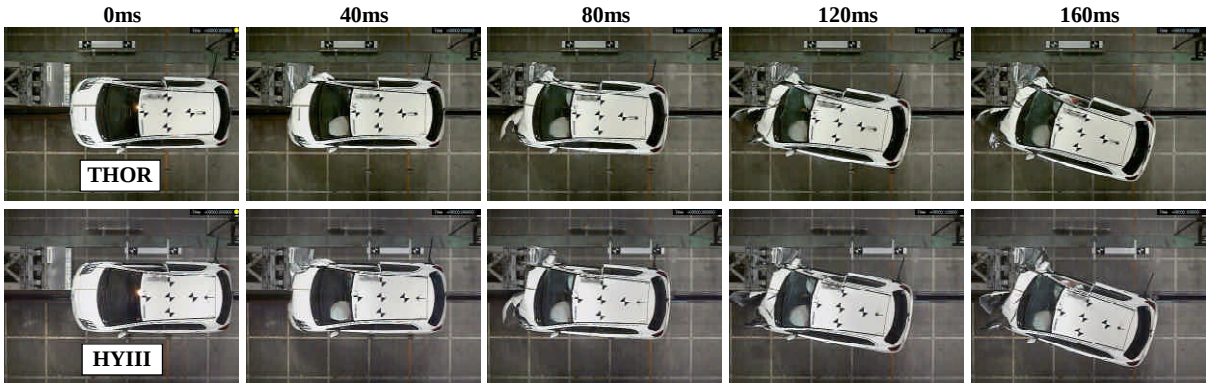

Figure 6. Vehicle Behavior During the Impact

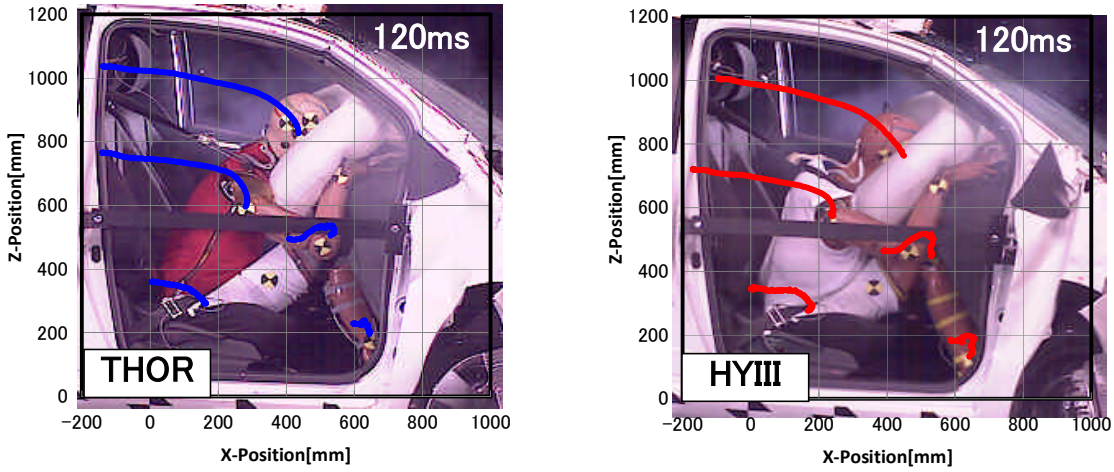

Figure 7. Track of Each Body Part of the Dummies

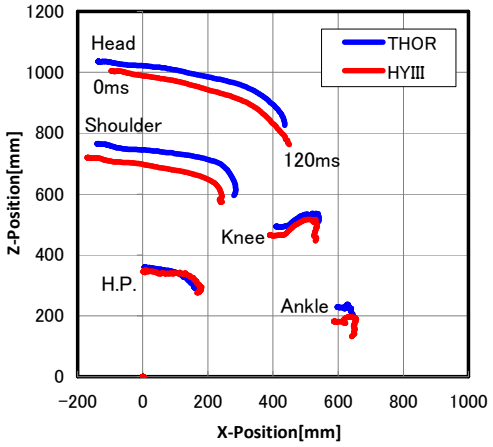

Figure 8. Comparison of the Track of Each Body Part of the Dummies (0 ms to 120 ms)

Table 2. Difference in the Maximum Displacement of Each Body Part of the Dummies

	THOR		HYIII		Difference between THOR and HYIII	
	X	Z	X	Z	X	Z
Head CG	570	−211	542	−242	28	31
Shoulder	423	−170	411	−147	12	−23
H.P.	156	−69	175	−70	−19	1
Knee	129	44	142	52	−13	−8
Ankle	43	−34	67	−51	−24	17

X−axis : Forward +, Rearward −
Z−axis : Upward +, Downward −
Unit : mm

(5) Dynamic Responses of the Dummies

Figure 9 indicates the head acceleration responses of the THOR-NT and Hybrid III. Although the initial time history curve of acceleration and the duration time were similar between the dummies, the responses of both dummies were different at the time (around 100 ms) when the peak accelerations occurred; namely, the peak acceleration of the THOR-NT was higher than that of the Hybrid III.

Figure 10 indicates the chest acceleration responses of the dummies. The initial time history curve of the acceleration, the values of the peak acceleration, and the duration time were similar in both the dummies. The acceleration responses were similar in both the dummies until about 70 ms, however, at about 70 ms to 100 ms, the acceleration of the Hybrid III was slightly higher than that of the THOR-NT.

Figure 11 indicates the pelvis acceleration responses of the dummies. The acceleration responses were similar in both dummies until about 40 ms. However, the responses from about 40 ms to the peak acceleration were different in both dummies, thus, the peak acceleration of the Hybrid III was higher than that of the THOR-NT.

Figure 12 and Figure 13 indicates Fz (axial force) and My (flexion and extension moment around the Y-axis) responses of the upper neck of the THOR-NT and Hybrid III. For the Fz, both the THOR-NT and the Hybrid III began to generate the tension forces at about 25 ms and reached the maximum forces at about 90 ms. For the My, on the whole, the occurring situations on moment were similar in both dummies; however, the timings of the peak flexion and extension of the Hybrid III were earlier than those of the THOR-NT.

