Comparison of Biofidelic Responses to Rear Impact of the Head/Neck/Torso among Human Volunteers, PMHS, and Dummies

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ABSTRACT

Several methods of rear impact test to reduce neck injuries in rear-end real world collisions have been suggested so far. One typical test method is a dynamic test similar to actual low-speed rear impacts.

This study aims to evaluate the biofidelity of BioRID-II, RID 2, Hybrid-III, Thor-NT, and Thor-FT dummies on the basis of the responses of head/neck/torso in order to identify the most suitable dummy for the dynamic test simulating low-speed rear impacts. Currently Hybrid-III developed for high-speed frontal impacts is a candidate for the low-speed rear impact test. Also, Thor-NT and Thor-FT are the next generation frontal impact dummies. Therefore, the evaluation on the potentials of Thor-NT and Thor-FT as dummies for low-speed rear impact tests is also included.

Two series of tests were conducted in order to evaluate the biofidelity of the dummies. One, a Mini-Sled Test simulating low-speed rear impacts, was conducted at a low acceleration level with an impact velocity of 8 km/h in order to avoid the risk of injury to human volunteers. The other was a Back Impact Test to identify dummy responses at higher impact level than that of the Mini-Sled Test.

If dummy characteristics differ, it is likely that even if tests are carried out under the same conditions, the impact responses would vary and the evaluation results would differ. Therefore, a HYGE Sled Test was conducted in order to clarify the response differences of the five types of dummies in the dynamic test that was proposed to evaluate car seats. From the test results, the response differences of the five types of dummies were clearly observed.

As for the low-speed rear impact, the responses of BioRID-II were the most similar to those of both human volunteers and PMHS (Post Mortem Human Subjects). Biofidelity of RID 2 was not so good compared to BioRID-II. On the other hand, biofidelity of Hybrid-III was relatively poor and biofidelity of the two Thor dummies were almost the same as that of the Hybrid-III. It is concluded that among the five dummies, BioRID-II is the most suitable for the evaluation of low-speed rear impacts.

Keywords: REAR IMPACT, BIOFIDELITY, MINI SLED, BACK IMPACT, HYGE SLED

THE NUMBER OF NECK INJURIES has recently been increasing in low-speed rear-end real world collisions. The majority of these injuries correspond to AIS 1 or 2, soft tissue injuries. This situation is common not only in Japan, but in all regions of the world. Therefore, the effort to formulate the test procedures to reduce neck injuries is ongoing under cooperation of multiple countries of the world.

The test procedures under discussion fall into two categories. One is a static test for the evaluation of the distance between a head and a head restraint, which is called "backset". The other is a dynamic test similar to actual low-speed rear impacts (ISO 2005, NHTSA 2004b, IIWPG 2004a). The conditions of the dynamic test correspond to ΔV of 15 to 17 km/h and accelerations of 8 to 10 G. There are differences in both ΔV and acceleration (level and shape) of a sled in the test procedures which each institutes and organizations have specified.

In addition, the type of the dummies used in the dynamic test differs according to the test procedure of respective institute and an organization to evaluate seat design. BioRID-II, RID 2, and Hybrid-III are currently suggested as suitable test candidates. The physique of the dummies is similar, but their structures and characteristics are designed on the basis of different biomechanical data. Thus, these dummies may exhibit different responses even under the same impact conditions.

Many studies on the comparison of the responses of these dummies in low-speed rear impacts have been conducted. Kim et al. (2001) reported on the issues of axial neck force and seated posture of BioRID-II based on the results of the low-speed rear impact tests using BioRID-II and Hybrid-III. Cappon et al. (2001) concluded that the responses of RID 2 head-neck system were better than those of

Hybrid-III, compared with the results of human volunteer and PMHS (Post Mortem Human Subjects) tests. Philippens et al. (2002) compared two types of rear impact dummies (BioRID-II and RID 2) and Hybrid-III responses in the tests conducted under the same test conditions as the original tests on the development and validation of the rear impact dummies and reported the performances of rear impact dummies and Hybrid-III compared with those of human responses.

In this study, we evaluated the biofidelity of five types of dummies in order to identify the most suitable dummy for use in low-speed rear impact tests. Unlike other studies, this study evaluated the biofidelity of five different types of dummies, including not only BioRID-II and RID 2 developed for low-speed rear impacts, but also Hybrid-III, Thor-NT and Thor-FT developed for high-speed frontal impacts. Although this study evaluated the biofidelity of the dummies in low-speed rear impacts, Hybrid-III was originally developed to validate the high-speed frontal impact requirements to protect occupants regulated in FMVSS No. 208 (Federal Motor Vehicle Safety Standard No. 208, Occupant Crash Protection). Also, Thor-NT and Thor-FT were developed as the next generation frontal impact dummies. However, Hybrid-III is currently a candidate used in low-speed rear impact tests. Thus, this study evaluated not only the biofidelity of BioRID-II, RID 2 and Hybrid-III suggested as candidates used in low-speed rear impact tests, but also the biofidelity of Thor-NT and Thor-FT in order to verify a potential regarding whether Thor dummies are available for use in low-speed rear impact tests.

In this biofidelity evaluation, the dummies' responses were compared with the responses of human volunteers on the volunteer tests performed by Ono et al. (1999). The dummies' responses were also compared with the responses of human subjects in the back impact tests conducted with PMHS reported by Viano et al. (2001). In addition, the dynamic test (HYGE Sled Test) was also carried out in order to clarify the differences in response between the dummies.

This paper would provide useful reference data for selecting a suitable rear impact dummy.

METHODS AND MATERIALS

DUMMIES EVALUATED IN THIS STUDY: The dummies evaluated in this study were Hybrid-III, BioRID-II, RID 2, Thor-NT, and Thor-FT (Figure 1). BioRID-II and RID 2 were developed for low-speed rear impacts. BioRID-II has a segmented spinal structure consists of the same number of vertebrae as that of a human, i.e. 7 cervical, 12 thoracic and 5 lumbar vertebrae. The thoracic spine has a kyphosis and the lumbar spine is straight as the human in seated posture (Davidsson 1999a). RID 2 basically has a rigid spinal structure, but it also has flexible elements in the thoracic and lumbar regions and a fully flexible neck design (Cappon et al. 2001, Philippens et al. 2002).

