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WorldSID-50M Repeatability and Reproducibility of Qualification Tests

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16. Abstract

In July 2022 NHTSA published a report summarizing the repeatability and reproducibility evaluation of the Worldwide Harmonized Side Impact Dummy 50th percentile adult male dummy (WorldSID-50M) in qualification tests. After minor revisions to the WorldSID-50M's thorax, NHTSA determined that an updated assessment of the WorldSID-50M's repeatability and reproducibility in qualification tests was warranted. NHTSA's Vehicle Research and Test Center and three independent test labs performed multiple qualification tests on three dummies. Average, standard deviation, and coefficient of variation were calculated for each required measurement parameter of each test condition.

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Table of Contents

Executive Summary **1**

Objective **3**

Background **5**

Thorax Pad 5
LED Positions 6
Flock Paper 8

Methodology **9**

Repeatability, Reproducibility, and Coefficient of Variation 9
Qualification Corridors 9

Shoulder Impacts **11**

Methodology 11
Test Results 11
Qualification Corridors 11
Discussion 12

Thorax With Arm Impacts **13**

Methodology 13
Results 13
Qualification Corridors 14
Discussion 14

Thorax Without Arm Impacts **15**

Methodology 15
Results 15
Qualification Corridors 16
Discussion 16

Abdomen Impacts **17**

Methodology 17
Results 17
Qualification Corridors 18
Discussion 18

Pelvis Impacts **19**

Methodology 19
Results 19
Qualification Corridors 20
Discussion 20

References **21**

Appendix. A **A-1**

Shoulder Impacts A-2
Thorax With Arm Impacts A-10

Thorax Without Arm Impacts A-22
Abdomen Impacts A-34
Pelvis Impacts A-43

List of Figures

Figure 1. Split thorax pad used in the July 2022 R&R study (left). One-piece thorax pad used in the present study (right). 5
Figure 2. Modified thorax without arm probe face attached to the probe 6
Figure 3. CAD model showing crash test with shoulder load cell blocking thorax rib 1 rear LED from top sensor. Gold lines represent path of LED light to top sensor. 7
Figure 4. Thorax rib 1 showing LEDs positioned at the bottom of the rib....7
Figure 5. CAD model showing repeat crash test of vehicle in Figure 3, with thorax rib 1 LEDs moved to the bottom of the rib, and no LEDs were blocked by the shoulder load cell....8
Figure A-1. Shoulder impact probe force – dummy EA-7820 .... A-5
Figure A-2. Shoulder impact probe force – dummy EF-5470 .... A-5
Figure A-3. Shoulder impact probe force – dummy EG-0792 .... A-6
Figure A-4. Shoulder impact shoulder force – dummy EA-7820.... A-6
Figure A-5. Shoulder impact shoulder force – dummy EF-5470 .... A-7
Figure A-6. Shoulder impact shoulder force – dummy EG-0792.... A-7
Figure A-7. Shoulder impact shoulder rib length change – dummy EA-7820 .... A-8
Figure A-8. Shoulder impact shoulder rib length change – dummy EF-5470.... A-8
Figure A-9. Shoulder impact shoulder rib length change – dummy EG-0792 .... A-9
Figure A-10. Thorax with arm impact probe force – dummy EA-7820.... A-13
Figure A-11. Thorax with arm impact probe force – dummy EF-5470.... A-13
Figure A-12. Thorax with arm impact probe force – dummy EG-0792.... A-14
Figure A-13. Thorax with arm impact T4 lateral acceleration – dummy EA-7820 .... A-14
Figure A-14. Thorax with arm impact T4 lateral acceleration – dummy EF-5470 .... A-15
Figure A-15. Thorax with arm impact T4 lateral acceleration – dummy EG-0792 .... A-15
Figure A-16. Thorax with arm impact T12 lateral acceleration – dummy EA-7820 .... A-16
Figure A-17. Thorax with arm impact T12 lateral acceleration – dummy EF-5470 .... A-16
Figure A-18. Thorax with arm impact T12 lateral acceleration – dummy EG-0792 .... A-17
Figure A-19. Thorax with arm impact thorax rib 1 length change – dummy EA-7820 .... A-17
Figure A-20. Thorax with arm impact thorax rib 1 length change – dummy EF-5470.... A-18
Figure A-21. Thorax with arm impact thorax rib 1 length change – dummy EG-0792 .... A-18
Figure A-22. Thorax with arm impact thorax rib 2 length change – dummy EA-7820 .... A-19
Figure A-23. Thorax with arm impact thorax rib 2 length change – dummy EF-5470.... A-19
Figure A-24. Thorax with arm impact thorax rib 2 length change – dummy EG-0792 .... A-20
Figure A-25. Thorax with arm impact thorax rib 3 length change – dummy EA-7820 .... A-20
Figure A-26. Thorax with arm impact thorax rib 3 length change – dummy EF-5470.... A-21
Figure A-27. Thorax with arm impact thorax rib 3 length change – dummy EG-0792 .... A-21
Figure A-28. Thorax without arm impact probe force – dummy EA-7820.... A-25
Figure A-29. Thorax without arm impact probe force – dummy EF-5470 .... A-25

Figure A-30. Thorax without arm impact probe force – dummy EG-0792 ..... A-26
Figure A-31. Thorax without arm impact T4 lateral acceleration – dummy EA-7820 ..... A-26
Figure A-32. Thorax without arm impact T4 lateral acceleration – dummy EF-5470 ..... A-27
Figure A-33. Thorax without arm impact T4 lateral acceleration – dummy EG-0792 ..... A-27
Figure A-34. Thorax without arm impact T12 lateral acceleration – dummy EA-7820 ..... A-28
Figure A-35. Thorax without arm impact T12 lateral acceleration – dummy EF-5470 ..... A-28
Figure A-36. Thorax without arm impact T12 lateral acceleration – dummy EG-0792 ..... A-29
Figure A-37. Thorax without arm impact thorax rib 1 length change – dummy EA-7820 ..... A-29
Figure A-38. Thorax without arm impact thorax rib 1 length change – dummy EF-5470 ..... A-30
Figure A-39. Thorax without arm impact thorax rib 1 length change – dummy EG-0792 ..... A-30
Figure A-40. Thorax without arm impact thorax rib 2 length change – dummy EA-7820 ..... A-31
Figure A-41. Thorax without arm impact thorax rib 2 length change – dummy EF-5470 ..... A-31
Figure A-42. Thorax without arm impact thorax rib 2 length change – dummy EG-0792 ..... A-32
Figure A-43. Thorax without arm impact thorax rib 3 length change – dummy EA-7820 ..... A-32
Figure A-44. Thorax without arm impact thorax rib 3 length change – dummy EF-5470 ..... A-33
Figure A-45. Thorax without arm impact thorax rib 3 length change – dummy EG-0792 ..... A-33
Figure A-46. Abdomen impact probe force – dummy EA-7820 ..... A-37
Figure A-47. Abdomen impact probe force – dummy EF-5470 ..... A-37
Figure A-48. Abdomen impact probe force – dummy EG-0792 ..... A-38
Figure A-49. Abdomen impact T12 lateral acceleration – dummy EA-7820 ..... A-38
Figure A-50. Abdomen impact T12 lateral acceleration – dummy EF-5470 ..... A-39
Figure A-51. Abdomen impact T12 lateral acceleration – dummy EG-0792 ..... A-39
Figure A-52. Abdomen impact abdomen rib 1 length change – dummy EA-7820 ..... A-40
Figure A-53. Abdomen impact abdomen rib 1 length change – dummy EF-5470 ..... A-40
Figure A-54. Abdomen impact abdomen rib 1 length change – dummy EG-0792. Note: vertical lines in plot were attributed to intermittent and loose LEDs. Peak response values were not affected A-41
Figure A-55. Abdomen impact abdomen rib 2 length change – dummy EA-7820 ..... A-41
Figure A-56. Abdomen impact abdomen rib 2 length change – dummy EF-5470 ..... A-42
Figure A-57. Abdomen impact abdomen rib 2 length change – dummy EG-0792 ..... A-42
Figure A-58. Pelvis impact probe force – dummy EA-7820 ..... A-46
Figure A-59. Pelvis impact probe force – dummy EF-5470 ..... A-46
Figure A-60. Pelvis impact probe force – dummy EG-0792 ..... A-47
Figure A-61. Pelvis impact T12 lateral acceleration – dummy EA-7820 ..... A-47
Figure A-62. Pelvis impact T12 lateral acceleration – dummy EF-5470 ..... A-48
Figure A-63. Pelvis impact T12 lateral acceleration – dummy EG-0792 ..... A-48
Figure A-64. Pelvis impact pubic force – dummy EA-7820 ..... A-49
Figure A-65. Pelvis impact pubic force – dummy EF-5470 ..... A-49
Figure A-66. Pelvis impact pubic force – dummy EG-0792 ..... A-50