Figure 14 indicates the thoracic deflection responses (fore-aft direction) of the THOR-NT where measured at four points (upper right, upper left, lower right, and lower left) on the thorax. Figure 15 indicates the thoracic deflection responses (fore-aft direction) of the Hybrid III where measured at one point (center) on the thorax. The deflection values on the lower left of the THOR-NT and the center of the Hybrid III were approximately same, and the deflection appearance was similar. However, the upper right of the THOR-NT indicated smaller deflection than the Hybrid III, and returned to the deflection around zero at about 120 ms. Furthermore, the deflection on the lower right of the THOR-NT was small, but generated in the opposite direction to the deflections on the other three points.

Figure 16 indicates the relative location between the seatbelt and the four measurement points of the THOR-NT thorax. The upper and lower measurement points on the left side of the thorax were approximately lapped over the seatbelt, and the point on the upper right was close to the seatbelt. Therefore, the three measurement points deflected in the compressive direction by loading of the seatbelt. On the other hand, the measurement point on the lower right was far position where it did not lap over the seatbelt. Due to this, it was presumed that the lower right of the thorax deflected in the tensile direction because the whole left side and the upper right of the thorax were distorted by the pressure of the seatbelt.

Figure 17 indicates the deflection response of the upper abdomen of the THOR-NT, and Figure 18 shows the deflection responses of its lower abdomen. The deflection of the upper abdomen was measured by the string potentiometer, while the right and left deflections of the lower abdomen were measured by the DGSP unit with

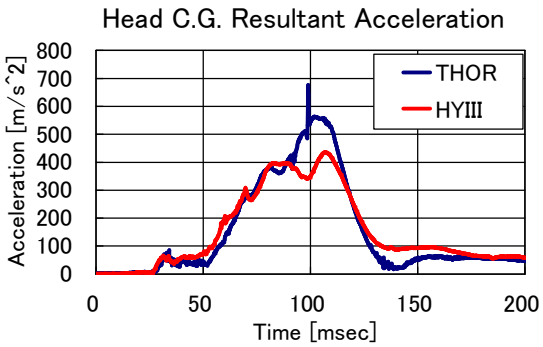

Figure 9. Head Acceleration

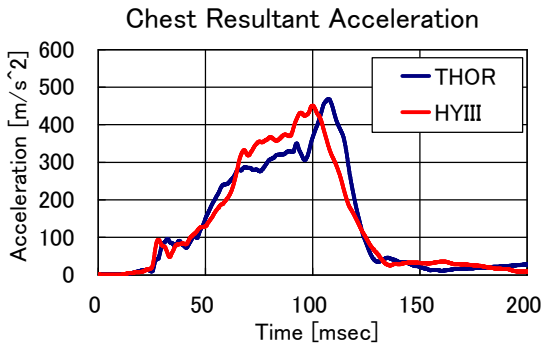

Figure 10. Chest Acceleration

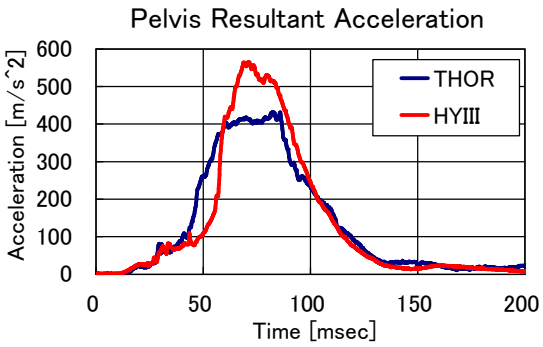

Figure 11. Pelvis Acceleration

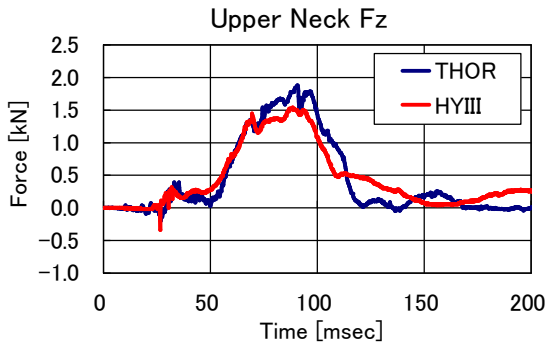

Figure 12. Upper Neck Axial Force

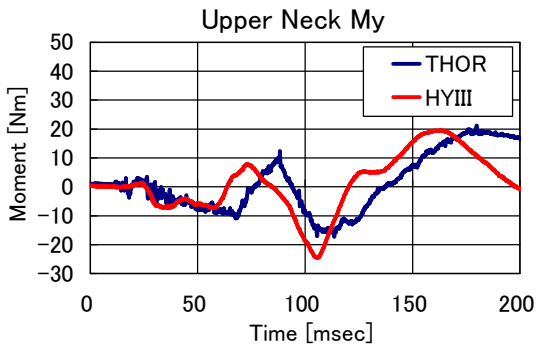

Figure 13. Upper Neck Moment (around Y-Axis)

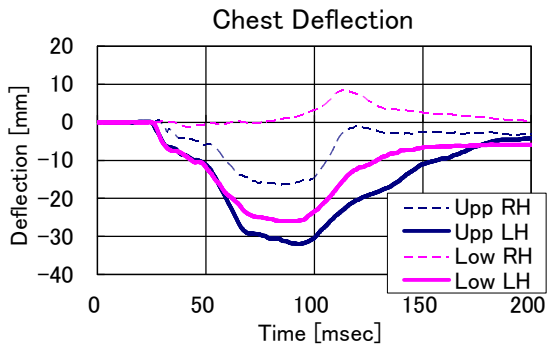

Figure 14. Thoracic Deflection of the THOR-NT (Upper Right, Upper Left, Lower Right, Lower Left)

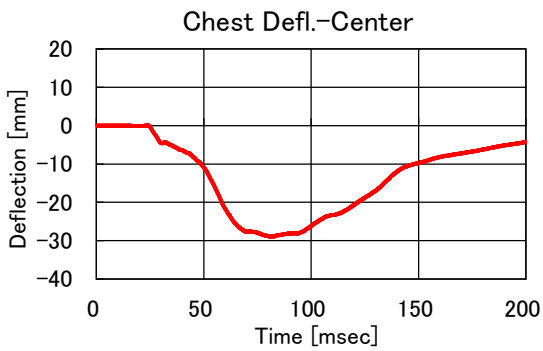

Figure 15. Thoracic Deflection of the Hybrid III (Center)

Figure 16. Relative Location between the Thoracic Measurement Points (UR, UL, LR, LL) and the Seatbelt

a linear potentiometer for measuring the fore-aft displacement and with two rotatory potentiometers for measuring the yaw and pitch angles. The abdominal deflection of the Hybrid III was not measured because it had not a sensor to measure the deflection. Therefore, only the results of the THOR-NT are stated herein. The deflection of the upper abdomen was smaller than that of the lower abdomen. The deflection of the upper abdomen reached the maximum value (10 mm) at about 90 ms and decreased to about 2 mm at about 120 ms. On the other hand, the right and left deflections of the lower abdomen exhibited a gentle decrease after reaching to the maximum deflection; the right side maintained the deflection of about 40 mm, and the left side was about 25 mm at 200 ms.