Hybrid-III, Thor-NT and Thor-FT were developed for high-speed frontal impacts. Hybrid-III basically has a rigid spinal structure except for the lumbar spine (Foster et al. 1977). Thor-NT and Thor-FT have spinal structures similar to those of Hybrid-III, but these dummies have flexible elements in the thoracic and lumbar regions (NHTSA/GESAC, Inc. 2005, Onda et al. 2006). Their development was based mainly on PMHS, and the neck was developed on the basis of flexion characteristics acquired from both human volunteers and PMHS (Mertz et al. 1971, Culver et al. 1972, Foster et al. 1977, GESAC, Inc. 2005).

Note: The structure and measurement requirements of a dummy for rear impact tests were set as follows:

- Having a physique of 50th percentile of adult males and having a human-like seating posture.
- The behavior of head, neck and torso and interaction between the spine and the seat back/seat cushion must be similar to those of humans, i.e. having an excellent biofidelity.
- Able to measure the proposed injury criteria.

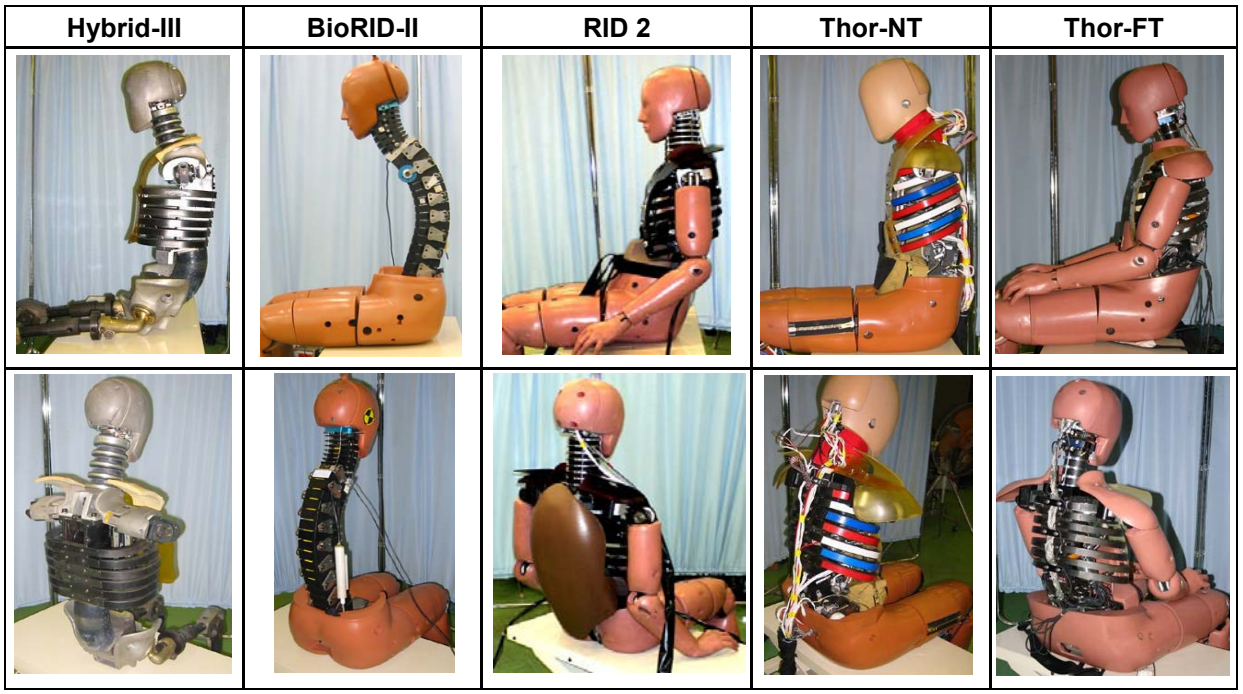


Figure 1. Candidate dummies for low-speed rear impact tests

BIOFIDELITY EVALUATION TESTS: In order to identify the most suitable dummy for low-speed rear impacts, the biofidelity of five types of dummies was evaluated. BioRID-II is specified in the protocol for dynamic tests of the IIWPG (International Insurance Whiplash Prevention Group). Hybrid-III is stipulated as the dummy for use in test procedure of FMVSS No.202a (NHTSA 2004b) regulated by NHTSA (National Highway Traffic Safety Administration). The requirements of FMVSS No. 202a add the dynamic test requirements of low-speed rear impacts to the geometric requirements of FMVSS No. 202 (Head Restraints) (NHTSA 2004a). In the ISO/TS22/SC12/WG5, BioRID-II, RID 2, and Hybrid-III are stipulated as candidate dummies for use in low-speed rear impact tests. Although Thor-NT and Thor-FT have not been considered as candidates for low-speed rear impact tests, they are next generation dummies that may replace Hybrid-III as the standard frontal impact dummies.

The biomechanical data of this study were obtained from the following experiments:

(1) Mini-Sled Test: Experiments on human volunteers using a mini-sled for simulating low-speed rear impacts (Ono et al. 1999, Davidsson et al. 1999b, 1999c).
(2) Back Impact Test: Experiments on the impacts to the back using PMHS (Viano et al. 2001).

Mini-Sled Test - Since the Mini-Sled Test simulated low-speed rear impacts and was conducted with human volunteers, it was performed at the level of impact condition that does not cause injuries (impact velocity: 8 km/h). The experiments were conducted without head restraints so that the volunteers were exposed to a head/neck inertia impact. The mini-sled apparatus simulates low-speed rear impacts by attaching the sled to a slope with an inclination angle of 10 degrees and allowing the mini-sled to slide freely from a constant height (Ono et al. 1999, Davidsson et al. 1999b, 1999c) (Figure 2). Since the objective of this study was to evaluate the inherent impact response of the dummies, rigid seats made of wood were used to prevent seat characteristics from influencing the dummies' impact response.