Figure A-67. Pelvis impact sacroiliac lateral force – dummy EA-7820 ..... A-50
Figure A-68. Pelvis impact sacroiliac lateral force – dummy EF-5470 ..... A-51
Figure A-69. Pelvis impact sacroiliac lateral force – dummy EG-0792 ..... A-51
Figure A-70. Pelvis impact pelvis lateral acceleration – dummy EA-7820 ..... A-52
Figure A-71. Pelvis impact pelvis lateral acceleration – dummy EF-5470 ..... A-52
Figure A-72. Pelvis impact pelvis lateral acceleration – dummy EG-0792 ..... A-53

List of Tables

Table 1. Shoulder impact R&R results 11
Table 2. Shoulder impact qualification corridors 11
Table 3. Thorax with arm impact R&R results 13
Table 4. Thorax with arm impact qualification corridors 14
Table 5. Thorax without arm impact R&R results 15
Table 6. Thorax without arm impact qualification corridors 16
Table 7. Abdomen impact R&R results 17
Table 8. Abdomen impact qualification corridors 18
Table 9. Pelvis impact R&R results 19
Table 10. Pelvis impact qualification corridors 20
Table A-1. Shoulder impact tests – dummy EA-7820 ..... A-2
Table A-2. Shoulder impact tests – dummy EF-5470 ..... A-3
Table A-3. Shoulder impact tests – dummy EG-0792 ..... A-4
Table A-4. Thorax with arm impact tests – dummy EA-7820 ..... A-10
Table A-5. Thorax with arm impact tests – dummy EF-5470 ..... A-11
Table A-6. Thorax with arm impact tests – dummy EG-0792 ..... A-12
Table A-7. Thorax without arm impact tests – dummy EA-7820 ..... A-22
Table A-8. Thorax without arm impact tests – dummy EF-5470 ..... A-23
Table A-9. Thorax without arm impact tests – dummy EG-0792 ..... A-24
Table A-10. Abdomen impact tests – dummy EA-7820 ..... A-34
Table A-11. Abdomen impact tests – dummy EF-5470 ..... A-35
Table A-12. Abdomen impact tests – dummy EG-0792 ..... A-36
Table A-13. Pelvis impact tests – dummy EA-7820 ..... A-43
Table A-14. Pelvis impact tests – dummy EF-5470 ..... A-44
Table A-15. Pelvis impact tests – dummy EG-0792 ..... A-45

Executive Summary

In July 2022 the National Highway Traffic Safety Administration published a report (Rhule & Stricklin, 2022) summarizing the repeatability and reproducibility (R&R) evaluation of the Worldwide Harmonized Side Impact Dummy 50th percentile adult male dummy (WorldSID-50M) in qualification tests ("July 2022 R&R report"). In that report, NHTSA established preliminary response requirements for the dummy's qualification tests. Since the report's completion, however, modifications to the dummy's configuration have occurred. These modifications could potentially result in minor changes to the dummy's response characteristics, therefore NHTSA decided that an assessment of the updated dummy's R&R in qualification tests was warranted.

Qualification tests were performed using the draft procedures specified in the manual titled *WorldSID 50th Percentile Male (WorldSID-50M) Qualification Procedures and Requirements* (NHTSA, 2024). NHTSA's Vehicle Research and Test Center (VRTC) performed several tests on three dummies. Additionally, NHTSA contracted with three independent testing labs to perform additional qualification tests on the same dummies. The test conditions included shoulder impacts, thorax (with and without arm) impacts, abdomen impacts, and pelvis impacts. Average, standard deviation, and coefficient of variation (CV) were calculated for each required measurement parameter of each test condition.

The results of the qualification test statistical analysis generally showed CV values less than 5 percent for the parameters examined with a few exceptions noted. In cases when CV values exceeded 5 percent, the result could generally be attributed to one of the dummies exhibiting a response that, although repeatable, was marginally different than that displayed by the other dummies. New qualification test response corridors were generated based on the results observed in the R&R assessment.

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Objective

The objective of this study was to perform qualification tests at several labs using three dummies to assess the WorldSID-50M's R&R, and to establish acceptance criteria for the qualification tests (i.e., qualification corridors).

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Background

After publication of the July 2022 R&R report, several design changes were identified and implemented into the WorldSID-50M, primarily intended to refine the performance of the dummy's thorax.

Thorax Pad

The original design of the WorldSID-50M utilized a one-piece thorax pad covering the lateral aspect of the thorax, extending from just above the top of thorax rib 1 to just below the bottom of abdomen rib 2. Tears in the one-piece thorax pad were frequently observed following thorax qualification tests, particularly between thorax rib 3 and abdomen rib 1. As a result, in the July 2022 R&R report NHTSA proposed the use of a split thorax pad configuration designed to minimize tearing that frequently occurred in thorax without arm qualification tests. While this configuration eliminated the possibility of damaging the thorax pad in qualification tests, it also removed the coupling effect between adjacent ribs that the one-piece thorax pad provided. Figure 1 illustrates the split thorax pad and the one-piece thorax pad. Subsequently, a proposal was made to modify the impact face of the probe used in the thorax without arm test. This new probe face (Figure 2) has demonstrated to substantially reduce the risk of tearing the one-piece thorax pad and thus NHTSA has adopted the one-piece thorax pad and the new probe impact face. Note that the new probe impact face is only used in the thorax without arm qualification test; the probe face for the thorax with arm test remains unchanged.