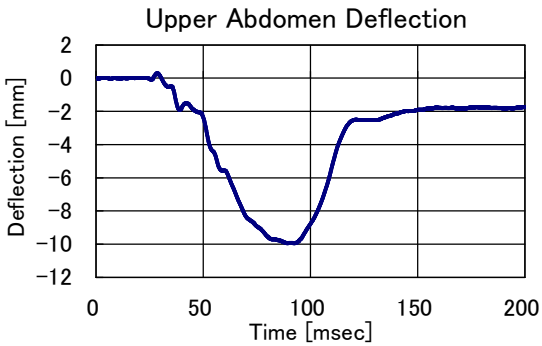

Figure 17. Upper Abdomen Deflection of the THOR-NT

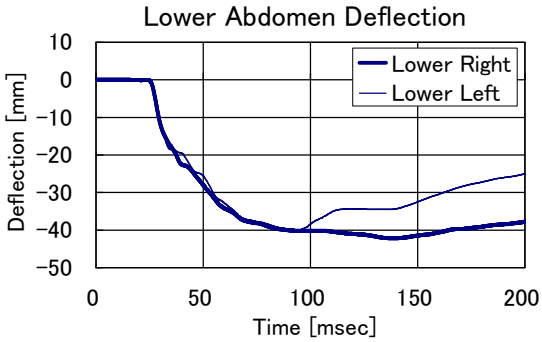

Figure 18. Lower Abdomen Deflection of the THOR-NT (Right and Left)

Figure 19 and Figure 20 indicates the axial force responses of the right and left femurs of the THOR-NT and Hybrid III. For the left femur, both the THOR-NT and the Hybrid III began to respond at about 40 ms. However, while the THOR-NT remained showing the compressive force from the occurrence and reached the maximum compressive force, the Hybrid III shifted to compressive force after showing the tensile force once, and then reached the maximum compressive force. The time of the maximum compressive force of the THOR-NT was slightly earlier than that of the Hybrid III, and the maximum force value of the THOR-NT was larger than that of the Hybrid III. For the right femur, also, the difference in the initial force response between the THOR-NT and the Hybrid III was observed. Although the time of the maximum compressive force of the Hybrid III was slightly earlier than that of the THOR-NT, the maximum forces of both the dummies were approximately the same.

Figure 21 to Figure 24 indicates the axial force responses of the tibia (upper right, upper left, lower right, and lower left) of the THOR-NT and Hybrid III. For the right tibia, the maximum force of the upper tibia was similar between the THOR-NT and Hybrid III. The maximum forces of the lower tibia were slightly different between the THOR-NT and Hybrid III, but the dummies exhibited similar responses. For the left tibia, the maximum axial forces of the upper and lower of the Hybrid III were larger than that of the THOR-NT, but the force responses were similar between the dummies.

Figure 25 to Figure 28 shows the time-series data of the Tibia Index (upper right, upper left, lower right, and lower left) of the THOR-NT and Hybrid III. For the upper side of the right tibia, the value of the Hybrid III increased until about 45 ms, whereas that of the THOR-NT decreased at 30 ms to 40 ms. In addition, the value of the THOR-NT increased at 40 ms to 55 ms and reached the maximum, while the value of the Hybrid III increased again after decreased at 40 ms and 70 ms and reached the maximum at about 80 ms. For the lower side of the right tibia, while

the THOR-NT showed two local peaks before the maximum at about 80 ms, the Hybrid III did not show any local peaks before the maximum at about 80 ms. As a result, the difference of the values between the dummies was large at about 55 ms. For the upper side of the left tibia, the time of the maximum value was approximately same between the dummies. For the lower side of the left tibia, the response until reached the maximum value was different; the time of the maximum value of the THOR-NT was earlier than that of the Hybrid III.

(6) Force Responses of the Seatbelt

Figure 29 shows the force responses of the shoulder belt of the dummies, and Figure 30 shows those of the lap belt. For the shoulder belt, the occurrence situations and amplitudes of the force were approximately the same between the dummies, whereas, for the lap belt, large difference of the force was observed between the dummies. The initial time history curve of the force was approximately the same (about 20 ms) between the dummies, however, the maximum force of the THOR-NT (3.1 kN) was less value than a half, compared to that of the Hybrid III (6.8 kN).