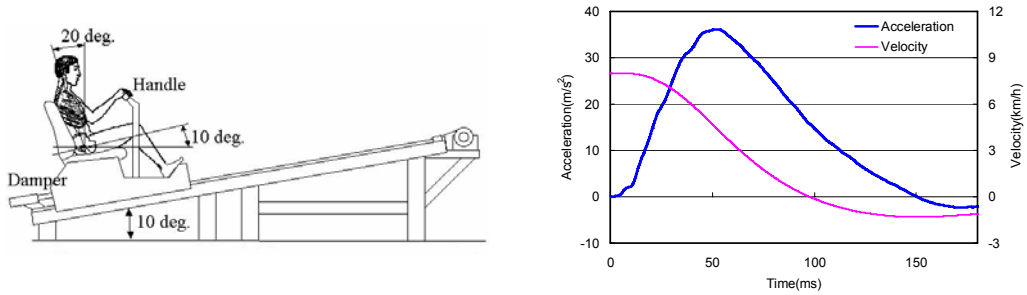


Figure 2. The mini-sled apparatus for simulating low-speed rear impacts, the acceleration and velocity conditions

Back Impact Test - In the Mini-Sled Test, the biofidelity of the dummies were validated at low impact levels in which human volunteers were not injured. In evaluating the biofidelity of dummies, it is also necessary to validate it at higher impact levels. Since experiments using human volunteers are impossible at this level, experimental data from PMHS were applied. In order to obtain a dynamic response with the dummies, this study referred to the impact experiments on the backs of PMHS (Viano et al. 2001, Linder et al. 2002) and assigned equivalent impacts. An impactor with a mass of 23 kg and a diameter of 152 mm was used in the back impact tests to the seated PMHS, and the test impact velocities were 4.6 m/s and 6.6 m/s. The impact positions were at T1 (the first thoracic spine) and at T6 (sixth thoracic spine), but this study was limited at an impact position to T6 and at a velocity of 4.6 m/s. The reason for this limitation is that due to the posture and the position of the dummy, it was difficult to apply the impact to T1. If attempted, the lower edge of the impactor might have come into contact with the T1 accelerometer and damaged it. With regard to the impact speed, since the dummies' backs are metal skeletons covered with skin, there was a risk of damage at higher speeds. Therefore, it was decided to conduct the tests at 4.6 m/s only.

Figure 3 shows the setup of the Back Impact Test. In the condition similar to the PMHS experiments conducted by Viano et al., the dummies were seated on a flat and rigid surface and positioned so that the spine was in a vertical position. The lower legs were bent to form a right angle at the knee joint and the feet were placed on the floor. The dummies were clothed in the standard pants of BioRID-II: low friction synthetic fiber pants made of Lycra.

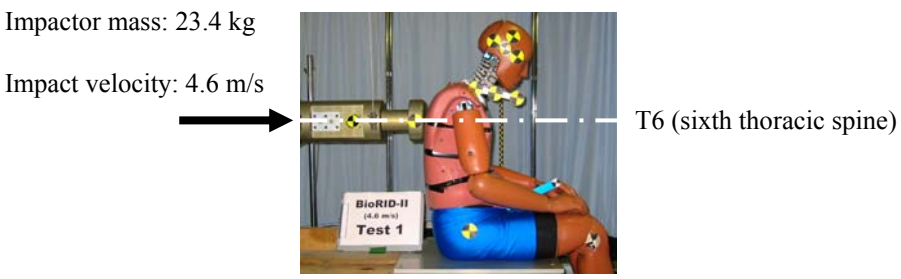


Figure 3. Setup of the Back Impact Test

HYGE SLED TEST: If characteristics of the dummies differ, it is likely that impact responses would vary and evaluation results would differ even if the tests are carried out under the same conditions. Therefore, this study carried out the dynamic test using a HYGE sled apparatus in order to clarify the difference in responses among the five types of dummies. At present, the dynamic test procedures for low-speed rear impacts of GTR (Global Technical Regulations) - Head Restraints and International Standard - ISO 17373 (2005) are under discussion. In addition, there exist dynamic test procedures regulated by FMVSS No. 202a, and specified in the protocol of IIWPG. However, when we carried out the dynamic tests in this study, there was still no discussion on GTR in any countries in the world. Furthermore, since our test apparatus was limited in generating acceleration pulses in accordance with

FMVSS No. 202a and the protocol of IIWPG, the dynamic test was restricted to the test conditions in ISO/TC22/SC10/WG1 N554 - ISO/CD 17373 (2003).

In the dynamic test with the HYGE sled apparatus in this study, the rearward inclination of head, the acceleration responses of head and T1, the force response of neck and the criteria for neck injury which discussed in ISO/TC22/SC12/WG6 were compared between five types of dummies. The test conditions were ΔV = 15 km/h with a sled acceleration of 75 m/s^2 (Figure 4). Furthermore, the test seats used were the front seats of a passenger car with an inactive head restraint.

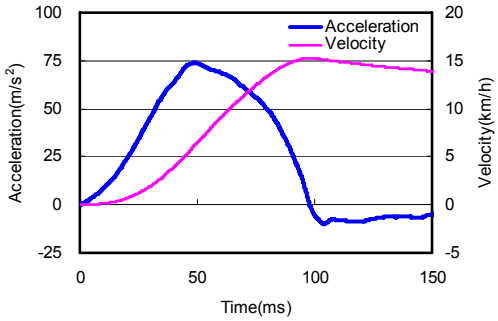


Figure 4. Acceleration and velocity of the HYGE sled

DATA ANALYSIS: In each of the three test series, the motion of the head/neck/torso during low-speed rear impacts was recorded with a high-speed video camera.

In the Mini-Sled Test, changes in the head rotation angle to T1 and changes in the distance between T1 and hip-point were analyzed. In the Back Impact Test, the vertical and horizontal displacement of the head to T1 and changes in the head rotation angle to T1 were analyzed. In the HYGE Sled Test, the extension angle of the head to the torso was analyzed. Additionally, in the HYGE sled test, the accelerations of head C.G. and T1 and the load/moment of upper neck were measured, and the neck injury criteria (NIC, Nkm) which be still discussed in ISO/TC22/SC12/WG6 were calculated.

RESULTS

BIOFIDELITY EVALUATION TESTS: The biofidelity of five types of dummies was evaluated by comparing the results with those of the Mini-Sled Tests on human volunteers and the Back Impact Tests on PMHS.

Mini-Sled Test – The left side graph shown in Figure 5 plots the time history of the head rotation angle (HA-TA) with respect to T1 (the first thoracic spine) of the dummies and the human volunteers' corridor. The corridor was derived from the average value and standard deviation (the upper bound and the lower bound) of seven volunteers' responses (Ave.±S.D) (Ono et al. 1999, Davidsson et al. 1999).

As for the head rotational angle with respect to T1 of human volunteers, the neck flexed slightly until nearly 100 ms during the initial impact (plus side) and then extends (minus side). Furthermore, the maximum extension of the neck of human volunteers occurred after 250 ms.

The flexion of BioRID-II's neck occurred in the same manner as that of the human volunteers, and the maximum value of the flexion came at 100 ms. After this, the neck of BioRID-II shifted to extension mode. The maximum value of extension was about 31 degrees.

