PERFORMANCE EVALUATION OF IMPACT RESPONSES OF THE SID-IIs SMALL SIDE IMPACT DUMMY

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ABSTRACT

A series of side impact tests have been conducted to evaluate the biofidelity of the latest prototype of a small side impact dummy, SID-IIs β+(plus). The tests were lateral impacts for the thorax, shoulder, and pelvis, as well as lateral drops for the head, thorax, abdomen, and pelvis. The test data were compared to the response target corridors that were estimated by scaling the cadaver test data to a smaller occupant.

The test results show that the head, shoulder, thorax, abdomen and pelvis of the SID-IIs β+ either completely or close to meets the response target corridors, and that its biofidelity has been improved from the previous dummy SID-IIs β-prototype.

INTRODUCTION

Two side impact dummies has been specified as the test dummy to be used in side impact regulation, the SID for the United States, and the EUROSID-1 for EUROPE and JAPAN, respectively. Additionally, the EUROSID-1 and BIOSID has been recommended in the side impact test procedure of the ISO 10997. While all these dummies are representatives of a mid-size male, each has a different design. In recent years, development of an internationally harmonized mid-male side impact dummy is being discussed by the experts of the ISO.

Under these circumstances, an advanced small side impact dummy, named Side Impact Dummy second [II] generation small (SID-IIs) shown in Figure 1, has been developed in the United States. The dummy has been developed as a tool for evaluating advanced side impact countermeasures such as side airbags when the occupant is smaller than existing side impact dummies. In addition, the dummy has been developed for providing a basis for worldwide harmonization of side impact dummy design in the future. Specifications of the SID-IIs were defined by the Occupant Safety Research Partnership (OSRP) of United States Council on Automobile Research (USCAR) formed by Chrysler, Ford, and General Motors. The dummy was designed and manufactured by First Technology Safety Systems (FTSS).

JARI/JAMA conducted a biofidelity evaluation test for the SID-IIs named β-prototype in 1996, and reported the results to the experts meeting in the ISO in June, 1997. Recently, the SID-IIs β-prototype has been updated to the SID-IIs β+, for which JARI/JAMA are planning to continue the evaluation.

This paper describes the results of evaluation tests completed so far concerning the SID-IIs β+ evaluations that JARI/JAMA are undertaking.

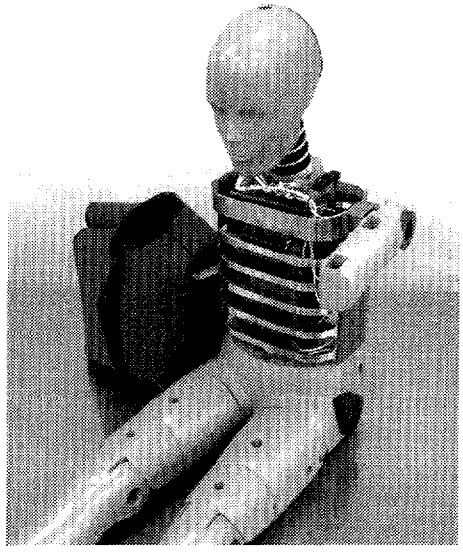

Figure 1. Small side impact dummy SID-IIs.

GENERAL SPECIFICATION AND CURRENT STATUS OF THE SID-IIs

The technical specifications and the biomechanical design targets for the SID-IIs were published by OSRP in the 39th STAPP conference proceedings.

SID-IIs has a similar anthropometry of a 5th percentile adult female. The structures of the shoulder, thorax, abdomen, and pelvis of the SID-IIs were designed by incorporating the best features of exiting side impact dummies, SID, EUROSID-1, and BIOSID. For other body region, the components of the small female Hybrid-III 5F dummy were used with or without modifications. Maximum of 148 instrumentation channels are available, which can be chosen depend on the side impact countermeasures being evaluated.

The early prototype SID-IIs dummy was called an α-prototype, and the first production version was called β-prototype(to be referred to as the β-type hereafter in this paper). In 1996-1997, the β-type dummy was evaluated by OSRP and JARI/JAMA and suggested to need to improve the biofidelity. Recently, the β-type dummy has been subjected to several modifications, then the dummy was called the SID-IIsβ+.