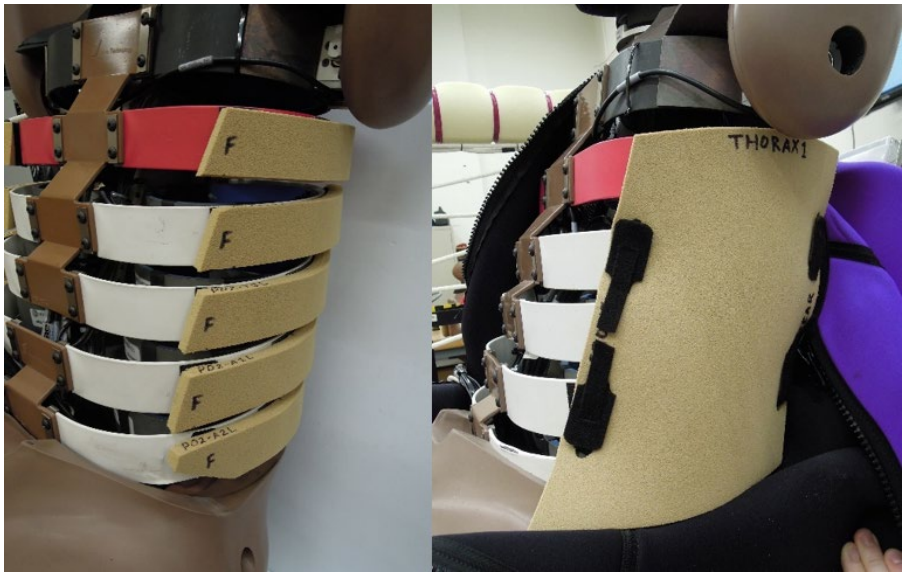

Figure 1. Split thorax pad used in the July 2022 R&R study (left). One-piece thorax pad used in the present study (right).

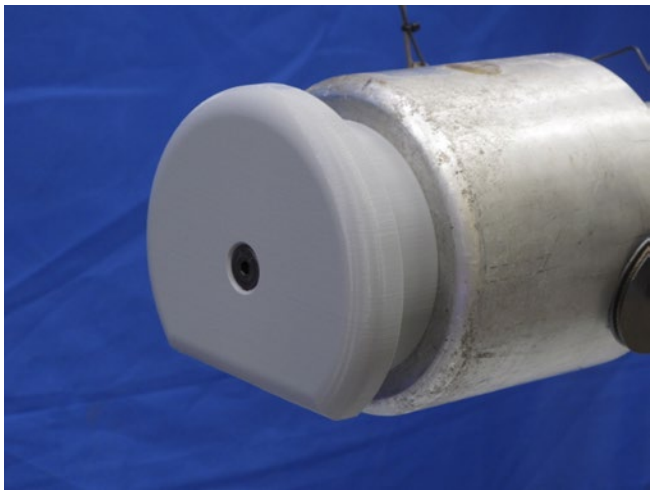

Figure 2. Modified thorax without arm probe face attached to the probe

LED Positions

The RibEye multi-point deflection measurement system uses electro-optical instruments to measure the three-dimensional position of several locations on each rib. When configured for the WorldSID-50M, the RibEye consists of two groups of three sensors (receivers) mounted on the impact side of the spine box, one at each rib level, and three light emitting diodes (LEDs) per rib, mounted on the inner surface of the inner rib on the impact side. In certain loading conditions, adjacent ribs may experience a significant difference in their amount of lateral displacement. For example, the shoulder rib might have direct loading and experience a relatively large displacement, while thorax rib 1 sees little or no loading and therefore has much less displacement than the shoulder rib. If the disparity in displacement is large enough, it is possible that the rib experiencing higher displacement may effectively block the path of the LED light emitted from the adjacent rib as illustrated by the CAD model in Figure 3.

The LEDs are strategically located along the rib length to capture the maximum rib deflection, which is a combination of x and y displacements. To reduce the likelihood of one rib blocking the LEDs of an adjacent rib, the vertical locations of the LEDs on thorax rib 1 and abdomen rib 1 have been moved from the middle of the rib to the bottom of the rib as shown in Figure 4. Figure 5 shows the CAD model of the upper three ribs loaded under the same conditions as Figure 3, but with the LEDs on thorax rib 1 moved to the bottom of the rib. This illustrates how moving the LEDs to the bottom of the rib reduces the likelihood of the rib above blocking the LED. Additional details of LED positions and RibEye operation are in the RibEye Evaluation report (Rhule et al., in press).

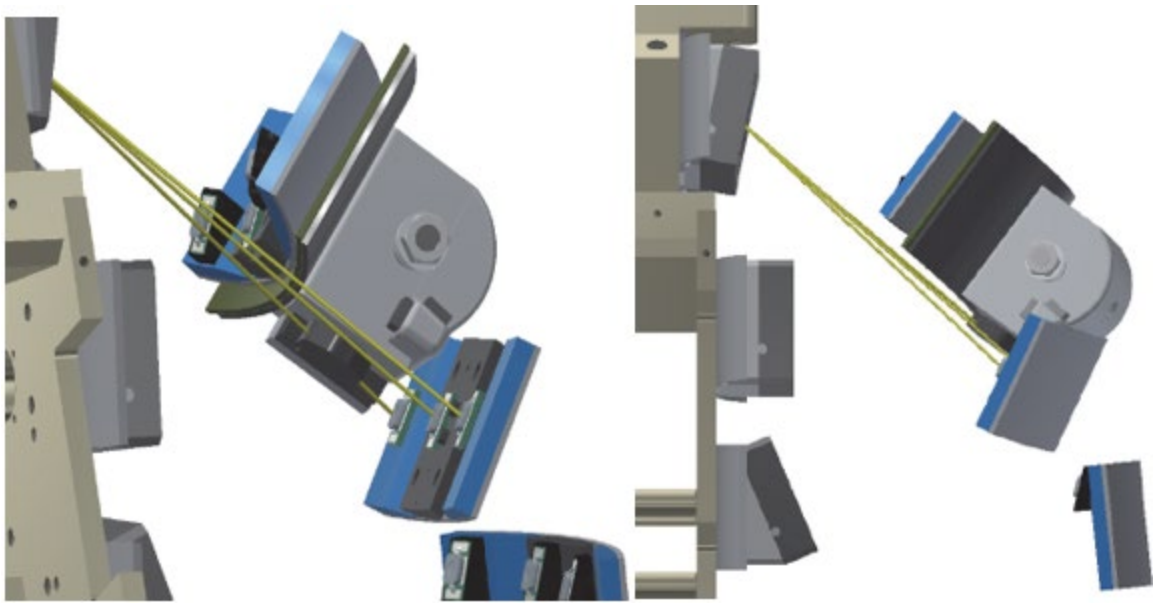

Figure 3. CAD model showing crash test with shoulder load cell blocking thorax rib 1 rear LED from top sensor. Gold lines represent path of LED light to top sensor.

