INFLUENCE OF PELVIS FLESH ON ABDOMEN DEFLECTIONS IN THE WORLDSID IN SIDE IMPACT SLED TESTS

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ABSTRACT

The ES-2re has limited abilities to output measures such as abdominal deflections which may be used to predict region-specific injuries. The WorldSID is being increasingly used in full-scale crash tests and sled experiments because of its ability to extract biomechanical metrics such as abdominal deflections in lateral impacts. Concerns have been raised by researchers around the world regarding the issue of the pelvis flesh interference in allowing the abdominal rib to deflect in side impacts and underestimate the local deflection/injury. The present study was conducted using a WorldSID 50th percentile male dummy to determine the influence of the flesh in constraining the abdomen rib kinetics.

A standard and modified pelvis was tested on a side impact buck with a 50 mm abdomen offset at 3, 4, and 5 m/s. The jacket, struck side arm, and rib padding were removed. Of specific study focus, deflections from the second abdomen rib are discussed. Increasing velocities produced increasing forces and deflections. Force and deflection responses were uni-modal and repeatable under both seating conditions and both types of pelvises. Peak deflections were not significantly different between the standard and modified dummies in the reclined seat configuration. This was independent of velocity. In the upright configuration, peak abdomen deflections were slightly greater at 3 and 4 m/s, and the trend was reversed at 5 m/s. Only two extreme seat configurations were chosen as a range of dummy pelvis angles in motor vehicles. A comparison with earlier tests was difficult due to numerous differences in test methodologies. These findings indicate that the standard WorldSID pelvis may be used without pelvic flesh-rib interaction inhibiting abdomen kinetics and that modification of the pelvis flesh is not necessary at this time.

INTRODUCTION

Recent changes to the U.S. FMVSS No. 214 regulatory side impact safety standards have incorporated the EuroSID 2re (ES-2re) dummy to assess crashworthiness in motor vehicles [1]. In 2007, the National Highway Traffic Safety Administration (NHTSA) commented that the WorldSID dummy was not ready for regulation and it would continue its evaluation of the WorldSID for future incorporation into Part 572. Future updates to FMVSS No. 214 may consider the WorldSID dummy which was designed to be the next generation side impact dummy for harmonization of worldwide safety standards.

The WorldSID has a shoulder rib, three thorax ribs and two abdominal ribs, all of which can measure individual rib acceleration and deflection [2]. Measurement of abdomen deflection extends the ability of the WorldSID to provide additional biomechanical metrics and injury criteria. The rib design is a double hoop structure made up of an outer plastic band to define the torso geometry and an inner ring which is tuned to produce the region specific response. The outer band is connected posteriorly to the spine box and anteriorly to a flexible plastic sternum. The inner band is connected to the outer band at the most lateral point of the rib. The pelvis consists of a two-piece hard plastic skeleton surrounded by a single molded flesh. The skeleton design was based on the Reynolds' pelvis anatomy data while the exterior dimensions used the Anthropometry for Motor Vehicle Occupants (AMVO) shape.

Depending on the seating condition, part of the anterior portion of the 2nd abdominal rib (lowest rib) rests behind the posterior wall of the anterior pelvis skin. As the angle between the spine and pelvis decreases (flexion), the contact between the rib and pelvis increases. In tests conducted by Transport

Research Labs (TRL) it was discovered that certain seating positions placed the 2nd abdominal rib on top of or in front of the anterior pelvis flesh [3]. The pre-test misalignment of the rib was difficult to detect as the jacket covered the pelvis and torso. One way to minimize rib contact with the pelvis is to remove material from the posterior side of the anterior pelvis to allow more clearance. It is not known how removal of material may change the WorldSID's response and raises the issue of the anterior pelvis's effect on abdomen deflection. The present study was conducted to determine the influence of the flesh in constraining the abdomen rib kinetics.