The description of the SID-IIs and recent modifications towards the SID-IIsβ+ are briefly shown in Table 1. The recent modifications were intended to improve the biofidelity of the shoulder, thorax, abdomen and pelvis, as well as to obtain better measurement performance. Details of these modifications were reported by OSRP in ISO meeting in March 1998.

Table 1.
SID-IIs and Modifications towards the β+ dummy

	SID-IIs	Modifications towards SID-IIsβ+
Head	Slightly modified Hybrid-III 5F head ·Shaved off skull sides ·Increased thickness of vinyl skin	No modifications
Neck	Slightly modified Hybrid-III 5F neck ·Plastic bushing installed to prevent metal contact	No modifications
Shoulder	Single far-side mounted rib with stub upper arm ·Upper arm on impact side only ·Linear potentiometer was used ·Rubber plug installed in the upper arm ·Arm positioned by using the detent stop	·Reduction of rib metal thickness ·Installation of support plate between the shoulder load cell and rib ·Arm plug hole was rounded corners ·Arm plug was molded on backing plate ·Enlargement of arm detent holes
Thorax, Abdomen	Asymmetrical spine box with 5 identical far-side mounted ribs ·High carbon spring steel ribs were used ·3 ribs for the thorax, 2ribs for the abdomen ·Ensolite® padding was placed inside the suits ·5 Linear potentiometers were used for each ribs ·4 load cells attached to the spine to measure rib to spine force	·Ribs were updated to Vascomax® Steel ·Reduction of rib metal thickness ·Redesigned rib-to-spine load cell ·Addition of accelerometer mounting hole on the non impacted side of the spine box ·Ensolite® padding was divided to the thorax and abdomen, and reduced padding thickness for the abdomen
Lumber Spine	Slightly modified Hybrid-III 5F lumber spine ·Cylindrical stepped shape rubber lumber ·Plastic bushing installed to prevent metal contact	No modifications
Pelvis	Bolted pelvic bone with removable pelvic Flesh ·Styrofoam® pelvic plug installed in the plug cup on the acetabulum ·Upper femur with rod end ball joints were used	·Plug material changed to a PP form ·Plug thickness and diameter were increased ·Plug retaining cup deleted ·Addition of rubber bumper to upper femur
Legs	Standard Hybrid-III 5F legs (The knee sliders were replaced with steel blocks)	No modifications

BIOFIDELITY EVALUATION TESTS

The biofidelity evaluation test procedures and the target responses for the SID-IIs were proposed by OSRP in the 39th STAPP paper, based on the technical reports ISO TR9790-1 through 6. These technical reports describe the test procedures and response requirements for the head, neck, thorax, shoulder, abdomen, and pelvis for the mid-size male side impact dummy to asses their biofidelity. The response requirements of the ISO TR9790-1 through 6 were based on the test data on cadavers or human volunteers that were normalized to the mid-size male. It should be noted that a revised document N455-Rev.4 has been proposed to these technical reports.

OSRP has reviewed the cadaver data used to establishing the response requirements in the ISO TR9790-1 through 6, and scaled them to the SID-IIs to establish the target responses. The test procedures and conditions are similar to those for the mid-size male provided in the ISO TR9790-1 through 6. However, the impactor mass for the thorax, shoulder, and pelvis has been reduced to amount in proportion to the total masses of the mid-size male and the SID-IIs. Table 2 shows a matrix of the biofidelity evaluation test procedures for each body region of the SID-IIs proposed by OSRP.

So far in this test series, JARI/JAMA have completed the impact tests for the thorax, shoulder, and pelvis, as well as the drop tests for the head, thorax, abdomen, and pelvis. The test data were compared to the response targets proposed by OSRP. Also, test data for the thorax, shoulder, and pelvis impacts were compared with those for β-type dummy previously tested. Future test plans include the 7.2 g HYGE neck sled test, and the WSU type sled tests for the shoulder, thorax, abdomen, and pelvis.

Some of the tests are not planned because the suitable test devices or paddings are not available in our laboratory (for example, neck 6.7g impact sled test and thorax 2m padded drop test). Further, tests for which the target response is established based on only one cadaver test data, or tests are considered too severe than necessary, are placed at a lower priority in the planning.