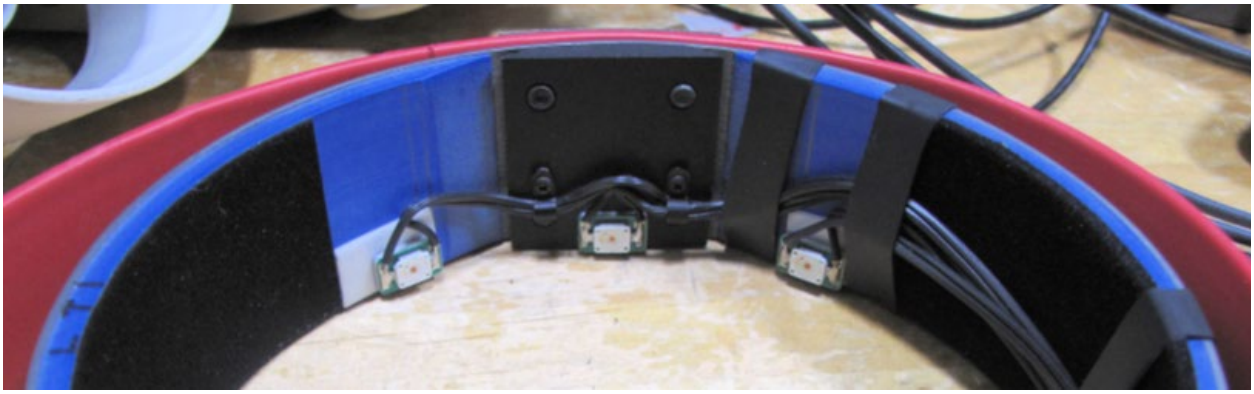

Figure 4. Thorax rib 1 showing LEDs positioned at the bottom of the rib

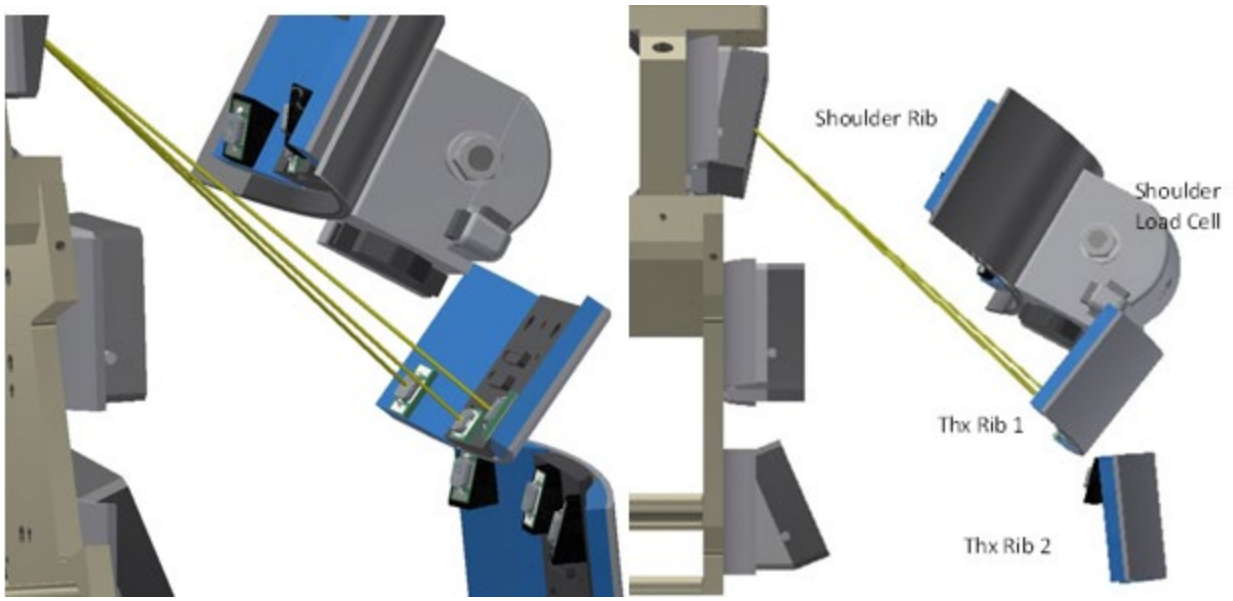

Figure 5. CAD model showing repeat crash test of vehicle in Figure 3, with thorax rib 1 LEDs moved to the bottom of the rib, and no LEDs were blocked by the shoulder load cell

Flock Paper

Accurate performance of the RibEye system requires that the sensors accurately detect the light from the LEDs. Reflected light from surrounding surfaces, such as the rib damping material, can result in measurement errors. To minimize such errors, flock paper, a light absorbing material, is applied to the inner surface of the rib damping material. Flock paper is shown on thorax rib 1 in Figure 4.

Methodology

Repeatability, Reproducibility, and Coefficient of Variation

Qualification tests were performed on the body regions that were potentially affected by the design changes discussed in the previous section. This included the following qualification tests: shoulder, thorax with arm, thorax without arm, abdomen, and pelvis. Tests were conducted according to the procedures described in the manual called *WorldSID 50th Percentile Male (WorldSID-50M) Qualification Procedures and Requirements* (NHTSA, 2024). The three WorldSID-50M dummies utilized for this study were manufactured by Humanetics, Inc.[1] VRTC subsequently installed a RibEye electro-optical deflection measurement system in each dummy. All test data in this report was collected in compliance with SAE J211 polarity specifications (SAE International, 2022).

WorldSID-50M dummies EA-7820, EF-5470, and EG-0792 were each tested at four labs: VRTC, Humanetics, MGA, and Calspan. For each qualification test condition, each lab conducted five repeat impacts. The data acquired from these tests was used to assess repeatability and reproducibility; this data was also used to generate the qualification corridors for each response requirement.

Repeatability is defined as the similarity of responses from a single dummy when subjected to multiple repeats of a given test condition. Reproducibility is defined as the similarity of test responses from multiple dummies when subjected to multiple repeats of a given test condition. A quantitative assessment of R&R is achieved by evaluating the CV for each measured response. The CV is a measure of variability expressed as a percentage of the mean. CV is calculated as follows:

Equation 1. Formula for CV

$$CV(\%) = \frac{\sigma}{\overline{X}} \times 100$$

where σ = standard deviation of responses

$\overline{X}$ = mean of responses

Results were assessed using the following criteria for the CV:

Below 5 percent: No further investigation needed.

Between 5- 10 percent: Sources of variability investigated; outliers may exist.

Greater than 10 percent: Test procedure thoroughly reviewed, and dummies inspected.

Qualification Corridors

A set of responses with a CV below 5 percent indicates the dummy is highly repeatable and reproducible in that test condition. In this study, the responses in all tests with a CV below 5 percent were also within ±10 percent of the target response, and no further examination of the data or test condition was carried out.

[1] Humanetics Innovative Solutions, Inc. Farmington Hills, Michigan. www.humaneticsgroup.com

When a test condition produced a CV above 5 percent, a response in at least one test was outside the ±10 percent limits, and when the CV exceeded 10 percent, several tests were outside the limits. In these instances, a close examination of the data and procedure was performed to pinpoint the source of the variation. When possible, an explanation for the likely source of the variation is provided.