METHODS

A WorldSID 50th percentile male dummy was placed on Teflon coated bench seat fixed to the top of an acceleration sled (Seattle Safety Systems, Seattle, WA). A uni-axial accelerometer measured sled acceleration. All data were sampled at 20 kHz according to SAE J211 [4]. The seat was positioned so that the occupant slid along the bench and impacted a pure lateral modular load-wall (Figure 1) at the time of maximum sled velocity [2, 5, 6]. The load-wall consisted of four rigid plates that were aligned to isolate loading to the thorax, abdomen, pelvis, and lower extremities. The abdomen plate was offset laterally from the thorax, pelvis, and lower limb plates by 50 mm to induce focal loads to the abdomen ribs. Tri-axial load cells mounted to the back of the rigid plates recorded the force time histories of the thorax, abdomen, and pelvis, while uni-axial load cells were used for the lower extremity plate.

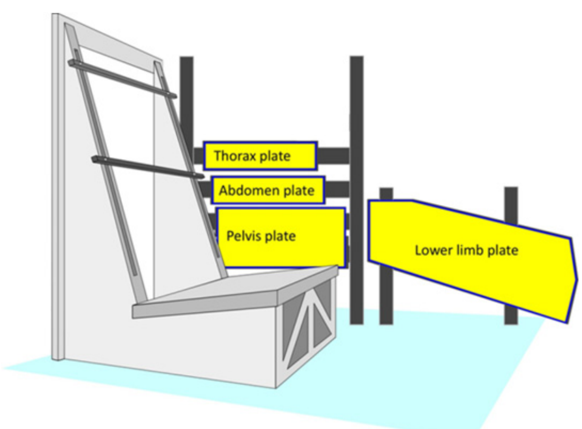

Figure 1: Schematic of the sled test setup showing the segmented load-wall. The bench seat and the lower limb plate are also shown.

The seat and seat back angle were independently adjusted and set to achieve two different pelvis/abdomen rib alignments. The upright seat position had a seat back and seat pan angle of 18 and 13 degrees, respectively (Figure 2) while the reclined seat configuration was 23 and 0 degrees (Figure 3).

The jacket, left shoulder, and left rib pad were removed to better isolate and visualize the abdomen ribs and the interaction with the anterior pelvis. Rib displacement was measured using WorldSID's internal deflection sensor, the InfraRed Telescoping Rod for Assessment of Chest Compression (IRTRACC) [7]. A standard pelvis was used for the first test series. The second series used a modified pelvis in which material was removed from the posterior section of the anterior pelvis skin extending from the left to the right anterior superior iliac spine. The anterior most surface of the pelvis was not altered (Figure 4). The upright configuration placed the 2nd abdominal rib directly in contact with the anterior portion of the standard pelvis while the reclined position had approximately 15 mm of clearance between the rib and posterior surface of the anterior standard pelvis.

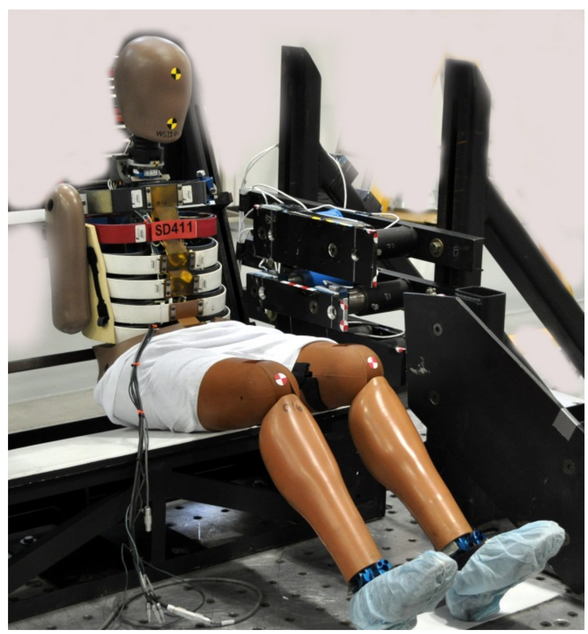

Figure 2: Photograph showing the WorldSID 50th device in the upright seated condition.