Table 2.
Biofidelity Evaluation Test Procedures for the SID-IIs

Target	Impact Tests	Drop Tests	Sled Tests
Head	No Target	200mm Rigid Drop 1200mmm Padded Drop	No Target
Neck	No Target	No Target	7.2g HYGE Sled 6.7g Impact Sled 12.2g HYGE Sled
Thorax	4.3m/s Lateral Impact 6.7m/s Lateral Impact	1m Rigid Drop 2m Padded Drop	Heidelberg- 6.8m/s Rigid WSU - 8.9m/s Padded
Shoulder	4.5m/s Lateral Impact	No Target	7.2g HYGE Sled 12.2g HYGE Sled WSU - 8.9m/s Padded
Abdomen	No Target	1m Drop onto Rigid Armrest 2m Drop onto Rigid Armrest	WSU - 6.8m/s Rigid WSU - 8.9m/s Rigid WSU - 8.9m/s Padded
Pelvis	6 - 10m/s Lateral Impact	0.5mRigid Drop 1m RigidDrop 2m Padded Drop 3m Padded Drop	Heidelberg- 6.8m/s Rigid Heidelberg- 8.9m/s Rigid Heidelberg- 8.9m/s Padded WSU - 6.8m/s Rigid WSU - 8.9m/s Rigid WSU - 8.9m/s Padded

; Completed. ; Will be performed.

Lateral Impact Tests

Lateral impact tests for the thorax, shoulder and pelvis were carried out by applying a pure lateral impact to the dummy, using a linearly guided impactor. The dummy (with suit) was seated in an upright position on a flat, rigid, horizontal surface, without back support. Two sheets of Teflon™ were placed between the dummy and the surface.

Thorax 4.3m/s and 6.7m/s Impact Tests – Five times thorax impact tests were carried out each for velocities of 4.3m/s and 6.7m/s. 14kg impactor having a flat face 120 mm in diameter was used. The centerline of the impactor was aligned to the center of the thorax middle rib. The upper arm of the dummy was removed because of possible interference with the impactor face. The thorax impact test setup is shown in Figure 2. In the test, the accelerations of the impactor and the upper spine (T1) of the dummy were measured. The impactor force was calculated by multiplying the acceleration of the impactor with its mass, 14kg.

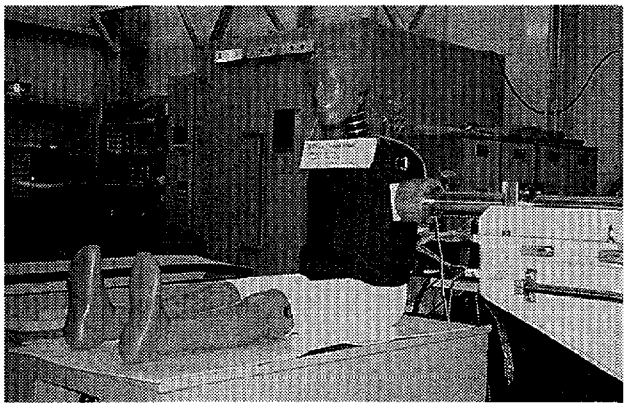

Figure 2. Test setup for the thorax lateral impact.

Figures 3 and 4 show the impactor force-time responses and the T1 acceleration-time responses for the 4.3m/s thorax impact tests, respectively. Figure 5 shows the impactor force-time responses for the 6.7m/s thorax impact tests. These figures also show that, the target response corridors estimated by OSRP, as well as the responses for β-type dummy previously tested.

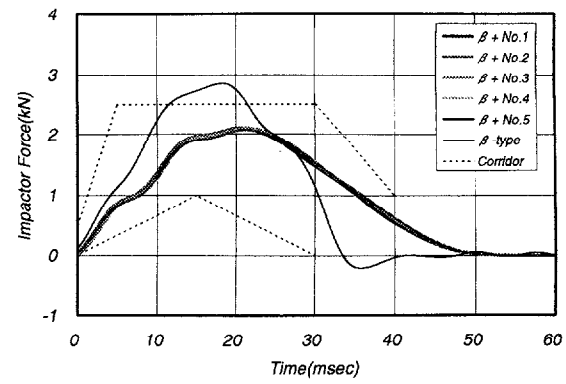

Figure 3. Impactor force-time responses with target corridor for the thorax 4.3m/s lateral impact.