RID 2 did not exhibit the same flexion behavior of the neck at the initial impact as did the human volunteers and BioRID-II: extension occurred from 80 ms. The maximum head angle at the time of extension was 54 degrees, a result that was outside the human volunteers' corridor. In comparison with human volunteers and the other dummies, the head rotation angle of RID 2 was larger; evidence of having flexible neck characteristics.

Hybrid-III, Thor-NT, and Thor-FT exhibited similar behavior, showing no flexion behavior of the neck at the initial impact. Compared with human volunteers, the extension of the three dummies shifted very early – at approximately 70 ms, and the maximum head angle at extension was also small – around 25 to 30 degrees. Furthermore, the time of maximum neck extension for the three dummies reached at 150 ms. At 250 ms, when the neck of the human volunteers reached the maximum extension, these dummies had already returned to the initial state.

The right side graph shown in Figure 5 plots the change in distance between T1 and the hip point (T1-HP) of the dummies and the human volunteers' corridor. The change in distance between T1 and the hip point (human volunteers: iliac crest) shows a straightened spine caused by a press from the seatback. The average change in distance of the human volunteers was 27±8 mm at the most.

The change in distance between T1 and the hip point of BioRID-II was close to the upper limit of the human volunteers' corridor, but was within the human volunteers' corridor throughout the impact.

In RID 2, this distance was close to the lower limit of the human volunteers' corridor, but was somewhat outside the corridor after 150 ms.

In Hybrid-III, Thor-NT and Thor-FT, there was little change in the distance between T1 and the hip point. Even at maximum, it was only about 12 mm in Thor-FT.

Hybrid-III basically has a rigid spinal structure, except for the lumbar spine. RID 2, Thor-NT and Thor-FT have spine structures similar to those of Hybrid-III, but have flexible elements in both the thoracic and lumbar regions.

Only BioRID-II has a segmented spine structure. Its spine consists of the same number of vertebrae as that of a human, i.e., 7 cervical, 12 thoracic and 5 lumbar vertebrae. The thoracic spine has a kyphosis and the lumbar spine is straight as the human in the seated position. Therefore, it can be said that the straightening between T1 and hip point of BioRID-II occurred well by such a spine structure.

The other results of the dummies' responses in the Mini-Sled Test are shown in APPENDIX A.

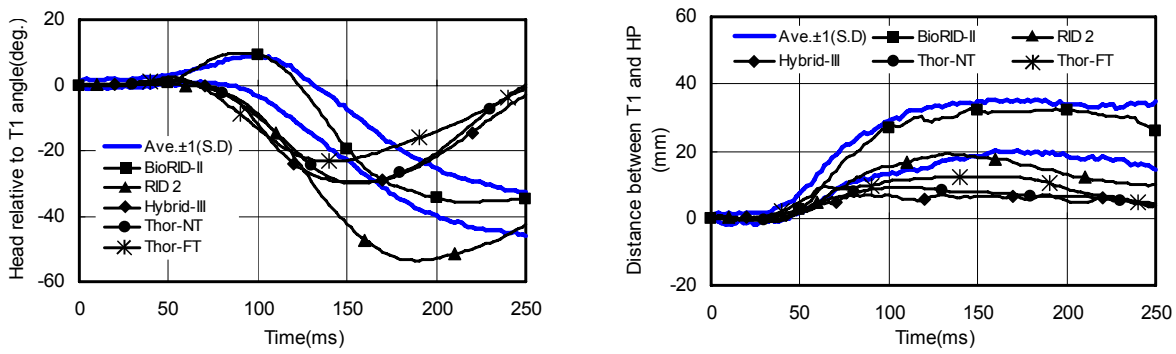


Figure 5. The responses of five types of dummies to the corridor of human volunteers in the Mini-Sled Test

Back Impact Test - The upper two graphs shown in Figure 6 plot the horizontal and vertical displacement of the head with respect to T1 of the dummies. In the lower two graphs, the left side plots the head rotation angle with respect to T1 of the dummies, while the right side plots the responses of impact force to the backs of the dummies. The corridors derived from responses of PMHS are also plotted in these graphs.

The horizontal displacement of the heads of BioRID-II and RID 2 were within the PMHS corridor, while those of Hybrid-III, Thor-NT and Thor-FT were outside the corridor after around 70 ms. When behavior is compared at 100 ms, the necks of PMHS, BioRID-II and RID 2 extended, while the necks of Hybrid-III, Thor-NT and Thor-FT shifted to flexion. As for the vertical displacement of the heads of these dummies, BioRID-II, RID 2 and Thor-NT were within the PMHS corridor, while Hybrid-III was outside the corridor after around 100 ms, and Thor-FT was outside the corridor after around 120 ms.

Hybrid-III and Thor-FT exhibited larger downward displacement at 100 ms since their neck flexed forward.

As for the head rotation angle with respect to T1, BioRID-II indicated the highest similarity to the responses of the PMHS, followed by RID 2. The heads of PMHS, BioRID-II and RID 2 maintained the rearward inclined state with respect to T1 until after 150 ms, while the heads of Hybrid-III, Thor-NT and Thor FT were already in the forward inclined state at 120 ms. The head rotational angle to T1 clearly represents the different responses of the necks. Since the necks of Hybrid-III, Thor-NT and Thor-FT are stiffer, these necks exhibited little rotation. Therefore, these necks returned to the initial state faster after impact.

The peak values of the impact forces in Hybrid-III and Thor-FT were the highest, exceeding 11 kN. RID 2 had 9.6 kN, Thor-NT had 8.9 kN, and BioRID-II had the lowest at 6.3 kN. Compared with the responses of PMHS, these values were considerably higher. The upper limit value for PMHS was around 4 kN, which is 1.5 times the load of BioRID-II with the lowest impact force value. Thus, it is indicated that the back characteristics of all the dummies were stiffer compared with those of PMHS.

The other results of the dummies' responses to PMHS's responses are shown in APPENDIX B.