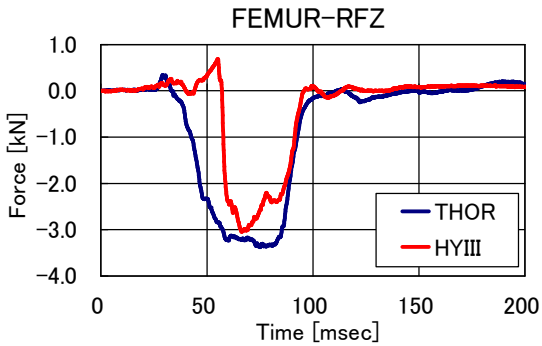

Figure 19. Axial Force of the Right Femur

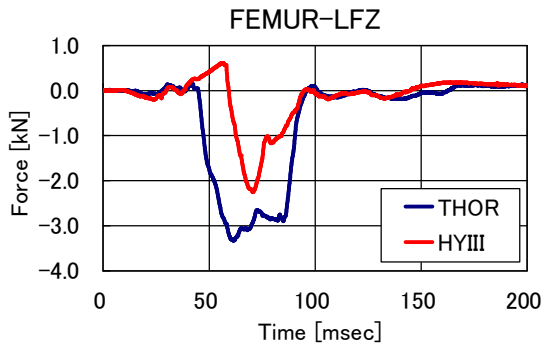

Figure 20. Axial Force of the Left Femur

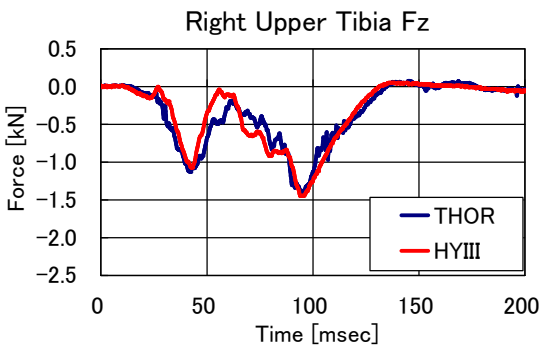

Figure 21. Axial Force of the Right Upper Tibia

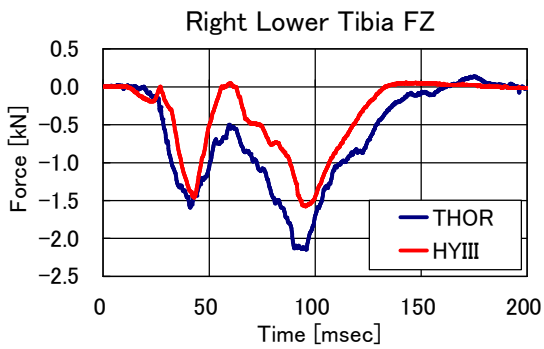

Figure 22. Axial Force of the Right Lower Tibia

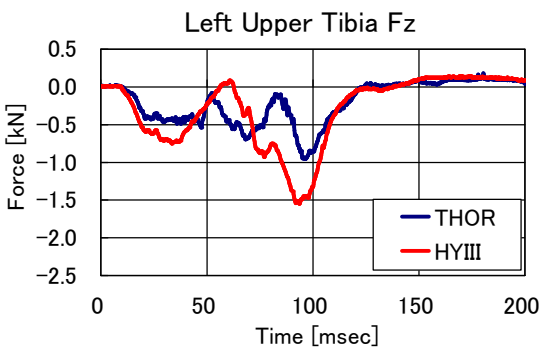

Figure 23. Axial Force of the Left Upper Tibia

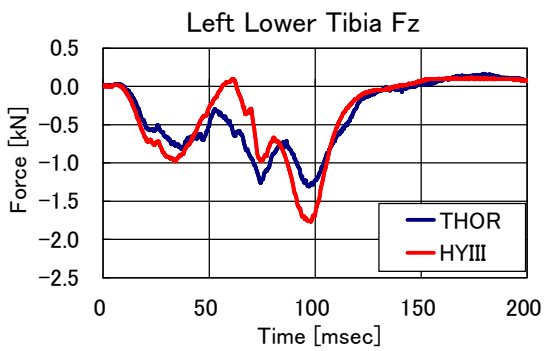

Figure 24. Axial Force of the Left Lower Tibia

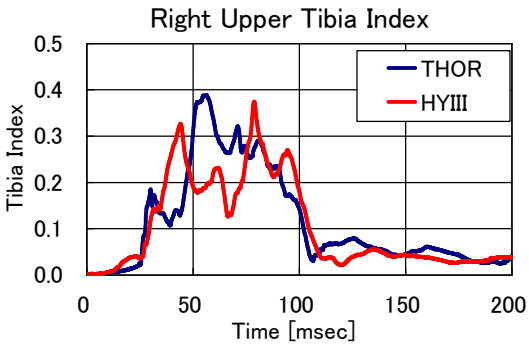

Figure 25. Tibia Index of the Right Upper Tibia

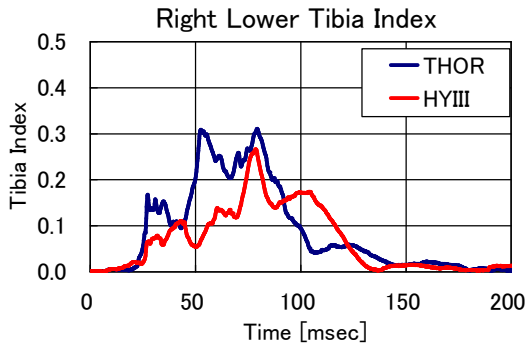

Figure 26. Tibia Index of the Right Lower Tibia

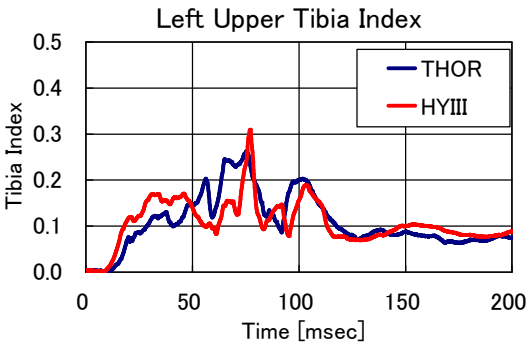

Figure 27. Tibia Index of the Left Upper Tibia

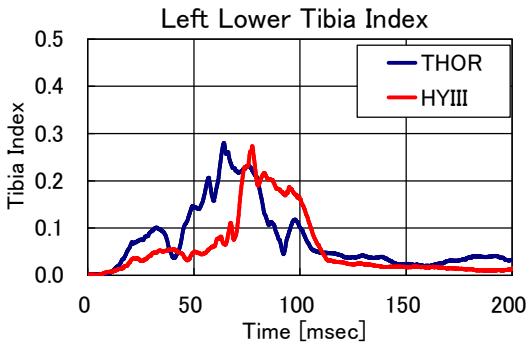

Figure 28. Tibia Index of the Left Lower Tibia

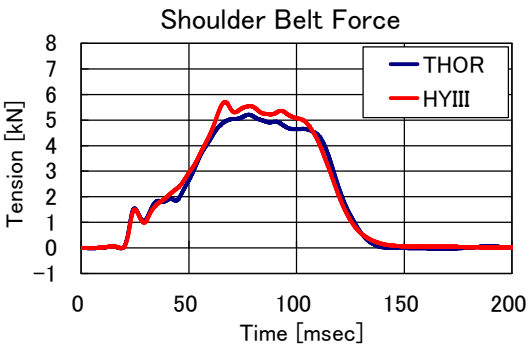

Figure 29. Shoulder Belt Force

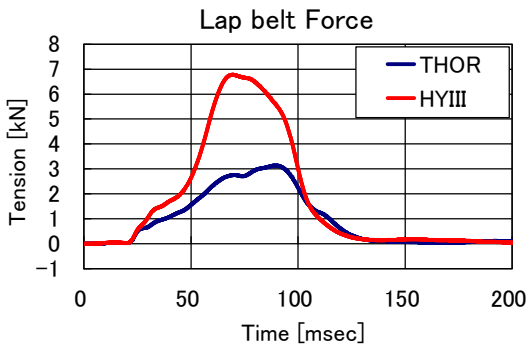

Figure 30. Lap Belt Force

(7) Injury Measurements

Table 3 indicates the injury measures of each component of the THOR-NT and Hybrid III. Furthermore, Figure 31 shows the ratios of the injury measures of the dummies to the injury criteria regulated in the ECE R94 and FMVSS208.