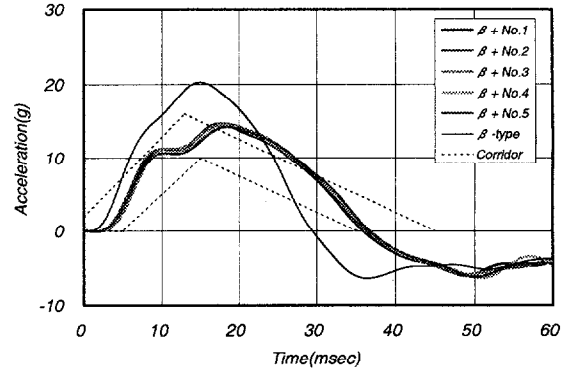

Figure 4. T1 acceleration-time responses with target corridor for the thorax 4.3m/s lateral impact.

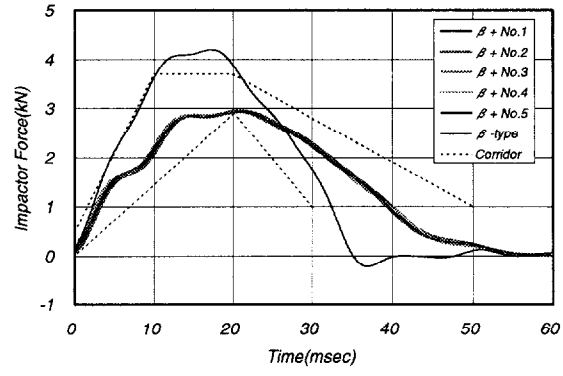

Figure 5. Impactor force-time responses with target corridor for the thorax 6.7m/s lateral impact.

In the 4.3m/s test, impactor force–time responses for the β + dummy are completely within the target corridor, while the β -type dummy shows higher peak force than the upper limit of the corridor. For the T1 acceleration, although the responses of the β + dummy are slightly above the upper limit of the corridor, the general shape and time duration are closer to the corridor than those of the β -type dummy.

In the 6.7m/s test, unlike the β -type dummy of which the peak impactor force exceed the upper limit of the corridor, the responses of the β + dummy are within the corridor close to the lower limit.

These test responses show that the modifications to the thorax rib have improved the rib deflection characteristics. In addition, it can be noted that the repeatability of the thorax impact test responses for the β + dummy appears to be very good.

Shoulder 4.5m/s Lateral Impact Test – Five times 4.5m/s shoulder impact tests were performed using an impactor identical to that in the thorax impact tests. The centerline of the impactor was aligned to the center of the shoulder pivot, and the upper arm was placed vertical beside to the thorax. The acceleration of the impactor and the shoulder rib deflection of the dummy were measured in the tests. The impactor force was calculated by multiplying the acceleration of the impactor with its mass, 14kg.

Figure 6 shows the impactor force-time responses for the shoulder impact tests, and Table 3, the peak shoulder rib deflections, together with the target responses estimated by OSRP and corresponding test results for the β -type dummy.

The peak impactor forces for the β + dummy are almost within the target corridor at the upper limit. While the time duration for the β + dummy is slightly shorter than the corridor, general shape is closer to the corridor than the β -type dummy. The peak shoulder rib deflections of the β + dummy are within the response target at the upper limit. These values considerably differ from those of the β -type dummy which shows values slightly below the lower limit of the response target.

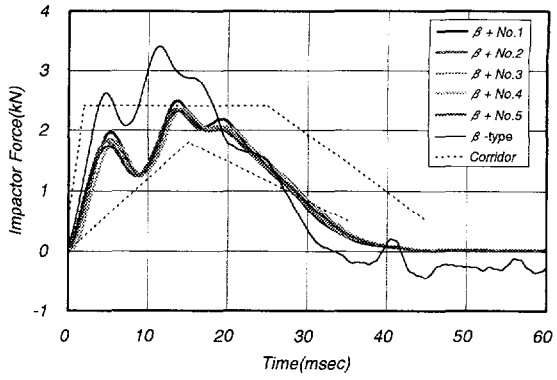

Figure 6. Impactor force-time responses with target corridor for the shoulder lateral impact.