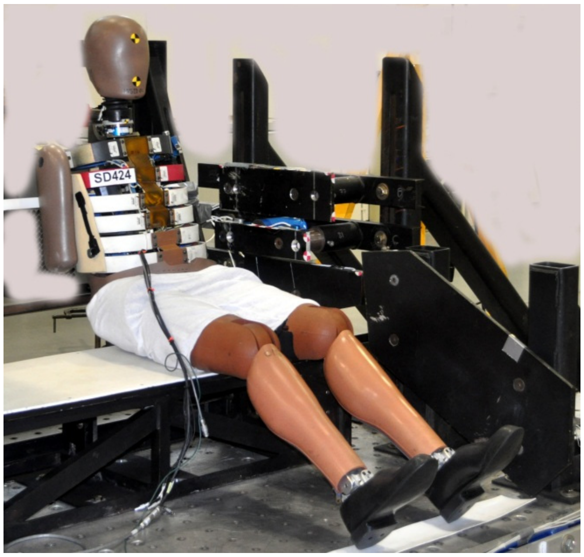

Figure 3: Photograph showing the WorldSID 50th device in the reclined seated position.

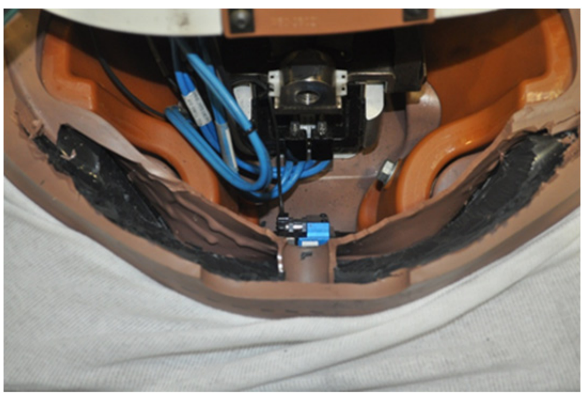

Figure 4: Photograph of the modification to the posterior portion of anterior pelvis flesh

Three repeat tests were run at 3, 4, and 5 m/s in the upright and reclined seating positions with the standard and modified pelvis for a total of 36 tests. Four high speed video cameras recorded the event at 1000 frames/sec from the front and overhead.

RESULTS

Sled accelerations for 3, 4, and 5 m/s are shown (Figure 5). Mean and standard deviations for the three pulses were 2.96 ± 0.07 m/s, 3.99 ± 0.05, and 5.01 ± 0.05. Peak abdominal rib 2 deflections and peak abdomen load-wall forces for all tests are shown (Table 1-Table 4). Average peak deflections and standard deviations for the standard pelvis in the upright position at 3, 4, and 5 m/s were 25.6 ± 0.7 mm, 37.1 ± 0.5 mm, and 53.9 ± 1.2 mm, respectively.

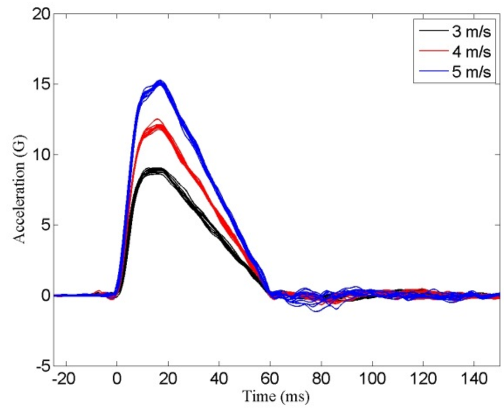

Figure 5: Sled acceleration pulses for the three velocities.

Deflections for the modified pelvis in upright position were 28.4 ± 0.6 mm, 40.1 ± 0.6 mm, and 51.8 ±0.4 mm; standard pelvis in reclined position 31.8 ± 0.4 mm, 44.4 ± 0.9 mm, and 56.6 ± 0.8 mm; and modified pelvis in reclined position 32.1 ± 0.3 mm, 44.8 ± 0.4 mm, and 56.3 ± 0.7 mm, respectively. Average peak deflections and standard deviations are compared (Figures 6-9).