With regard to HIC 36 ms, HIC 15 ms, and head 3 ms G, the differences of the ratios of the measurements to the injury criteria between the dummies were larger than other injury measures; the injury values of the THOR-NT were larger than those of the Hybrid III. Secondly, with regard to the tension force and extension moment of the neck and the compressive force of the left femur, the differences of the results between the dummies were large; the neck tension force and femur force of the THOR-NT was larger than that of the Hybrid III, whereas the neck extension moment of the Hybrid III was larger than that of the THOR-NT. Other injury measures were approximately the same between the dummies. All injury measures of both dummies were less than the injury criteria. The chest G of both dummies and the head G of the THOR-NT showed relatively larger ratio against the injury criteria, comparing to the other injury measures.

On the other hand, as reference, the additional injury measures for the abdomen, knee-thigh-hip (KTH) and tibia in the THOR-NT are shown in Table 4.

Table 3. Injury Measures of the THOR-NT and the Hybrid III

		Injury Criteria	THOR	HYIII
Head	HIC 36ms	1000	549.0	351.2
	HIC 15ms	700	339.4	158.4
	3ms clip (G)	80	56.97	43.84
Upper Neck	Shear Force (Fx+) (kN)	3.1	0.320	0.170
	Tension Force (Fz+) (kN)	3.3	1.881	1.542
	Compression Force (Fz-) (kN)	4.0	0.197	0.337
	Extension Moment around Y-axis (My-) (Nm)	57	17.22	24.60
	Nij	1.0	0.350	0.305
Chest	Deflection (Upper Right) (mm)	50	-16.33	-
	Deflection (Upper Left) (mm)		-32.00	-
	Deflection (Lower Right) (mm)		8.34	-
	Deflection (Lower Left) (mm)		-25.94	-
	Deflection (Center) (mm)		-	-28.91
	Viscous Criterion (Upper Right) (m/s)	1.0	-0.053	-
	Viscous Criterion (Upper Left) (m/s)		-0.178	-
	Viscous Criterion (Lower Right) (m/s)		0.030	-
	Viscous Criterion (Lower Left) (m/s)		-0.093	-
	Viscous Criterion (Center) (m/s)		-	-0.149
	3ms clip (G)	60	46.78	44.57
Femur	Right Femur Axial Force (Compression) (kN)	10	3.38	3.05
	Left Femur Axial Force (Compression) (kN)		3.33	2.25
Knee	Right Tibia to Femur Translation (mm)	15	2.47	0.01
	Left Tibia to Femur Translation (mm)		0.16	0.75
Tibia	Right Upper Axial Force (kN)	8	1.44	1.45
	Right Lower Axial Force (kN)		2.15	1.58
	Left Upper Axial Force (kN)		0.95	1.55
	Left Lower Axial Force (kN)		1.31	1.77
	Right Upper Tibia Index	1.3	0.39	0.37
	Right Lower Tibia Index		0.31	0.27
	Left Upper Tibia Index		0.26	0.31
	Left Lower Tibia Index		0.28	0.27

For calculation of the upper rib VC of THOR-NT; Deformation Constant at #3 Rib: 219 mm, Scaling Factor: 1.3
For calculation of the lower rib VC of THOR-NT; Deformation Constant at #6 Rib: 234 mm, Scaling Factor: 1.3

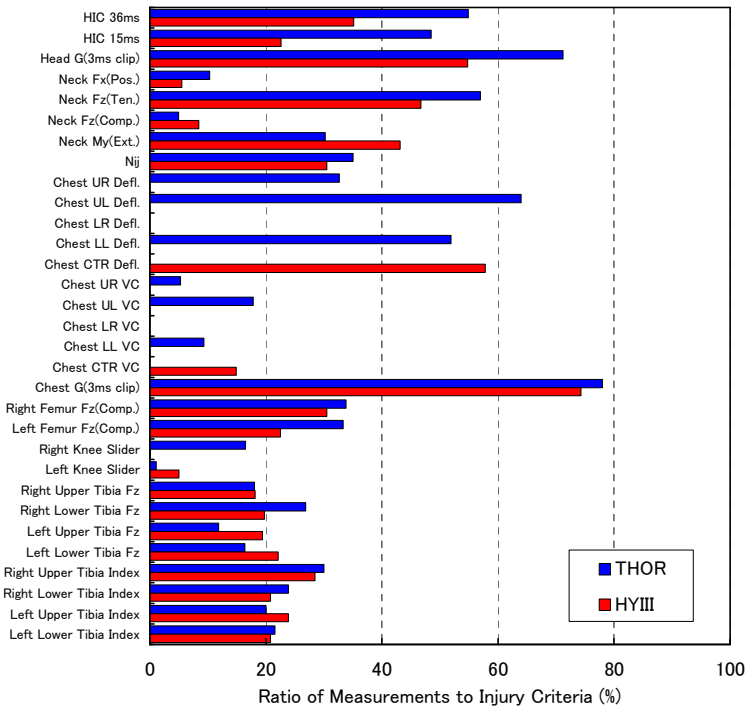

Figure 31. Ratio of the Injury Measures of the Dummies to the Injury Criteria in the Frontal Impact Regulations

Table 4. Injury Measures of the THOR-NT Except the Injury Criteria in the Frontal Impact Regulations