Table 3.
Peak Shoulder Rib Deflections with Response Target for the Shoulder lateral Impact

Response Target		Test Results					
		No.1	No.2	No.3	No.4	No.5	Mean
Shoulder Rib Defl.	β -type	21.5	21.7	21.4	21.6	21.7	21.58
22 - 30 (mm)	β +	28.4	28.6	28.0	29.4	29.2	28.71

These test results indicate, just as in the case of the thorax, that the modifications in the shoulder rib have improved the rib deflection characteristics. In addition, as is for thorax, the test data repeatability can be described as well in the shoulder impacts.

Pelvis 6 – 10m/s Lateral Impact Test - The pelvis impact tests were conducted using a 10.0kg impactor having a spherical face of 175mm-radius and a diameter of 120 mm. The test for the β + dummy was repeated twice at each velocities of 6m/s and 6.7m/s. (For the β -type dummy, two tests each were conducted for velocities of 6m/s, 6.7m/s, and 7.5m/s). The center axis of the impactor was aligned to the H-point of the dummy. In the test, the acceleration of the impactor was measured, and multiplied with its mass, 10.0kg to obtain the impactor force.

Figure 7 shows the peak impactor force versus impact velocity relationship together with the target corridor and corresponding test results for the β -type dummy.

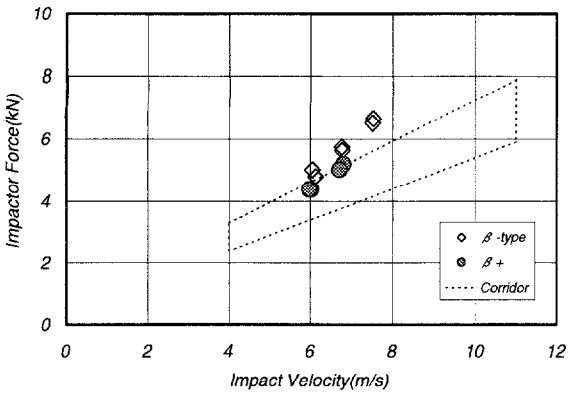

Figure 7. Peak impactor force vs. impact velocity with target corridor for the pelvis lateral impact.

The impactor peak forces for the β + dummy are within the corridor for 6m/s and right at the upper limit for 6.7m/s, while the β -type dummy shows higher responses than the upper limit of the corridor.

These test results were achieved by modifying the material, diameter, and thickness of the pelvic plug that is installed into the sides of the pelvis. However, since this pelvic plug presently needs to be renewed after each test, development of a re-useable plug is expected.

Drop Tests

Drop tests were conducted for the dummy's head by itself, as well as for the thorax, pelvis, and abdomen using a whole dummy.

In the head drop test, a dummy head is suspended at a certain height and allowed to free-fall onto a flat surface to impact the upper side portion of the head. Only the 200mm rigid drop was conducted; the 1200mm padded drop was not performed because the test conditions were considered too severe than necessary.

Two types of drop tests were conducted to the whole dummy, one for the thorax and pelvis, other for the abdomen. In the tests, the dummy (with suits) was suspended with its midsagittal plane horizontal, and a quick release device was used to provide a free fall onto the impact surface. For the thorax and pelvis, the 0.5m and 1m rigid drop tests were conducted, but the 2m and 3m drop tests were not carried out because the required APR form padding was not available. For the abdomen, only the 1m drop test was conducted; the 2m drop was not performed because the test conditions were considered too severe than necessary.

Head 200mm Drop Test - The head was suspended with its midsagittal plane making an angle of 35° to the horizontal. Then the head was dropped onto a flat, rigid and horizontal surface from a height of 200mm. The test was repeated five times, to the upper left side of the head. Figure 8 shows the test setup for the head 200mm drop. The triaxial accelerations were measured at the non-impact side of the head cavity on the left-right axis passing through the center of gravity.