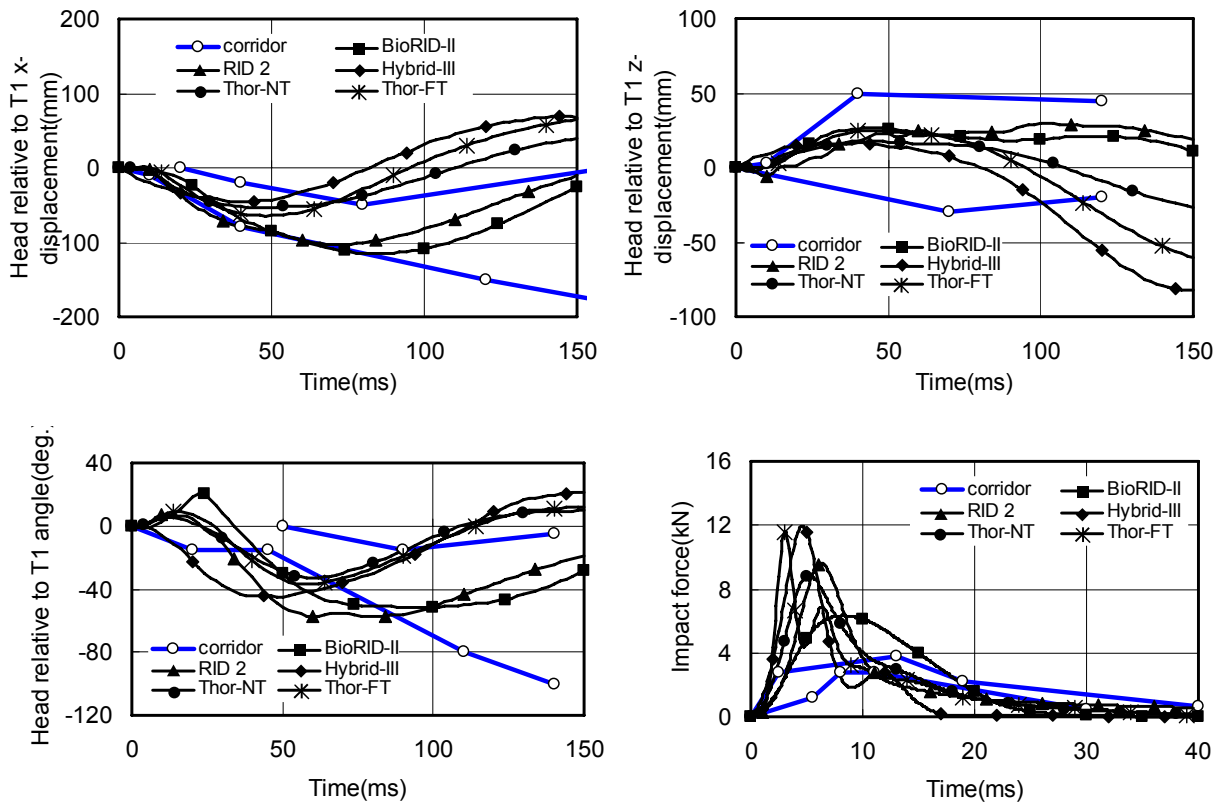
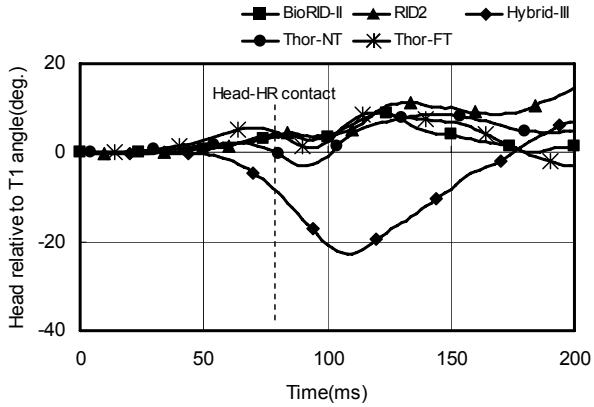
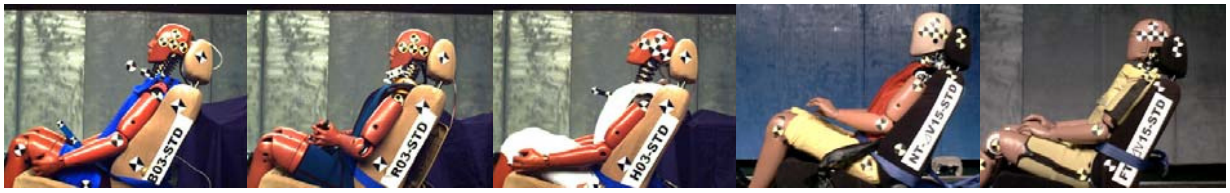


Figure 6. The responses of five types of dummies to the corridor of PMHS in the Back Impact Test

HYGE SLED TEST: This section states the results analyzed from the extension angle of the head of the five dummies against the torso. It also describes the following results: the accelerations of the head's C.G. and T1, the load/moment of the upper neck of the dummies, and the neck injury criteria (NIC, Nkm) which will be discussed in ISO/TC22/SC12/WG6.

Figure 7 plots the rearward inclined angle of the head to T1 of the dummies. The head of Hybrid-III was already inclined backward at the instant contact with the head restraint; conversely, the heads of the other dummies slightly inclined forward. This result clearly shows the differences in neck behavior. Thus, if the rearward inclined angle of the head is used as an injury criterion, the evaluation results will be different, depending on the dummy used.





BioRID-II RID 2 Hybrid-III Thor-NT Thor-FT

Figure 7. Head rearward inclination angle relative to T1

Figure 8 compares the results measured on the main body regions of the dummies with the results calculated against the injury criteria of the necks in the five types of dummies. In all the dummies, the heads' C.G. acceleration ranged from 200 to 250 m/s^2, which could be viewed as substantially close. The T1 acceleration values ranged from 90 to 120 m/s^2 in all the dummies. Therefore, all five types of dummies exhibited similar results.

When the shear forces on the neck in the plus direction were compared, Hybrid-III exhibited the highest value, while the other dummies exhibited almost equal values. The maximum value of the shear force in the minus direction occurred when rebounding (at rebound from a seat). In measuring the tensile forces, BioRID-II exhibited the highest value, while Hybrid-III, which exhibited the highest value in shear force, had the second lowest value after RID 2.

From these results, it can be maintained that the force response compared with the acceleration response differs greatly, depending on the dummy used.