To establish the acceptance criteria for the qualification tests, limits have been set at ±10 percent of the mean value for each measurement.

Shoulder Impacts

Methodology

The shoulder qualification test is a dynamic impact to the center of the arm pivot joint using a 23.36 kg rigid impactor at 4.30 m/s. Responses measured in this test include probe force, shoulder force, and shoulder rib length change. All tests were performed on the dummies' left side.

Test Results

The shoulder impact R&R test results are summarized in Table 1. All individual test results (Tables A-1 to A-3) and response plots (Figures A-1 to A-9) are in Appendix A.

Table 1. Shoulder impact R&R results

Dummy S/N	Metric	Peak Impactor Force	Peak Shoulder Rib Length Change	Peak Shoulder Force
		kN	mm	kN
EA-7820	Mean	3.01	37.8	-1.65
	Std Dev	0.05	1.21	0.04
	CV	1.80%	3.20%	2.42%
EF-5470	Mean	2.71	39.2	-1.65
	Std Dev	0.07	0.60	0.05
	CV	2.71%	1.53%	2.90%
EG-0792	Mean	3.00	38.9	-1.72
	Std Dev	0.10	0.72	0.03
	CV	3.26%	1.85%	1.80%
ALL	Mean	2.91	38.6	-1.67
	Std Dev	0.16	1.1	0.05
	CV	5.50%	2.74%	3.13%

Qualification Corridors

The qualification corridors were calculated using the mean plus or minus 10 percent of the mean of the specified response. The shoulder impact qualification corridors are summarized in Table 2.

Table 2. Shoulder impact qualification corridors

Parameter	Units	Min	Max
Peak Impactor Force	kN	2.62	3.20
Peak Shoulder Rib Length Change	mm	34.8	42.5
Peak Shoulder Force	kN	-1.84	-1.51

Discussion

The CV values for each dummy were well below 5 percent for all measured parameters, indicating good repeatability. When combining the responses of all three dummies to assess reproducibility, the CV values were also below 5 percent except for one parameter, peak impactor force, which was only marginally above 5 percent. Dummies EA-7820 and EG-0792 exhibited nearly identical values for mean impactor force (3.01 and 3.00 kN, respectively) while dummy EF-5470's response was somewhat lower with a mean value of 2.71 kN. A review of the individual test data for EF-5470 reveals that only two of the 20 tests conducted provided responses that did not fall within the ±10 percent qualification corridors. Additionally, for each of the two non-compliant instances, the response was within 0.7 percent of passing. For these reasons, the qualification corridors remained set at ±10 percent of the mean value.

Thorax With Arm Impacts

Methodology

The thorax with arm qualification test is a dynamic impact to the thorax using a 23.36 kg rigid impactor. For this test, the center of the impactor is aligned with the center of thorax rib 2 at its lateral-most point, and then the dummy's half-arm is positioned so that it is interposed between the impactor and the thorax ribs. Responses measured in this test include probe force, T4 and T12 lateral acceleration, and length change of all three thoracic ribs. All tests were performed on the dummies' left side.

Results

The thorax with arm impact R&R test results are summarized in Table 3. All individual test results (Tables A-4 to A-6) and response plots (Figures A-10 to A-27) are in Appendix A.

Table 3. Thorax with arm impact R&R results

Dummy S/N	Metric	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
		kN	g	g	mm	mm	mm
EA-7820	Mean	6.27	34.1	25.7	41.7	43.4	35.0
	Std Dev	0.12	1.03	0.89	0.72	1.02	0.95
	CV	1.88%	3.00%	3.44%	1.74%	2.35%	2.71%
EF-5470	Mean	6.16	34.6	26.6	40.3	46.5	38.1
	Std Dev	0.21	1.67	1.25	0.72	1.35	1.15
	CV	3.34%	4.83%	4.71%	1.78%	2.91%	3.01%
EG-0792	Mean	6.17	35.5	26.5	40.9	44.7	36.4
	Std Dev	0.13	1.05	0.71	0.88	0.84	0.95
	CV	2.18%	2.95%	2.69%	2.16%	1.89%	2.61%
ALL	Mean	6.20	34.8	26.3	41.0	44.9	36.5
	Std Dev	0.16	1.39	1.04	0.96	1.66	1.64
	CV	2.62%	4.00%	3.95%	2.33%	3.69%	4.50%

Qualification Corridors

The qualification corridors were calculated using the mean plus or minus 10 percent of the mean of the specified response. The thorax with arm impact qualification corridors is summarized in Table 4.

Table 4. Thorax with arm impact qualification corridors

Parameter	Units	Min	Max
Peak Impactor Force	kN	5.58	6.82
Peak T4 Lateral Acceleration	g	31.3	38.2
Peak T12 Lateral Acceleration	g	23.6	28.9
Peak Length Change - Thorax Rib 1	mm	36.9	45.1
Peak Length Change - Thorax Rib 2	mm	40.4	49.3
Peak Length Change - Thorax Rib 3	mm	32.8	40.1

Discussion

All tests were within the ±10 percent qualification corridors and all CV values were less than 5 percent, indicating good repeatability and reproducibility. There were no indications of any issues for this test condition.

Thorax Without Arm Impacts

Methodology

The thorax without arm qualification test is a dynamic impact to the thorax using a 23.36 kg rigid impactor with the modified 0.50 kg face attachment (total mass is 23.86 kg). For this test, the center of the impactor is aligned with the center of thorax rib 2 at its lateral-most point, and the impacted-side half-arm is raised so that the impactor directly contacts the ribs. Responses measured in this test include probe force, T4 and T12 lateral acceleration, and length change of all three thoracic ribs. All tests were performed on the dummies' left side.

Results

The thorax without arm impact R&R test results are shown in Table 5. All individual test results (Tables A-7 to A-9) and response plots (Figures A-28 to A-45) are in Appendix A.

Table 5. Thorax without arm impact R&R results

Dummy S/N	Metric	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
					Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
		kN	g	g	mm	mm	mm
EA-7820	Mean	3.66	14.4	14.6	37.5	39.1	33.6
	Std Dev	0.05	0.72	1.25	0.48	0.37	0.79
	CV	1.41%	5.01%	8.55%	1.29%	0.94%	2.37%
EF-5470	Mean	3.56	15.6	15.4	38.7	42.9	36.6
	Std Dev	0.06	1.08	0.83	1.24	1.43	1.14
	CV	1.74%	6.88%	5.38%	3.20%	3.32%	3.12%
EG-0792	Mean	3.60	15.6	15.9	37.5	39.6	35.0
	Std Dev	0.05	0.89	0.88	1.09	0.83	0.90
	CV	1.40%	5.68%	5.53%	2.90%	2.10%	2.58%
ALL	Mean	3.61	15.2	15.3	37.9	40.5	35.1
	Std Dev	0.07	1.05	1.14	1.12	1.96	1.57
	CV	1.91%	6.92%	7.43%	2.94%	4.83%	4.49%

Qualification Corridors

The qualification corridors were calculated using the mean plus or minus 10 percent of the mean of the specified response. The thorax without arm impact qualification corridors is summarized in Table 6.