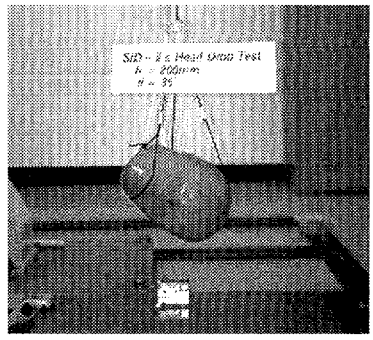

Figure 8. Test setup for the head 200mm drop.

The test results and the target response are given together in Table 4. The resultant accelerations of the head slightly exceed the upper limit of the target response for all five tests.

According to OSRP, the head response will improve if powder is applied between the skin and the skull. Although powder was used in the tests, the skin might have been outdated and hardened slightly. Accordingly, head tests will be rerun using a new skin.

Table 4.
Peak Head Resultant Accelerations with Response target for the Head 200mm Rigid Drop

Response Target	Test Results					
	No.1	No.2	No.3	No.4	No.5	Mean
Head Res.Acc. 106 - 158 (g)	162.3	167.9	167.3	165.5	167.6	166.12

Thorax and Pelvis Drop Test - In the thorax and pelvis drop tests, the whole dummy was dropped onto a flat, rigid, horizontal surface from a height of 0.5m and 1m. Two tests for 0.5m drop and three tests for 1m drop were carried out, respectively.

The impact surface consists of four separated force measuring surfaces correspond to the shoulder, thorax, pelvis and thigh, respectively. An edge of the thorax impact surface was aligned to the lower edge of the thorax lower rib. The upper arm of the dummy was rotated 20° forward to the spine. Figure 9 shows the setup for the thorax and pelvis drop tests. In the tests, the forces at the shoulder and thorax impact surfaces, thoracic rib deflection and the pelvic accelerations were measured. The target responses for the thorax were specified as the force-time response of the thorax impact surface (including the shoulder) and the peak thoracic rib deflection at the 1 m drop test. The peak pelvic resultant accelerations were specified to the 0.5m and 1m drop tests as the pelvis targets.

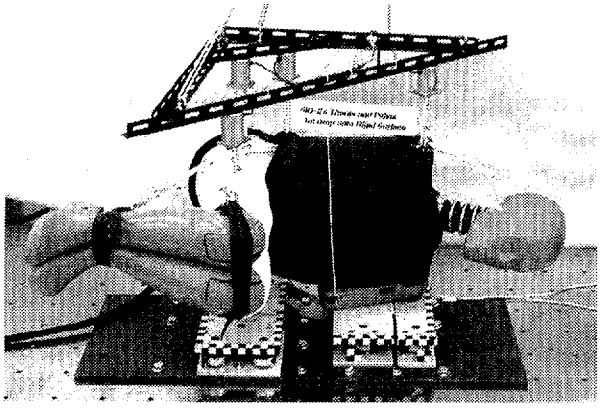

Figure 9. Test setup for the thorax and pelvis drop.

Figure 10 gives the force-time responses of the combined thorax and shoulder impact surfaces for the 1m drops together with the target response corridor. Table 5 shows the peak thoracic rib deflections for the 1m drops, and Table 6, the peak pelvic resultant accelerations for the 0.5m and 1m drops, together with the corresponding response targets.

For the impacted surface force for the thorax, while slightly exceeding the upper limit of the corridor at the beginning of the curve, peak forces are close to meet the lower limit of the corridor. However, the time duration is longer than the corridor. For the peak thoracic rib deflections, all three ribs within the response target near the upper limit for the three tests.

The peak pelvic resultant accelerations within the response target for the 0.5m drops but show values below the lower target limit at the 1m drops.

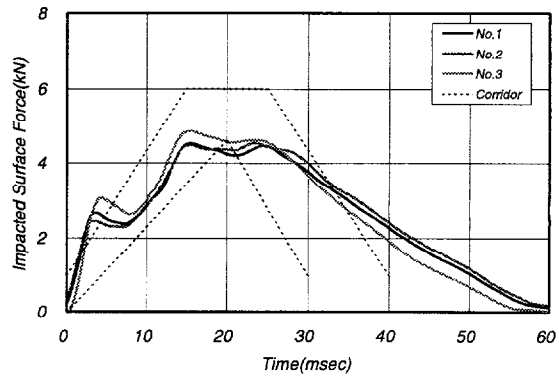

Figure 10 Impacted surface force-time responses with target corridor for the thorax 1m drop.