In the evaluation of NIC (neck injury criteria based on the horizontal relative acceleration and the horizontal relative speed between the head and T1), which is under discussion as injury criteria of the neck (Boström et al. 1996), Hybrid-III and Thor-FT exhibited low values, while RID 2 exhibited the highest value. In the evaluation of Nkm (neck injury criteria based on the hypothesis that a combination of the neck shear force and the flexion/extension moment should be considered), which is also under discussion as injury criteria of the neck, (Schmitt et al. 2001), Hybrid-III exhibited the highest values both in Nfa (moment > 0 - flexion, shear force > 0 - head rearward and chest forward) and in Nep (moment < 0 - extension, shear force < 0 - head forward and chest rearward). As for Nep, the highest values in all the dummies were recorded when rebounding. In Thor-FT, the moment was not measured due to the defect in a sensor, making it impossible to calculate Nkm.

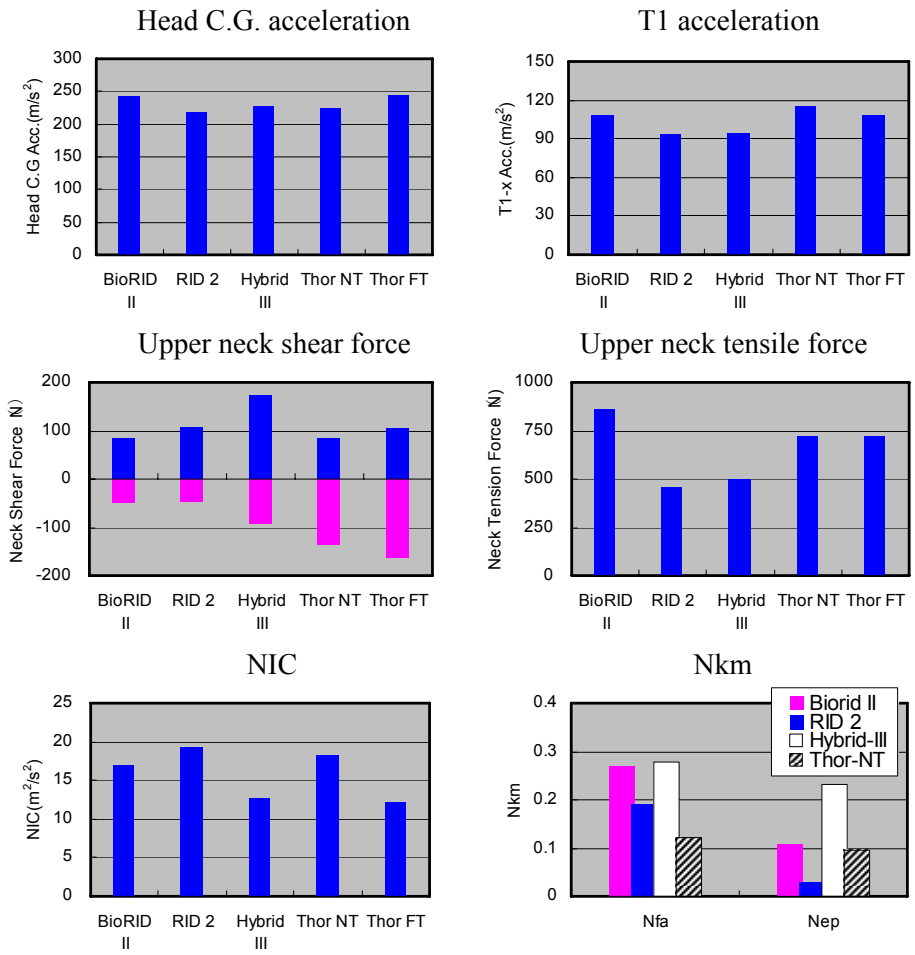


Figure 8. The measurement on the main body regions of dummies and the calculated injury criteria

DISCUSSION

THE RELATIONSHIP BETWEEN DUMMY IMPACT RESPONSE AND AN EVALUATION OF INJURY CRITERIA: This study evaluated the biofidelity of the five types of dummies by comparing the dummies' responses with the responses of human volunteers on the volunteer tests performed by Ono et al. (1999). BioRID-II was based on and validated against human volunteer tests performed by Davidsson et al. (1999) and Ono et al. (1999). That will make it easy for BioRID-II to comply with the human volunteer responses in the Mini-Sled Tests. However, compared with the human responses in the Back Impact Tests conducted on PMHS and reported by Viano et al. (2001), BioRID-II also exhibited similar but better responses than PMHS's responses. If more effective responses of the dummies are evaluated, these responses should be compared with various biomechanical data. It is expected that various biomechanical data for low-speed rear impacts will be collected and become available worldwide.

In analyzing the results of the HYGE Sled Test, the differences in peak force values on the neck can be identified as different responses among the five types of dummies. In the rating of the IIWPG, comprised of international insurance groups, the results of the peak force on the neck exert an influence on their final rating since the peak force on the neck is one of the criteria being evaluated. Results of this study were applied to the IIWPG rating (IIWPG 2004b) as are shown in Figure 9. All the dummies, except for RID 2, were in the same moderate neck force zone, and there was a significant difference in the values when Hybrid-III and BioRID-II were compared. In addition, only RID 2 was in the low neck

force zone. Thus, even if tests are carried out under the same conditions, evaluation results differ, depending on the dummy used. If the dummy used for evaluating dynamic responses is different from the dummy used for the development of the seat system, it is likely that discrepancies will occur in the evaluation results.

The requirements of FMVSS No. 202a added dynamic tests to FMVSS No.202 (Head Restraints). This requires that the rearward inclination angle of the head to the torso does not exceed 12 degrees. Among the five dummies, only Hybrid-III exhibited an angle of rearward head inclination of up to 23 degrees (Figure 7). As for the other dummies, the heads were inclined slightly forward, clearly showing that the head behavior of the dummies differed. However, as for the neck rotation angle with respect to torso (T1), Hybrid-III exhibited a rotational angle greater than the other dummies, but all the dummies exhibited extension behavior (the left side graph in Figure 10). As for the T1 rotation angle with respect to seatback, only Hybrid-III exhibited slightly forward inclining angle at 50 to 120 ms (the right side graph in Figure 10).

The differences of the head/neck/torso behavior between Hybrid-III and the other dummies are stated on the behavior at 110 to 120 ms. This occurred when the rotational angle of the head/neck to T1 was at maximum (Figure 11). In the interaction between the dummy's back and the seatback, the back of Hybrid-III was pushed into the seatback from the rear without rotating. Only Hybrid-III head/neck inclines rearward due to inertia. In all the dummies except Hybrid-III, their back was pushed into the seatback from the rear while it was inclined rearward, and the neck also extended along with this. However, the neck showed an S-shape, since the head moved to the rear almost without rotating.