Table 1: Peak rib 2 deflection and peak abdomen force – Standard Upright Tests

Test	Velocity	Pelvis	Seat Condition	Peak Deflection mm	Peak force N
1	3	Standard	Upright	26.0	2394.0
2	3	Standard	Upright	24.9	2312.9
3	3	Standard	Upright	26.0	2268.5
4	4	Standard	Upright	37.5	2848.9
5	4	Standard	Upright	36.5	2717.8
6	4	Standard	Upright	37.4	2778.3
7	5	Standard	Upright	52.5	3394.6
8	5	Standard	Upright	54.2	3280.9
9	5	Standard	Upright	54.9	3292.2

Table 2: Peak rib 2 deflection and peak abdomen force - Modified Upright Tests

Test	Velocity	Pelvis	Seat Condition	Peak Deflection mm	Peak force N
10	3	Modified	Upright	27.7	2211.1
11	3	Modified	Upright	28.7	2187.4
12	3	Modified	Upright	28.6	2191.5
13	4	Modified	Upright	40.7	2743.6
14	4	Modified	Upright	40.2	2799.5
15	4	Modified	Upright	39.4	2848.6
16	5	Modified	Upright	51.8	3336.7
17	5	Modified	Upright	52.2	3461.7
18	5	Modified	Upright	51.4	3169.1

Table 3: Peak rib 2 deflection and peak abdomen force - Standard Reclined Tests

Test ID	Velocity	Pelvis	Seat Condition	Peak Deflection mm	Peak force N
19	3	Standard	Reclined	31.4	2192.6
20	3	Standard	Reclined	32.2	2152.2
21	3	Standard	Reclined	31.8	2119.1
22	4	Standard	Reclined	44.5	2713.4
23	4	Standard	Reclined	43.4	2716.9
24	4	Standard	Reclined	45.3	2711.9
25	5	Standard	Reclined	56.5	3287.6
26	5	Standard	Reclined	55.8	3303.7
27	5	Standard	Reclined	57.4	3258.5

Table 4: Peak rib 2 deflection and peak abdomen force - Modified Reclined Tests

Test ID	Velocity	Pelvis	Seat Condition	Peak Deflection mm	Peak force N
28	3	Modified	Reclined	32.4	2163.4
29	3	Modified	Reclined	31.9	2169.2
30	3	Modified	Reclined	32.0	2165.5
31	4	Modified	Reclined	45.1	2663.2
32	4	Modified	Reclined	45.0	2687.4
33	4	Modified	Reclined	44.4	2655.5
34	5	Modified	Reclined	55.6	3339.1
35	5	Modified	Reclined	56.3	3343.9
36	5	Modified	Reclined	57.0	3386.6

Force-deflection curves are shown (Figures 10-15). Briefly, average peak deflection increased for all configurations with increasing velocity. The reclined seated position had similar values and curve morphologies for average peak displacements and force deflection functions at all velocities for the standard and modified pelvis. In the upright seated condition comparing the standard and modified pelvises, average peak deflections were lower at 3 and 4 m/s and slightly higher at 5 m/s. Force deflection responses were slightly stiffer at the lower velocities and similar at 5 m/s.

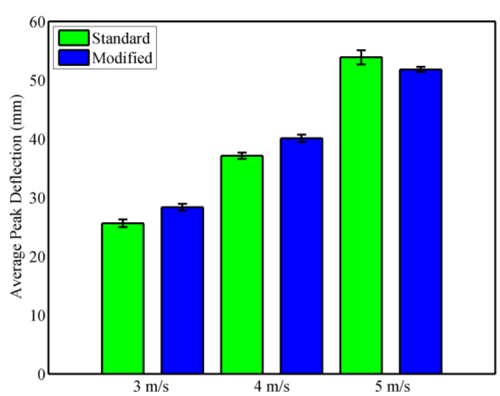

Figure 6: Average peak deflections and standard deviations for the upright seat.

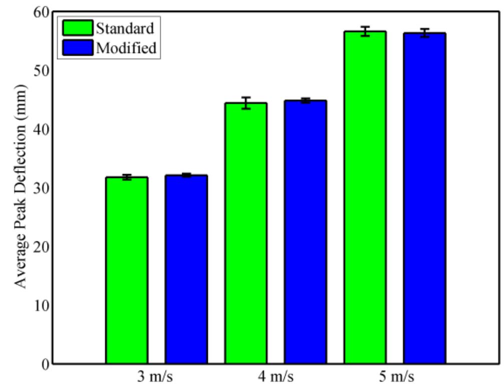

Figure 7: Average peak deflections and standard deviations for the reclined seat.