Table 5.
Peak Thoracic Rib Deflections with Response Target for the Thorax 1m Drop

Response Target	*Test Results*		
	No.1	*No.2*	*No.3*
Thorax Rib Defl. 24 - 32 (mm)	*Upper ; 31.0*	*Upper ; 30.0*	*Upper ; 30.9*
	Middle ; 30.9	*Middle ; 30.2*	*Middle ; 32.0*
	Lower ; 28.0	*Lower ; 27.7*	*Lower ; 30.6*

Table 6.
Peak Pelvic Resultant Accelerations with Response Targets for the Pelvis 0.5m and 1m Drops

	Response Target	*Test Results*		
		No.1	*No.2*	*No.3*
0.5m Rigid	*Pelvis Res.Acc. 41 - 55 (g)*	*41.5*	*46.8*	
1m Rigid	*Pelvis Res.Acc. 70 - 94 (g)*	*58.1*	*55.1*	*56.9*

In the whole dummy drop tests, it is very difficult to maintain the proper posture of the dummy at the moment of impact. Slight differences in the contact area at the impacting face or in the impact timing could cause data variation. Taking these factors into consideration, the drop tests for both 0.5m and 1m can be regarded as showing good repeatability.

Abdomen Drop Test - In the abdomen drop test, the whole dummy was allowed to free fall from a height of 1m to impact abdomen with a simulated armrest. The test was repeated three times. Figure 11 shows the setup for the abdomen drop test.

The simulated armrest is 70mm wide and 300mm long, protruding 33mm above the surrounding surface, and mounted on the two load cells. The centerline of the armrest was aligned to the center of the gap of the two abdominal ribs. The upper arm of the dummy was positioned upward. In the tests, the force applied to the armrest, the deflection and acceleration of two abdominal ribs, and the acceleration of the T12 spine were measured.

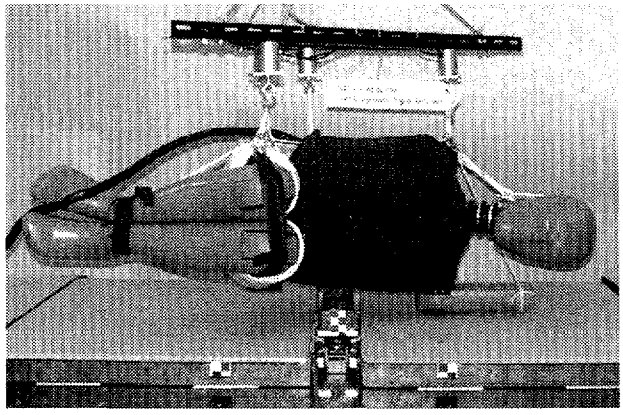

Figure 11. Test setup for the abdomen 1m drop onto rigid armrest.

Figure 12 shows the force-time responses of the armrest for the abdomen 1m drop tests with the response target corridor. The peak accelerations of T12 and the abdominal rib as well as peak abdominal rib deflections, with the response targets are given in Table 7.

The peak armrest forces are close to meet the lower limit of the corridor, and the time duration is slightly longer than the corridor in the abdomen 1m drops. The peak accelerations for the abdominal upper rib and the peak deflections for the upper and lower abdominal ribs within the response targets. However, the peak accelerations of T12 and the lower abdominal rib show values slightly exceeding the upper limit of the response targets.

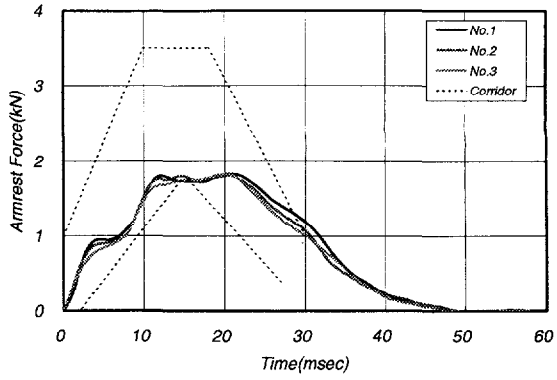

Figure 12. Armrest force-time responses with target corridor for the abdomen 1m drop.