These differences in rotational behavior of the back in relation to the seatback are believed to be caused by the differences in the spinal structures and ribcage shapes of the dummies. BioRID-II has a flexible spine structure, which is covered by a thick urethane skin. RID 2, Thor-NT, and Thor-FT are equipped with flexible thorax/lumbar joints and have ribcages connected by arrangement close to humans. The thoracic spine of Hybrid-III is rigid and the ribcage is connected vertically to the thoracic spine. Due to these differences in structure, it is believed that the dummies, except Hybrid-III with its combination of a more flexible spine and ribcage design close to humans, have an easier rearward inclination of the back against the seatback because pushing the back into the seatback is easier. On the other hand, as for Hybrid-III, it is believed that the back is difficult to incline rearward against the seatback since pushing the back into the seatback is harder due to structural differences from the other dummies.

The structures and characteristics of the dummies mentioned as candidates for low speed rear impact have been designed on the basis of different biomechanical data. In addition, the biomechanical data used for determining the characteristics of the structures and for each part differ. Therefore, determining injury criteria from a particular type of dummy and evaluating the same criteria using another dummy, would definitely cause discrepancies in the results.

Therefore, it is important to design a harmonized dummy suitable for low-speed rear impacts. Furthermore, if the dummy used has a high biofidelity and exhibits a response close to that of the injury mechanism of the human body, more effective injury criteria could probably be derived.

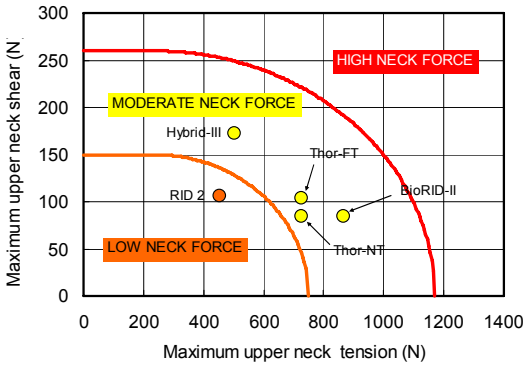


Figure 9. The IIWPG rating for upper neck forces

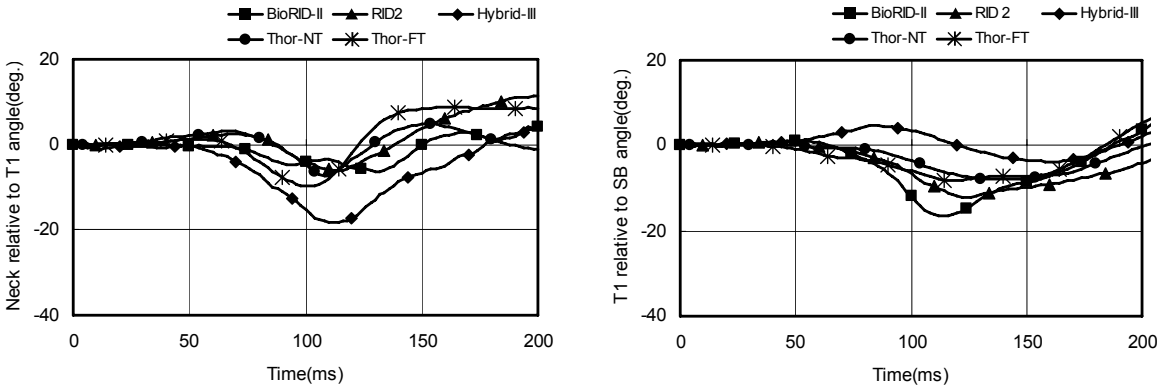


Figure 10. Neck-T1 relative angle and T1-seatback relative angle

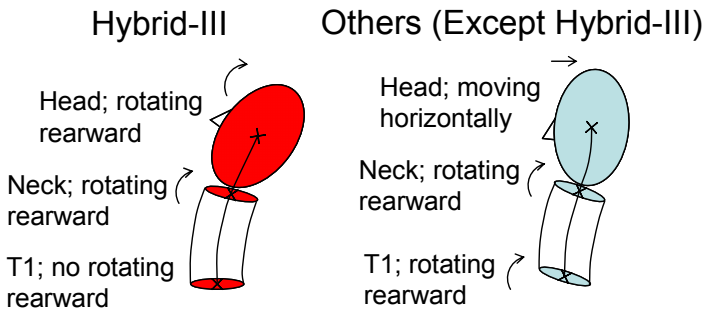


Figure 11. Difference in the behavior of the heads/necks/torsos between Hybrid-III and others at 110 – 120 ms

CONCLUSION

This study has evaluated the biofidelity of the five types of dummies from the viewpoint of head/neck/torso behavior. The evaluation on the potentials of Thor-NT and Thor-FT as dummies for low-speed rear impact tests is also included.

The Mini-Sled Test that simulates low-speed rear impacts was conducted without head restraints, where the dummies were exposed to a head/neck inertia impact. Namely, the results of the Mini-Sled Tests indicate the inherent impact response of the dummies since there was no interaction with a head restraint.

BioRID-II was the most similar to human volunteers and PMHS in terms of its response to low-speed rear impacts. Biofidelity of the RID 2 was not so good compared to the BioRID-II. The biofidelity of Hybrid-III for frontal impact was relatively poor and the biofidelity of the two Thor dummies were almost the same as that of the Hybrid-III.

Furthermore, based on the HYGE sled test, it was found that even if tests were carried out under the same conditions, the responses of the dummies differ, depending on the type of dummy used. Thus, it is preferable that injury criteria be determined by parameters measurable by a dummy with superior biofidelity based on the injury mechanism of human bodies and that the evaluation be conducted using the same dummy. For this reason, we believe that a rear impact evaluation dummy that satisfies these conditions is required and it is important to design a harmonized dummy suitable for low speed rear impact evaluations. In addition, if the dummy used has a high biofidelity and exhibits a response close to that of the injury mechanism of the human body, more effective injury criteria could probably be derived.

Currently, discussions on the injury criteria and mechanism of human bodies in rear impacts are still underway. Therefore, the current dummy selection should consider rear impact responses that are closely similar to those of human volunteers and PMHS. In line with this, based on our study on the behavior during impact, we conclude that BioRID-II is the most suitable dummy for the evaluation of low speed rear impacts.