Table 6. Thorax without arm impact qualification corridors

Parameter	Units	Min	Max
Peak Impactor Force	kN	3.25	3.97
Peak Length Change -Thorax Rib 1	mm	34.1	41.7
Peak Length Change -Thorax Rib 2	mm	36.5	44.6
Peak Length Change -Thorax Rib 3	mm	31.6	38.6

Discussion

Repeatability and reproducibility were less than 5 percent for peak impactor force and peak length change of all three thoracic ribs. Additionally, all tests were within the ±10 percent corridors for peak impactor force and peak length change for thorax ribs 1 and 3. Peak length change of thorax rib 2 exhibited 2 tests that were outside of the ±10 percent corridors, but only by 0.1 and 0.3 mm, respectively. Considering that the CV of thorax rib 2 was less than 5 percent, NHTSA considers the ±10 percent corridors to be appropriate for these measurements.

Repeatability and reproducibility were greater than 5 percent for the peak T4 and T12 lateral accelerations. The mean T4 and T12 values for the thorax without arm test were 15.2 and 15.3 g, respectively. In comparison, the values for peak T4 and T12 acceleration in the thorax with arm test were 34.8 and 26.3 g. The relatively low magnitudes of the mean T4 and T12 accelerations in the without arm condition contribute to the higher CV results in this test condition (see Equation 1); i.e. a smaller mean value for a given standard deviation produces a larger CV. Review of the individual test responses indicate that nine tests would fall outside of the ±10 percent corridors for T4 and 12 tests would fall outside of the ±10 percent corridors for T12. Thus, NHTSA believes that the viability of T4 and T12 accelerations are best assessed in the thorax with arm test and therefore, no assessment of T4 or T12 acceleration will be required in the thorax without arm qualification test. It's also worth noting that NHTSA is not currently considering any injury assessment based on the T4/T12 responses.

Abdomen Impacts

Methodology

The abdomen qualification test is a dynamic impact to the abdomen using a 24.36 kg rigid impactor with the armrest simulator face attachment at 4.30 m/s. The impactor mass of 24.36 kg includes the standard impactor mass of 23.36 kg and the armrest simulator face attachment with a mass of 1.0 kg. For this test, the center of the impactor is aligned with the center of the space between abdomen rib 1 and abdomen rib 2 at their lateral-most points. The impact-side half-arm is positioned in the detent that places the arm in the most-raised position (nearly horizontal). Responses measured in this test include probe force, T12 lateral acceleration, and length change of both abdominal ribs. All tests were performed on the dummies' left side.

Results

The abdomen impact R&R test results are summarized in Table 7. All individual test results (Tables A-10 to A-12) and response plots (Figures A-46 to A-57) are in Appendix A.

Table 7. Abdomen impact R&R results

Dummy S/N	Metric	Peak Impactor Force	Peak T12 Y-axis Accel	Peak Length Change	
				Abdomen Rib 1	Abdomen Rib 2
		kN	g	mm	mm
EA-7820	Mean	3.28	16.6	34.2	34.1
	Std Dev	0.07	0.37	0.88	0.80
	CV	2.28%	2.25%	2.57%	2.36%
EF-5470	Mean	3.18	17.8	36.2	34.9
	Std Dev	0.07	0.40	0.84	0.95
	CV	2.35%	2.23%	2.32%	2.72%
EG-0792	Mean	3.16	17.5	34.0	34.8
	Std Dev	0.04	0.30	0.69	0.67
	CV	1.35%	1.71%	2.04%	1.94%
ALL	Mean	3.21	17.3	34.8	34.6
	Std Dev	0.08	0.62	1.27	0.88
	CV	2.61%	3.57%	3.66%	2.55%

Qualification Corridors

The qualification corridors were calculated using the mean plus or minus 10 percent of the mean of the specified response. The abdomen impact qualification corridors are summarized in Table 8.

Table 8. Abdomen impact qualification corridors

Parameter	Units	Min	Max
Peak Impactor Force	kN	2.88	3.53
Peak T12 Lateral Acceleration	g	15.6	19.0
Peak Length Change - Abdomen Rib 1	mm	31.3	38.3
Peak Length Change - Abdomen Rib 2	mm	31.1	38.0

Discussion

All tests were within the ±10 percent qualification corridors and all CV values for both repeatability and reproducibility were less than 5 percent. There were no indications of any issues for this test condition.

Pelvis Impacts

Methodology

The pelvis qualification test is a dynamic impact to the pelvis using a 23.36 kg rigid impactor at 6.70 m/s. For this test, the center of the impactor is aligned with the H-point and the impact-side half-arm is positioned in the detent that places the arm in the most-raised position (nearly horizontal). Responses measured in this test include probe force, T12 and pelvis lateral accelerations, and pubic symphysis and sacroiliac lateral forces. All tests were performed on the dummies' left side.

Results

The pelvis impact R&R test results are summarized in Table 9. All individual test results (Tables A-13 to A-15) and response plots (Figures A-58 to A-72) are in Appendix A.

Table 9. Pelvis impact R&R results

Dummy S/N	Metric	Peak Impactor Force	Peak Pubic Y-force	Peak Sacroiliac Y-force	Peak T12 Y-accel	Peak Pelvis Y-accel
		kN	kN	kN	g	g
EA-7820	Mean	8.06	-1.50	-2.40	13.6	41.1
	Std Dev	0.08	0.04	0.05	0.86	1.03
	CV	1.00%	2.46%	1.91%	6.33%	2.51%
EF-5470	Mean	7.67	-1.29	-2.08	12.6	41.6
	Std Dev	0.10	0.05	0.09	0.66	2.06
	CV	1.26%	3.58%	4.31%	5.21%	4.95%
EG-0792	Mean	8.01	-1.37	-2.14	12.0	44.1
	Std Dev	0.21	0.06	0.06	0.51	1.16
	CV	2.56%	4.04%	2.86%	4.20%	2.64%
ALL	Mean	7.91	-1.39	-2.21	12.8	42.3
	Std Dev	0.22	0.10	0.16	0.95	1.99
	CV	2.79%	7.13%	7.16%	7.43%	4.70%

Qualification Corridors

The qualification corridors were calculated using the mean plus or minus 10 percent of the mean of the specified response. The pelvis impact qualification corridors are summarized in Table 10.

Table 10. Pelvis impact qualification corridors

Parameter	Units	Min	Max
Peak Impactor Force	kN	7.12	8.70
Peak Pubic Y-Force	kN	-1.53	-1.25
Peak Sacroiliac Y-Force	kN	-2.43	-1.98
Peak Pelvis Lateral Acceleration	g	38.0	46.5

Discussion

For the peak impactor force and the peak pelvis lateral acceleration responses, all tests were within the ±10 percent qualification corridors and all CV values were less than 5 percent, indicating good repeatability and reproducibility of these parameters.

Concerning T12 lateral accelerations, dummy EG-0792 displayed repeatability less than 5 percent, however, repeatability of EA-7820 and EF-5470 were both greater than 5 percent. In addition, the reproducibility of the T12 response was greater than 5 percent. Similar to the observations made regarding T4/T12 accelerations in the thorax without arm test, the relatively low mean value of the T12 acceleration response contributes to the higher CV scores. As NHTSA is not considering the T12 response for any injury assessment purposes, there will be no requirements on the T12 responses for the pelvis test condition.