Table 7.
Peak Abdominal Responses with Response Targets for the Abdomen 1m Drop

Response Target	Test Results		
	No.1	No.2	No.3
T12 Acc. 29 - 39 (g)	46.7	43.6	50.3
Abdominal Rib Acc. 112 - 152 (g)	Upper; 145.7	Upper; 129.9	Upper; 113.6
	Lower; 169.1	Lower; 162.9	Lower; 160.3
Abdominal Rib Defl. > 33 (mm)	Upper; 44.1	Upper; 43.7	Upper; 43.4
	Lower; 52.4	Lower; 51.9	Lower; 54.3

As with the thorax and pelvis drop test, it is also difficult to maintain the proper posture of the dummy for the abdomen drop test. Moreover, the small size of the contact area at the armrest is apt to cause data variations. In particular, as the peak acceleration of the abdominal ribs occurs in an early in the impact, slight differences in the dummy's posture or position at the moment of impact could translate into significant data variations.

SUMMARY

A series of side impact tests has been conducted by JARI/JAMA to evaluate the biofidelity of the latest prototype of a small side impact dummy, SID-IIsβ+. The dummy has been developed as a tool for evaluating advanced side impact countermeasures when the occupant is smaller than existing side impact dummies, and for providing a basis for internationally harmonized side impact dummy design in the future.

The tests conducted were lateral impacts for the thorax, shoulder, and pelvis, as well as lateral drops for the head, thorax, abdomen, and pelvis. The test data were compared to the target response corridors and values that were estimated by OSRP after scaling the cadaver data to smaller occupant.

The test results show that the SID-IIs β+ either completely or nearly meets the targeted responses for the head, thorax, shoulder, abdomen, and pelvis. Then the biofidelity of the SID-IIs β+ has been improved over the previous dummy called the SID-IIs β-prototype. In addition, the responses of the shoulder, thorax, and pelvis have shown very good repeatability in the lateral impact tests. For the drop tests, although a substantial difficulty exists in the preparatory setting of the dummy, the test responses showed comparatively reasonable repeatability.

An outline of the test results for each part of the dummy are as follows:

1. For the head, the peak resultant accelerations of the head exceed the upper limit of the response target in the 200mm rigid drop test. However, since this may be due to the old head skin used, a retest would be required using a new head skin.
2. For the thorax, although the T1 acceleration responses slightly exceed the upper limit of the target corridor, the impactor force-time responses are within the target corridor in the 4.3m/s and 6.7m/s impact tests. In addition, in the 1m drop test, the thorax impacted surface force-time responses are close to meet the target corridor and the peak thoracic rib deflections are within the targets.
3. In the shoulder impact test, the peak forces of the impactor are almost within the corridor at the upper limit, and the peak shoulder rib deflections are within the response targets.
4. In the abdomen 1m drop test, the armrest forces are almost within the target corridor at the lower limit. In addition, the peak deflections of the abdominal ribs and peak accelerations of the abdominal upper rib are within the response targets. However, the peak accelerations of T12 and the abdominal lower rib show values slightly exceed the upper limit of the response targets.
5. In the pelvis impact test, the peak impactor forces are within the target corridor at 6m/s impact, and right at the upper limit of the corridor at 6.7m/s impact. The peak pelvic accelerations are within the response target for the 0.5m drop test, but show values lower than lower limit of the target in the 1m drop.

TASKS IN FUTURE

The SID-IIs evaluation tests by JARI/JAMA are still continuing on with future test plans including the 7.2 g neck sled test, and the WSU type sled tests for the shoulder, thorax, abdomen, and pelvis. After these tests have been completed, biofidelity ratings of the dummy will be calculated based on the ISO biofidelity rating procedure. Further, JARI/JAMA intend to co-operate in the establishing the calibration corridors for the SID-IIs that has been not defined yet.

The study results of JARI/JAMA will be reported at the experts meeting of ISO, when those become available. It is the opinion of JARI/JAMA that by publishing our study results the two organizations should be able to make contributions toward the development and research of the side impact dummies to be harmonized under worldwide specifications.

The SID-IIs is a dummy on which development effort continues even now, and as such could be subjected to further improvements. The evaluation test program by JARI/JAMA needs to respond flexibly to such improvements.

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