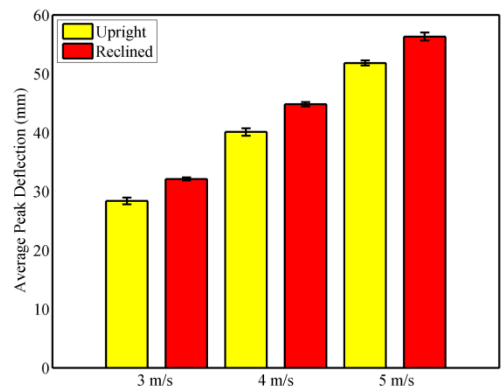

Figure 8: Average peak deflections and standard deviations for the modified pelvis.

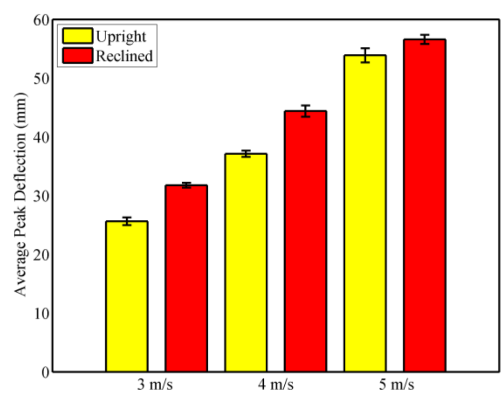

Figure 9: Average peak deflections and standard deviations for the standard pelvis.

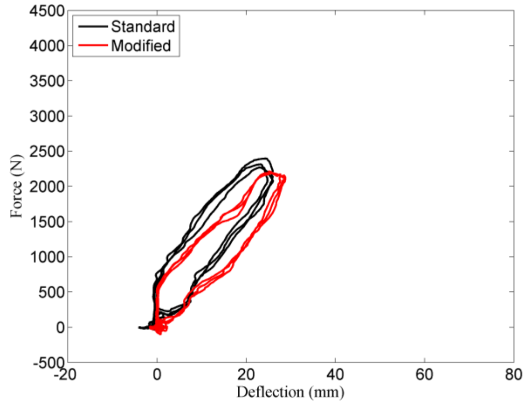

Figure 10: Force-deflection curves at 3 m/s for the upright seat.

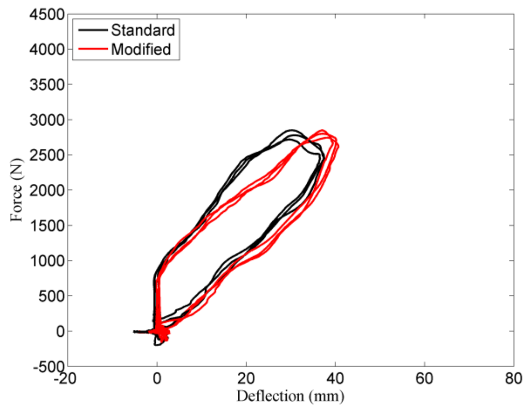

Figure 11: Force-deflection curves at 4 m/s for the upright seat.

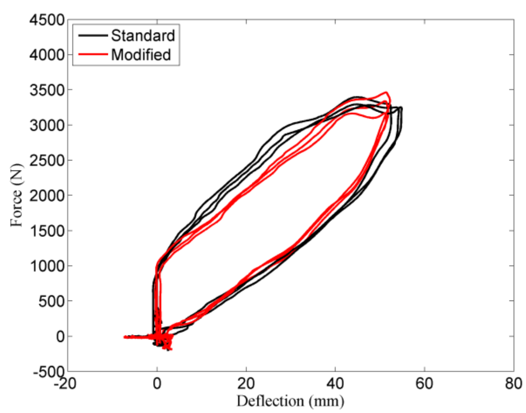

Figure 12: Force-deflection curves at 5 m/s for the upright seat.

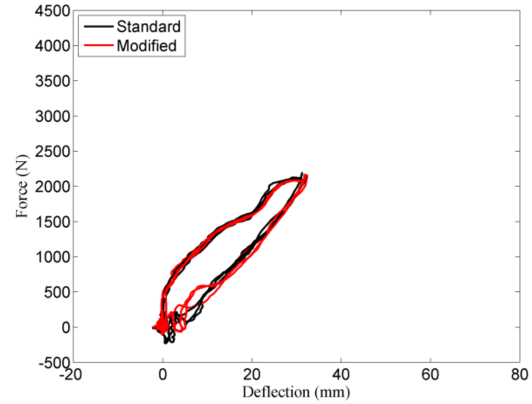

Figure 13: Force-deflection curves at 3 m/s for the reclined seat.