		THOR
Abdomen	Deflection (Upper) (mm)	9.93
	Deflection (Lower Right) (mm)	42.14
	Deflection (Lower Left) (mm)	40.02
	Viscous Criterion (Upper) (m/s)	0.012
	Viscous Criterion (Lower Right) (m/s)	0.141
	Viscous Criterion (Lower Left) (m/s)	0.169
Knee-Thigh-Hip (KTH)	Acetabulum Force with Neutral Posture (Right) (kN)	1.46
	Acetabulum Force with Neutral Posture (Left) (kN)	0.25
	Femur Bending Moment (Right) (Nm)	108.1
	Femur Bending Moment (Left) (Nm)	94.3
Tibia	Rivised Tibia Index (Right Upper)	0.39
	Rivised Tibia Index (Right Lower)	0.37
	Rivised Tibia Index (Left Upper)	0.28
	Rivised Tibia Index (Left Lower)	0.30
	Proximal Tibia Axial Force (Right) (N)	1437.7
	Proximal Tibia Axial Force (Left) (N)	955.0
	Distal Tibia Axial Force (Right) (N)	2147.8
	Distal Tibia Axial Force (Left) (N)	1306.5
	Ankle Dorsiflexion Angle (Right) (deg)	20.96
	Ankle Dorsiflexion Angle (Left) (deg)	20.39
	Ankle Inversion Angle (Right) (deg)	7.15
	Ankle Eversion Angle (Right) (deg)	6.66
	Ankle Inversion Angle (Left) (deg)	17.72
	Ankle Eversion Angle (Left) (deg)	21.16

For calculation of the upper and lower abdomen VC of THOR-NT;
Deformation Constant: 250 mm
(Supposed the abdominal depth of the THOR-NT equals that of the Hybrid III.)
Scaling Factor: 1.3

DISCUSSION

Differences in the Kinematics and Responses of the Dummies

(1) Differences in the Kinematics and Response of the Head

The face of the Hybrid III was positioning approximately forward at the early contact with the airbag, whereas the face of the THOR-NT was positioning downward (Figure 32). Furthermore, the head of the Hybrid III was rotating about Z-axis during the contact with the airbag by yaw of the vehicle, while the head of the THOR-NT was little rotating. For these differences in the kinematics of the flexion and twist of the head-neck, it was presumed that the difference in the structure and characteristics of the neck caused the different kinematics, but that the act on the head-neck of the resistant force from the airbag might have differed. The difference in the kinematics based on the different structure and characteristics of the neck might have affected the difference in the head response.

The head-neck of the THOR-NT flexed than that of the Hybrid III at near 100 ms. It was presumed that since the Z-axis sensitivity of the THOR-NT's head was near the fore-aft direction, the Z-axis acceleration of the THOR-NT was higher than that of the Hybrid III. On the other hand, the X-axis acceleration of the Hybrid III was smaller than that of the THOR-NT.

The Hybrid III generated the Y-axis acceleration because the head was rotating about Z-axis at near 120 ms. However, the THOR-NT was low Y-axis acceleration due to little rotating. With regard to the difference of the twist behaviors of the head-neck about Z-axis, it was presumed because of the differences in the structure and characteristics between both dummies.

(2) Differences in the Responses of the Thorax, Pelvis and Lap Belt

As shown in Figure 33, the chest acceleration response of the dummies differed. In the section of the mark 1, as for the relative position between the thorax and the steering wheel, and the thorax contact situation with the airbag, the difference between the dummies was not observed. Therefore, it was presumed that the difference in the acceleration in the section of the mark 1 was different in the transmissive force from the pelvis in the internal of the dummy. The pelvis acceleration of the Hybrid III was higher than that of the THOR-NT. It was presumed that the difference in the pelvis acceleration was caused by the different contact situation of the knees, due to the different leg length between the dummies, and caused the difference in the thorax acceleration because this difference was transmitted to the thorax as the transmissive force in the internal of the dummy. Furthermore, it was presumed that the event that the arms came in contact with the instrument panel affected the occurrence situation of the acceleration in the section of the mark 2.

As shown in Figure 30, for the lap belt, large difference of

the force was observed between the dummies. Herein, it states the consideration why the lap belt force of the THOR-NT was lower than that of the Hybrid III.

Figure 34 shows the lap belt force relative to the pelvis stroke of the dummies, and the femur force (total of the right and left) relative to the pelvis stroke. Moreover, Table 5 shows the cause of the difference in the lap belt force relative to the pelvis stroke between the dummies. Herein, the pelvis stroke was calculated according to Equation 1.

The difference of the lap belt force between the dummies began to appear until the pelvis stroke of the dummies reached to 39 mm. This difference is presumed because the characteristics of the lower abdomen of the THOR-NT is softer than that of the Hybrid III [8].

The difference of the lap belt force between the dummies became larger until the pelvis stroke of the dummies reached to 39 mm to 114 mm; this cause was presumed as follows: The characteristics of the lower abdomen of the dummies differ. In addition, the restricted timing of the motion of the legs was different. Because the THOR-NT has longer upper legs than the Hybrid III, the initial clearance between the knees and instrument panel for the THOR-NT was shorter than Hybrid III. Due to this, the timing when the legs of the THOR-NT contacted to the instrument panel was earlier than the Hybrid III. The THOR-NT began to generate the femur force from about 39 mm of the pelvis stroke (the legs contacted to the instrument panel), while the Hybrid III began to generate the femur force from about 114 mm. Based on this difference, the load to the lap belt of the THOR-NT was reduced, and its lap belt force became lower, compared to the Hybrid III.

The lap belt force of the THOR-NT was lower than that of the Hybrid III after 114 mm in the pelvis stroke; this cause was presumed as follows: In addition to the consideration explained above, it was presumed that the difference in the femur force affected the lap belt force. The femur force of the THOR-NT after 114 mm in the pelvis stroke was larger than the Hybrid III. The THOR-NT was earlier than the Hybrid III with regard to the timing when the legs contacted to the instrument panel, and the legs of the THOR-NT deeply intruded into the instrument panel.

Furthermore, it states the factor of the difference in the resultant pelvis acceleration in the tri-axis of the dummies shown in Figure 11 and Figure 33.

Figure 35 shows the resultant pelvis acceleration in the X and Z-axis relative to the pelvis stroke of the dummies, and the calculated pelvis acceleration relative to the pelvis stroke. The calculated pelvis acceleration means the acceleration calculated from the lap belt force and femur force (Equation 2).