However, human volunteers and PMHS test data, serving as the basis for evaluating the biofidelity of rear impact dummies, are very limited and the injury mechanism remains to be clarified. Therefore, it is necessary to obtain data for the evaluation of biofidelity and to elucidate the injury mechanism. With regard to the elucidation of the injury mechanism, it is deemed that analysis using computer simulation is necessary. However, the important point will be to find data on biomechanical tissue characteristics required for constructing simulation models. In the future, we think that it is necessary to promote further joint international research projects in order to attain this goal.

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APPENDIX A

The following are other responses of the dummies in the Mini-Sled Test.

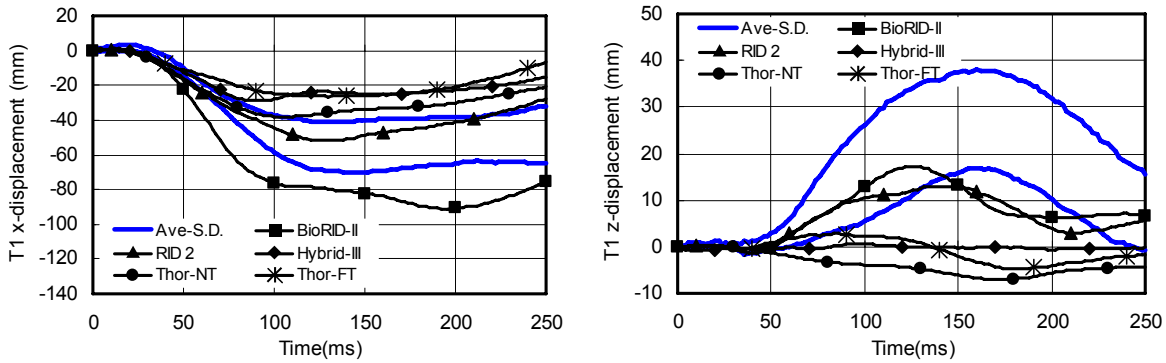

Figure A-1. X and Z displacements of T1

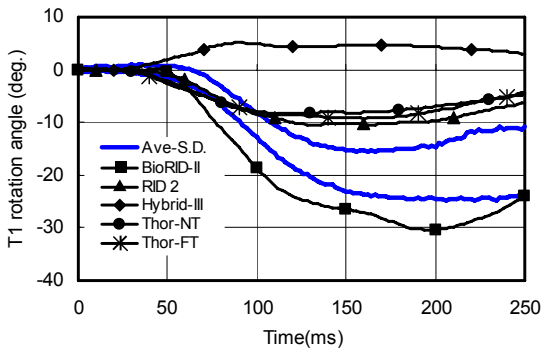

Figure A-2. T1 rotation angle

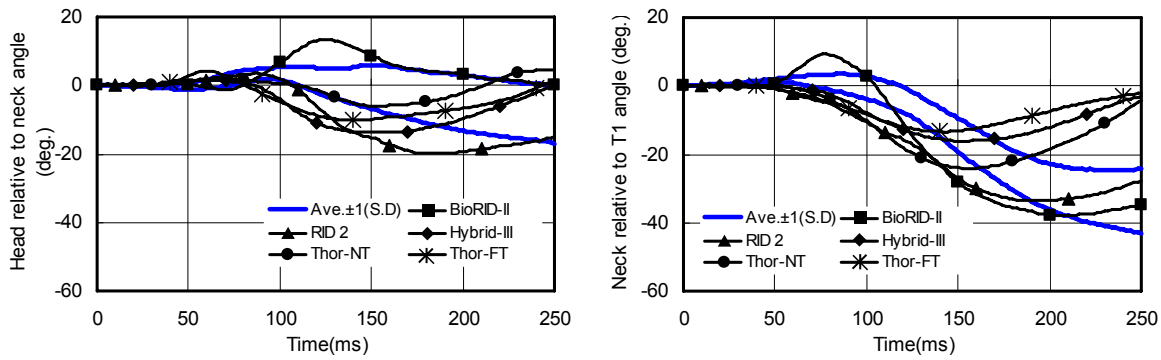

Figure A-3. Head-Neck relative angle and Neck-T1 relative angle

APPENDIX B

The following are other responses of the dummies in the Back Impact Test.

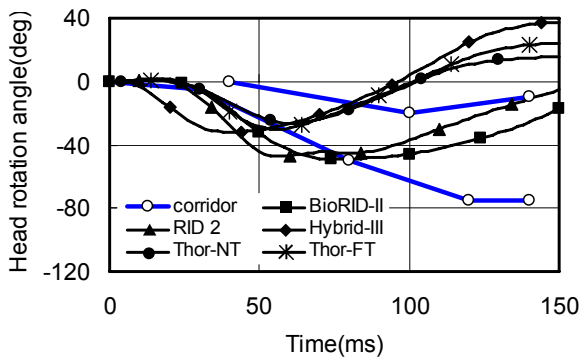

Figure B-1. Head rotation angle

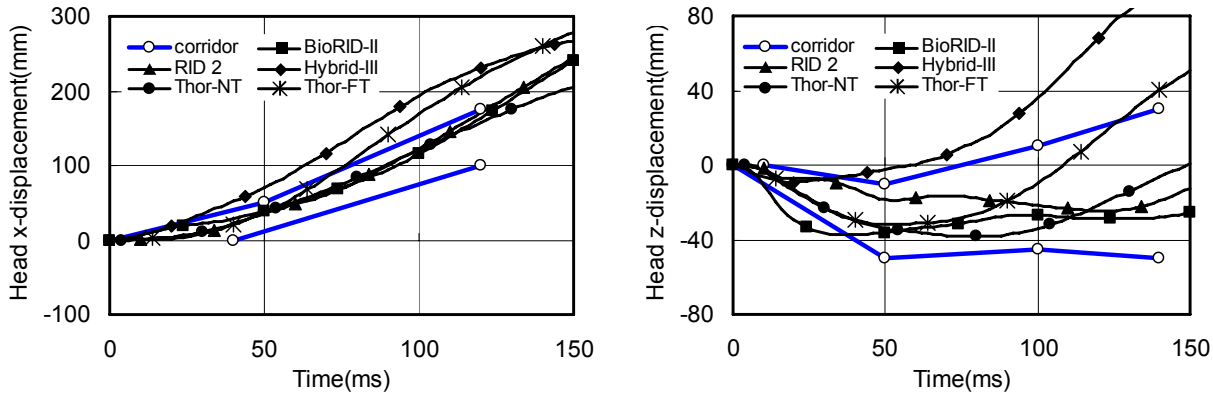

Figure B-2. X and Z displacements of Head