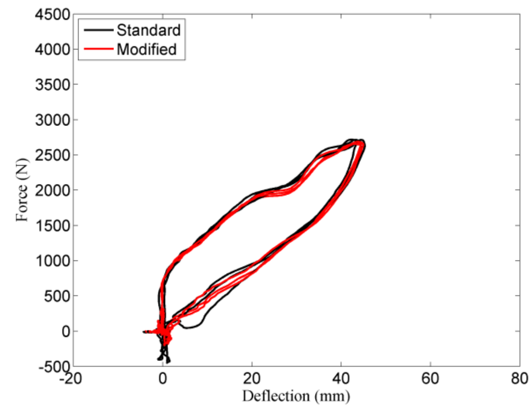

Figure 14: Force-deflection curves at 4 m/s for the reclined seat.

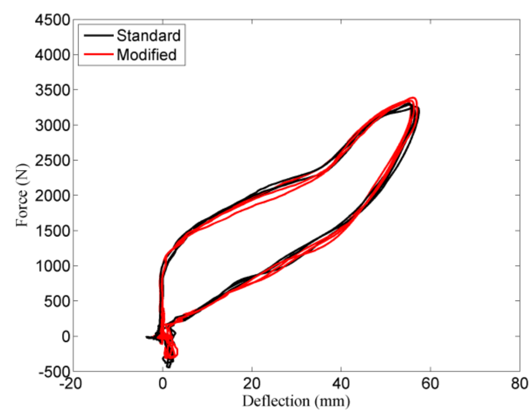

Figure 15: Force-deflection curves at 5 m/s for the reclined seat.

DISCUSSION

A report by TRL discussed tests with the WorldSID 50th device in which it was possible to accidentally position the dummy such that (a) abdomen rib 2 rested on top of the flat upper face of the anterior pelvis flesh or (b) the anterior pelvis flesh was pushed behind/tucked under the lower abdomen rib [3]. The authors of the report further examined this problem using a WorldSID 5th device equipped with a 2d IRTRACC and ran a series of sled tests at 5 m/s with an impacting abdomen plate. The dummy was tested in three conditions:

1. Normal seating position with standard pelvis.
2. Anterior pelvis flesh pushed behind Abdomen rib 2 with standard pelvis.
3. Normal seating position with modified pelvis flesh.

The pelvis was modified using a procedure similar to the current study. Slightly higher rib deflections and less rib rotation were seen with the misaligned rib position compared to the normal seating position. The modified pelvis had a similar trend with more rib rotation and higher deflections than the normally seated standard pelvis. TRL concluded that it is very difficult to force the abdomen rib on top of the pelvis during normal use and proper orientation and position of the rib is easy to verify with a quick visual check. While pelvis modification was probably not needed to prevent rib misalignment, they concluded that the standard pelvis flesh did limit abdomen rib 2 deflections.

Results from the TRL tests are difficult to compare to the current study as the WorldSID 5th device has been shown to have a stiffer rib response than the WorldSID 50th device. For similar force inputs, the overall rib contour shape and deflection may be different between the two dummies. The relative shape of the rib may affect the contact area and location with the posterior wall of the anterior pelvis and the extent to which it influences rib deflection.

TRL also tested the dummy with the arm, rib pad, and jacket, whereas these components were removed in the current study. The rib pad and jacket may have modulated some of the initial deflection of the rib, which could have changed the timing of the interaction with the pelvis flesh.

In addition, TRL used a 2d IRTRACC which incorporates rib rotation to calculate rib deflection. The 1d IRTRACC does not measure rib rotation and tests have shown it to be insensitive to certain loading conditions [8, 9]. Also, the TRL tests used a single plate positioned to impact the abdomen on the load-wall. It is not known how this single plate configuration compares with the offset modular load-wall. In the current study, the thorax and pelvis plates eventually accept the load of the dummy after initial abdomen compression. This load sharing with the other plates limited the overall abdomen rib compression.