For the peak pubic and sacroiliac forces, repeatability values were less than 5 percent for the individual dummies, however, the reproducibility values were greater than 5 percent. As seen in Table 9, dummies EF-5470 and EG-0792 had similar mean response values for peak pubic and sacroiliac forces, while the magnitude of EA-7820's responses were greater than the other two dummies. Despite efforts to examine this observation, VRTC has been unable to identify the root cause of dummy-to-dummy variation in pubic and sacroiliac loads. NHTSA is currently considering using both peak pubic and sacroiliac force for injury assessment purposes, and therefore these responses will have acceptance corridors of ±10 percent of the mean. NHTSA will continue to investigate the source of variation in these responses. Additionally, NHTSA has been notified by the dummy manufacturer (Humanetics) that one of the primary materials used in the construction of the pelvis (Hyperlast) has become obsolete and will be replaced with a new material. It is unclear how this material change will affect the dummy's responses in pelvis qualification tests and therefore likely that pelvis R&R, as well as the qualification corridors, will need to be reassessed once the material change has been implemented and NHTSA has evaluated the new material.

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Appendix. A

Shoulder Impacts

Table A-1. Shoulder impact tests – dummy EA-7820

Dummy S/N	Lab	Test ID	Test #	Impact Speed m/s	Rib Temp ºC	Peak Impactor Force kN	Peak Shoulder Rib Length Change mm	Peak Shoulder Force kN
EA-7820	VRTC	221026-1	1	4.28	21.5	2.93	40.4	-1.69
		221026-2	2	4.29	23.0	3.03	39.2	-1.68
		221026-3	3	4.28	22.9	3.02	39.1	-1.65
		221026-4	4	4.29	22.4	3.02	38.5	-1.69
		221026-5	5	4.29	22.0	3.02	39.6	-1.66
	Humanetics	230105-1	1	4.30	21.6	3.02	37.3	-1.70
		230105-2	2	4.30	21.3	2.98	36.8	-1.67
		230105-3	3	4.30	21.4	3.00	37.8	-1.66
		230106-4	4	4.29	21.1	2.95	37.9	-1.68
		230106-5	5	4.30	21.3	3.04	38.9	-1.68
	MGA	230208-1	1	4.29	21.5	2.91	36.4	-1.68
		230208-3	2	4.30	21.3	3.09	36.6	-1.60
		230208-4	3	4.29	21.6	3.06	36.7	-1.57
		230208-5	4	4.29	21.4	2.98	36.1	-1.58
		230208-7	5	4.31	21.6	2.92	36.0	-1.57
	Calspan	230307-2	1	4.30	22.6	3.05	37.6	-1.65
		230308-1	2	4.30	21.1	3.08	37.6	-1.66
		230308-2	3	4.30	22.1	3.05	37.4	-1.66
		230308-3	4	4.30	22.8	3.07	38.0	-1.64
		230308-4	5	4.30	21.5	3.08	37.7	-1.65
All Tests EA-7820			Mean			3.01	37.8	-1.65
			Std Dev			0.05	1.21	0.04
			CV			1.80%	3.20%	2.42%

Table A-2. Shoulder impact tests – dummy EF-5470

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak Shoulder Rib Length Change	Peak Shoulder Force
				m/s	ºC	kN	mm	kN
EF-5470	VRTC	221114-1	1	4.31	21.9	2.82	38.3	-1.72
		221115-1	2	4.30	21.0	2.65	38.4	-1.67
		221115-2	3	4.30	21.1	2.67	38.7	-1.64
		221115-3	4	4.30	21.4	2.65	39.6	-1.65
		221115-4	5	4.30	21.1	2.61	39.4	-1.63
	Calspan	230104-1	1	4.28	21.6	2.75	40.4	-1.69
		230105-2	2	4.28	21.6	2.89	38.7	-1.70
		230105-3	3	4.28	22.4	2.76	40.0	-1.69
		230105-4	4	4.30	22.4	2.74	40.0	-1.69
		230105-5	5	4.31	22.6	2.73	40.2	-1.69
	Humanetics	230302-1	1	4.30	21.3	2.69	38.5	-1.56
		230302-2	2	4.29	21.3	2.60	39.2	-1.57
		230302-3	3	4.29	21.2	2.73	39.0	-1.58
		230302-4	4	4.29	21.3	2.64	39.0	-1.58
		230302-5	5	4.29	21.2	2.63	39.2	-1.59
	MGA	230324-1	1	4.32	21.6	2.68	38.8	-1.68
		230324-2	2	4.31	21.5	2.77	39.1	-1.68
		230324-3	3	4.31	21.5	2.66	39.1	-1.65
		230324-4	4	4.31	21.5	2.76	39.0	-1.67
		230324-5	5	4.32	21.6	2.76	38.7	-1.68
All Tests EF-5470			Mean			2.71	39.2	-1.65
			Std Dev			0.07	0.60	0.05
			CV			2.71%	1.53%	2.90%

Table A-3. Shoulder impact tests – dummy EG-0792

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak Shoulder Rib Length Change	Peak Shoulder Force
				m/s	ºC	kN	mm	kN
EG-0792	VRTC	221123-1	1	4.30	23.1	2.81	40.8	-1.69
		221123-2	2	4.30	21.9	2.91	38.7	-1.77
		221123-4	3	4.30	21.4	2.93	39.5	-1.73
		221123-6	4	4.30	21.4	2.92	38.7	-1.75
		221123-7	5	4.30	21.3	2.88	39.2	-1.72
	Calspan	230227-1	1	4.30	23.0	2.97	39.6	-1.66
		230227-2	2	4.30	22.3	2.96	38.9	-1.69
		230228-1	3	4.30	22.4	2.90	38.3	-1.69
		230228-2	4	4.30	21.4	2.94	38.2	-1.69
		230228-3	5	4.30	23.0	2.93	39.0	-1.67
	Humanetics	230404-1	1	4.31	21.7	3.09	39.3	-1.74
		230405-1	2	4.30	20.6	3.11	38.7	-1.76
		230405-2	3	4.30	21.0	3.15	38.9	-1.74
		230405-4	4	4.30	21.0	3.15	39.5	-1.73
		230410-5	5	4.30	21.8	3.04	39.5	-1.77
	MGA	230504-1	1	4.32	21.3	3.05	37.5	-1.74
		230504-2	2	4.32	21.5	3.12	38.2	-1.73
		230504-3	3	4.27	20.9	3.08	38.3	-1.73
		230504-4	4	4.29	20.6	3.01	38.2	-1.74
		230504-5	5	4.29	20.8	2.98	39.1	-1.72
All Tests EG-0792			Mean			3.00	38.9	-1.72
			Std Dev			0.10	0.72	0.03
			CV			3.26%	1.85%	1.80%