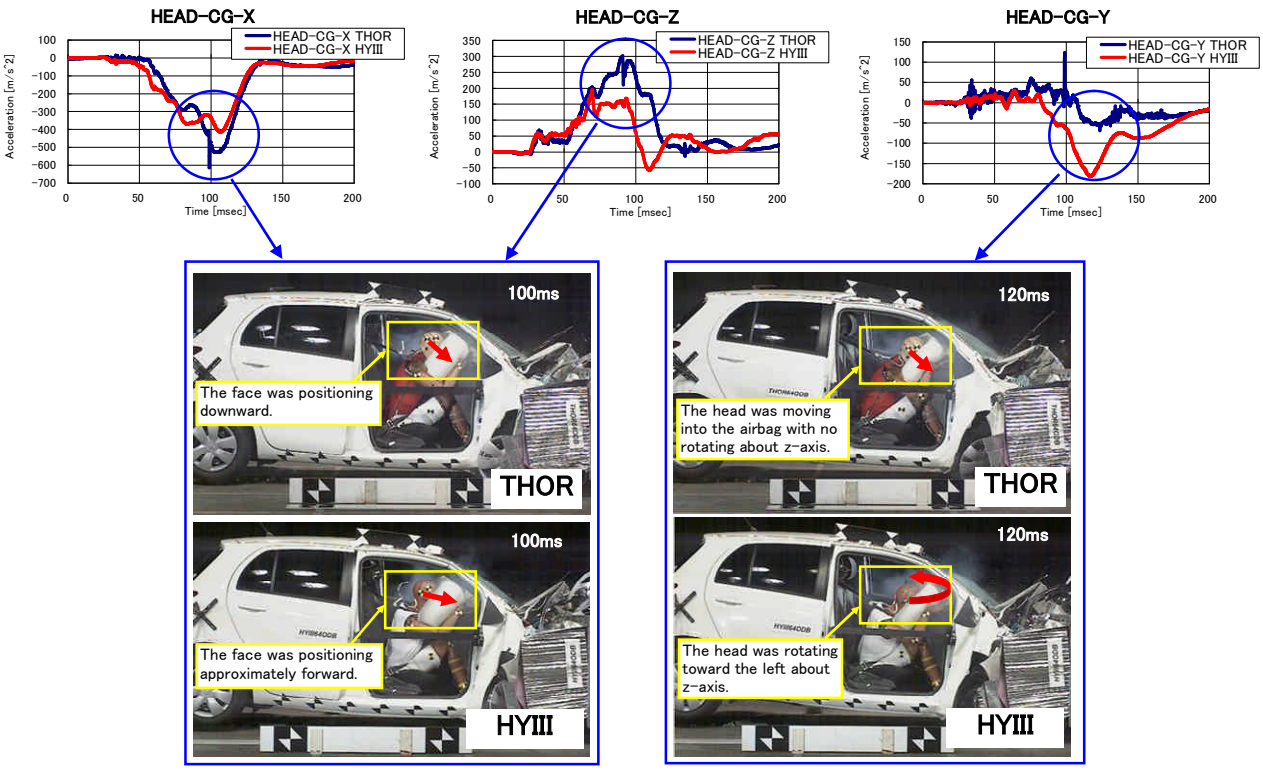

Figure 32. Differences in the Kinematics and Response of the Head

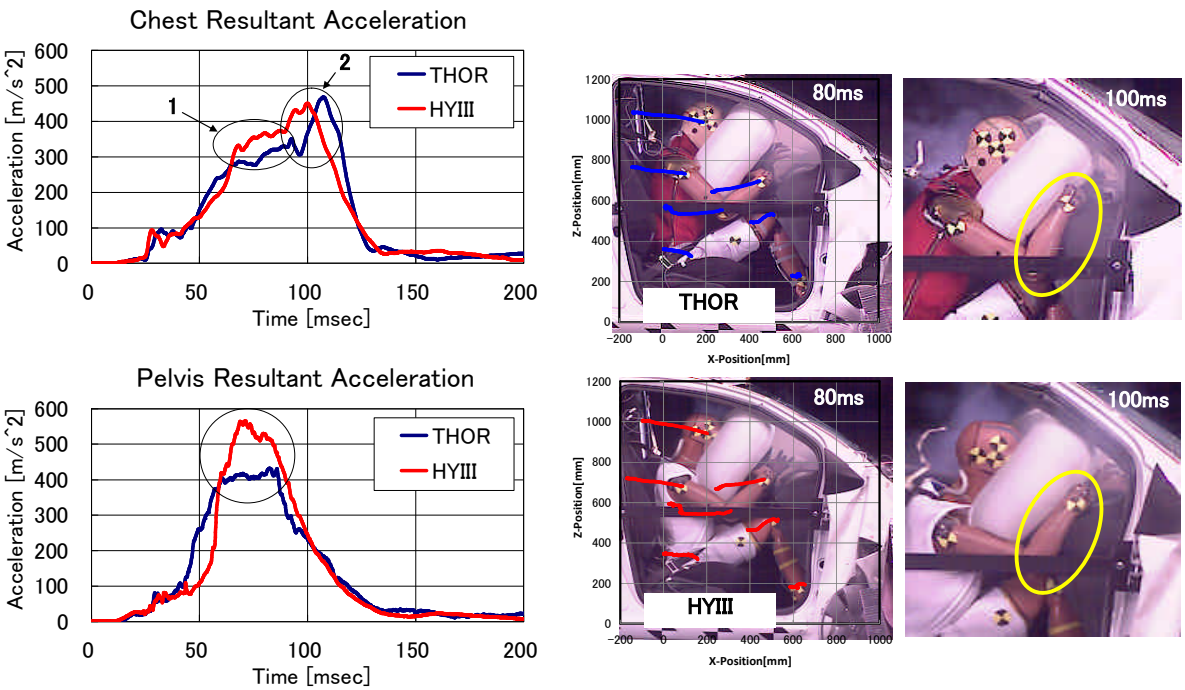

Figure 33. Differences in the Kinematics and Response of the Thorax and Pelvis

The resultant pelvis acceleration in the X and Z-axis and the calculated pelvis acceleration was almost the same. Therefore, it was presumed that two factors of the lap belt force and femur force affected the difference in the resultant pelvis acceleration between the dummies. The cause that the lap belt force and femur force differed between the dummies is as stated above. Therefore, it was presumed that the following factors affected the difference in the resultant pelvis acceleration in the tri-axis of the dummies; i) the lower abdomen of the THOR-NT is softer than the Hybrid III, and ii) the THOR-NT was earlier than the Hybrid III with regard to the timing when the legs contacted to the instrument panel because the THOR-NT has longer upper legs than the Hybrid III.