Finally, TRL used a single, slightly different, seat configuration where the relative angle between the seat back and seat bottom was 90 degrees. In the current study, the reclined seat configuration relative angle was 113 degrees and the upright was 95 degrees which corresponded to a difference of about 18 degrees between the two seat positions. The seat back and seat bottom angles for the current study were selected as a range of likely seating positions in motor vehicles and probably had more clearance in the reclined position and more interference in the upright position than what are seen in most full scale vehicle crash tests. The TRL tests had 5 more degrees of relative forward lean than the upright seated condition. As shown in Figures 8 and 9, the current study demonstrated significant differences in rib deflections for the standard and modified pelvis based on seating position. Based on this result, there may be enough of a difference in occupant position between the two studies to produce differences in rib deflections.

The reclined seat position showed no statistical difference ($p<0.05$) in peak deflections between the standard and modified pelvis and the force deflection functions were very similar for the two pelvises at all velocities. As the lateral most point of the rib gets pushed inward the plastic sternum rib mount and the anterior portion of the rib gets pushed outward (Figure 16). With the modified pelvis, there is very little or no contact of the rib with the pelvis as it bulges outward. The standard pelvis shows some contact with sternum, but little with the rib. Results of the reclined test suggest that the pelvis does not contain the anterior portion of the rib and has little influence on the rib deflection.

The upright seat position demonstrated statistically ($p<0.05$) greater deflections for the modified pelvis at 3 and 4 m/s and no statistical difference ($p>0.05$) at 5 m/s. The force deflections functions at 3 and 4 m/s showed a stiffer response with the standard pelvis. With the standard pelvis, the entire anterior portion of the rib is placed in contact with the pelvis, while the modified pelvis has slight gap anterio-laterally increasing up to about 10 mm at the sternum. The standard pelvis may have restricted the outward bulging of the sternum rib mount more than the modified pelvis yielding different rib contour profiles. The 1d IRTRACC single axis of deflection measurement may have been insensitive to the different rib shapes at 5 m/s.

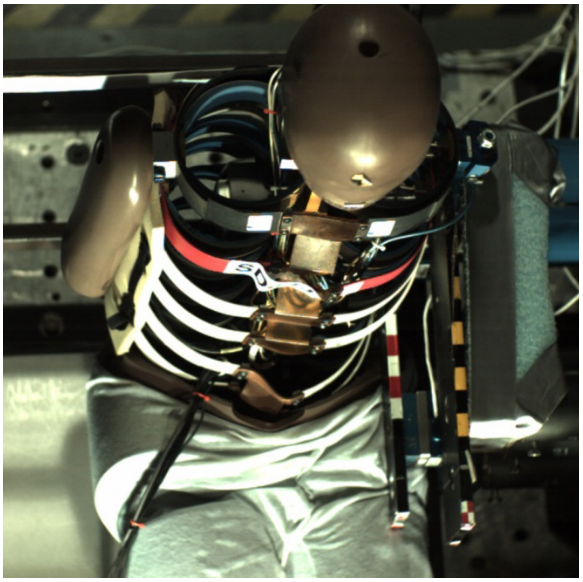

Figure 16: Overhead photograph of WorldSID 50th during impact showing the anterior bulging of the abdomen ribs.

Results of the current investigation suggest that modification to the anterior pelvis flesh may not be the best solution to prevent misalignment of the 2nd abdomen rib. While the pelvis flesh influenced the average peak deflection of the rib at lower velocities in the upright configuration, this effect was insignificant at the highest velocity. Because higher velocities are more representative of real world scenarios wherein the intruding door and side airbag interact with the occupant's torso, the modification of the pelvis may not be necessary. This is further reinforced by the observation that the force deflection curves derived at 5 m/s were very similar for the modified and standard pelvis. Thinning out the pelvis wall may have consequences to regional biofidelity of the pelvis and the overall biofidelity of the dummy. If the pelvis is modified to allow more abdomen deflection, it may reduce deflections in the superior ribs. A more practical solution would be to add a visual/physical check of the abdomen ribs prior to testing. From these perspectives modification of the pelvis should be considered only if rib misalignment becomes an issue in full-scale vehicle crash tests.

ACKNOWLEDGMNETS

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