Equation 1:

$$Pelvis\ Stroke = \iint (a_{Pelvis} - a_{Vehicle})dt$$

where

a_{Pelvis} : *Resultant Pelvis Acc. in the X and Z – Axis*

$a_{Vehicle}$: *Vehicle Acc. in the X – Axis*

Equation 2:

$$Calculated\ Pelvis\ Acceleration = \frac{[Lap\ Belt\ Force + Femur\ Force\ (Total\ of\ the\ Right\ and\ Left)]}{Pelvis\ Mass}$$

where

Pelvis Mass is 22 kg for both THOR – NT and Hybrid III

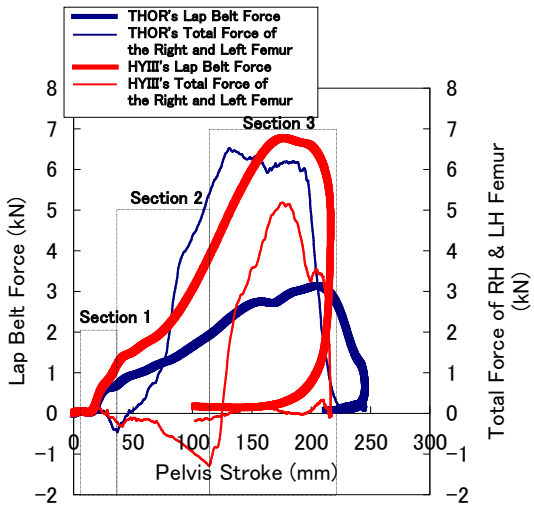

Figure 34. Lap Belt Force and Femur Force vs Pelvis Stroke

Table 5. Cause of the Difference in the Lap Belt Force Relative to the Pelvis Stroke Between the Dummies.

Pelvis Stroke		Factor for affecting the difference in the lap belt force
Section 1	To 39 mm	Difference in the characteristics of the lower abdomen
Section 2	39 mm to 114 mm	↑ + Difference in the timing when the legas contacted to the instrument panel
Section 3	After 114 mm	↑ + Difference in the femur force

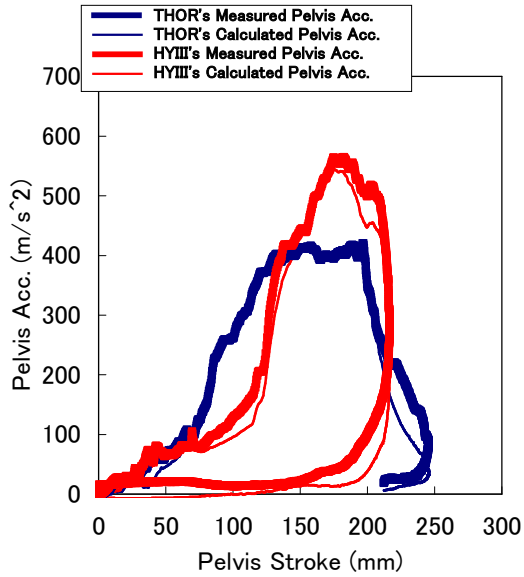

Figure 35. Resultant Pelvis Acceleration in the X and Z-axis and Calculated Pelvis Acceleration vs Pelvis Stroke

CONCLUSIONS

A 64 km/h offset frontal crash test was conducted with the THOR-NT and Hybrid III to investigate the responses of both dummies under a crash situation that includes both deformation and rotational behavior of a vehicle.

Although the THOR-NT and the Hybrid III were respectively installed in the driver seat in accordance with the ECE R94 positioning procedure, their postures were slightly different. The knees of the THOR-NT were positioned more forward and upward than those of the Hybrid III, because the THOR-NT has longer legs than the Hybrid III.

The THOR-NT and Hybrid III showed similar kinematics during the tests, except for the rotation about Z-axis of the head, and the contact situation to the instrument panel of the arms.

It was presumed that the difference in kinematics between both dummies affected the differences in the head, chest, and pelvis acceleration responses of the dummies. The difference in the head acceleration was affected by the different kinematics of the flexion and twist of the head-neck of the dummies caused by the differences in both structure and characteristics of the neck. The difference in the chest acceleration was affected by the differences in the transmissive force from the pelvis in the internal of the dummy, and the contact situation between the arms and the instrument panel. The difference in the pelvis acceleration was affected by the differences in the lap belt force and femur force between both dummies.

With regard to the differences in the lap belt force between the dummies, it was presumed that was because of the following factors; i) the lower abdomen of the THOR-NT is softer than the Hybrid III, and ii) the difference in the femur force between the dummies (The THOR-NT was earlier than the Hybrid III with regard to the timing when the legs contacted to the instrument panel because the THOR-NT has longer upper legs than the Hybrid III).

The injury measures showed almost equivalent values between the dummies, and all injury measures were less than the injury criteria specified in FMVSS 208 and ECE R94.

ACKNOWLEDGMENTS

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APPENDIX

Table A-1. Instrumentations of theTHOR-NT and Hybrid III

		# of channels	
		THOR-NT	Hybrid III
Head	Head accelerometer array	9	9
Neck	Upper neck six-axis load cell	6	6
	Lower neck six-axis load cell	6	-
	Neck compression load cells (front and right)	2	-
	Head rotation potentiometer	1	-
Chest	CRUX chest rotary potentiometers	12	-
	Chest displacement potentiometer (normalized)	-	1
	Chest accelerometer triax	3	3
	Mid sternum uniaxial accelerometer	1	-
Abdomen	Upper abdomen string potentiometer	1	-
	Lower abdominal DGSP transducers (left and right)	6	-
	Upper abdomen uniaxial accelerometer	1	-
Spine	Spine T1 accelerometer triax	3	-
	T12 five-axis load cell	5	-
	Lumbar spine three-axis load cell	-	3
	Spine T12 accelerometer triax	3	-
Pelvis	Acetabular three-axis load cells (left and right)	6	-
	Iliac load cells (left and right)	2	-
	Pelvis accelerometer triax	3	3
Femur	Femur six-axis load cells (left and right)	12	-
	Femur single-axis load cells (left and right)	-	2
Knee	Knee slider potentiometers (left and right)	2	2
	Knee clevis, inside load cells (left and right)	-	2
	Knee clevis, outside load cells (left and right)	-	2
Tibia	Upper tibia five-axis load cells (left and right)	10	-
	Lower tibia five-axis load cells (left and right)	10	-
	Upper tibia four-axis load cells (left and right)	-	8
	Lower tibia four-axis load cells (left and right)	-	8
	Tibia x-axis uniaxial accelerometers (left and right)	2	-
	Tibia y-axis uniaxial accelerometers (left and right)	2	-
Ankle	Ankle rotary potentiometers (left and right)	6	-
Foot	Foot accelerometer triaxes (left and right)	6	-
Total		120	49