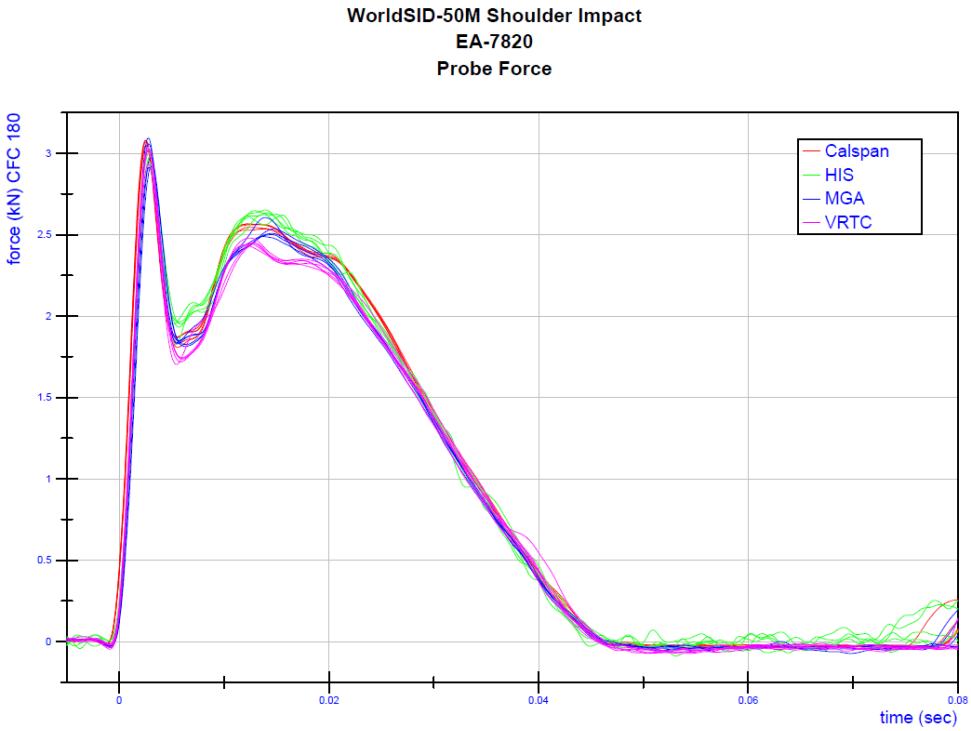

Figure A-1. Shoulder impact probe force – dummy EA-7820

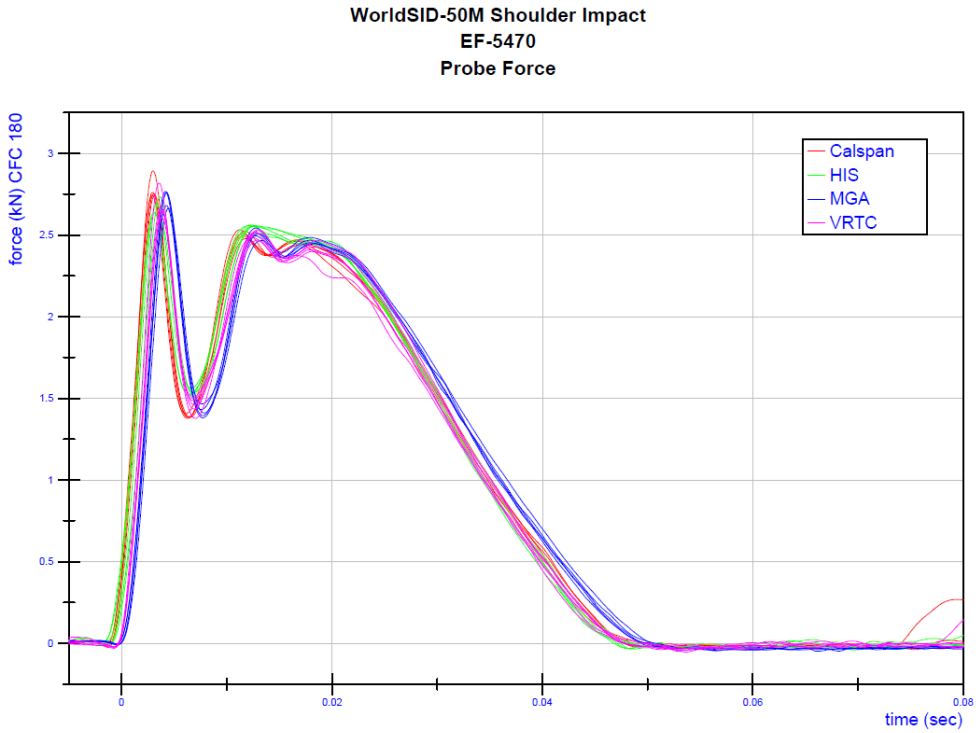

Figure A-2. Shoulder impact probe force – dummy EF-5470

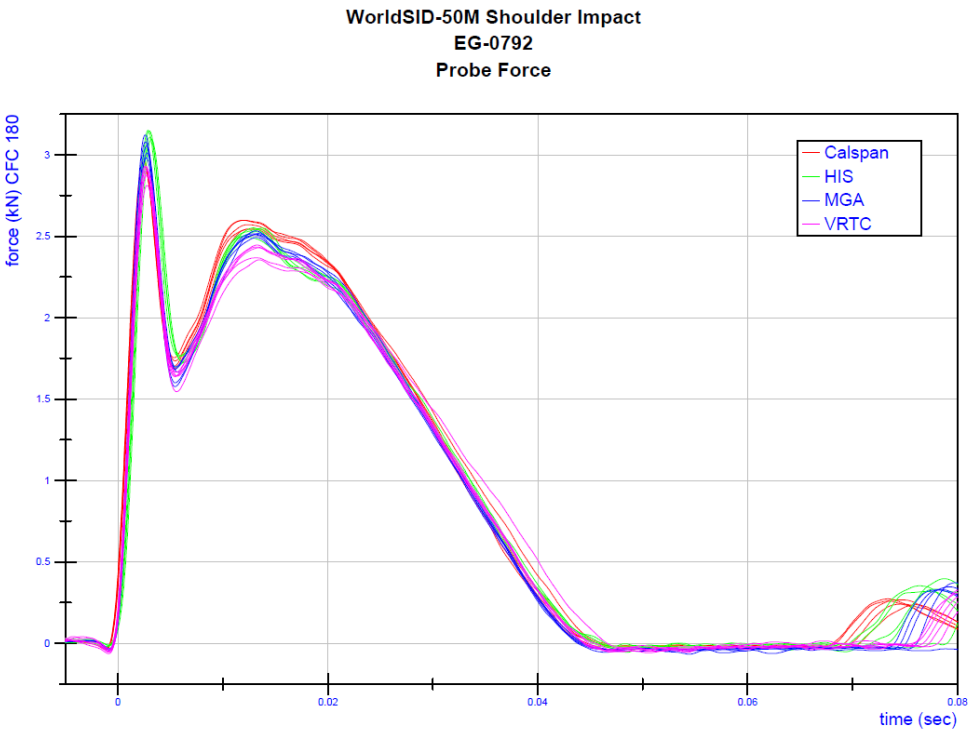

Figure A-3. Shoulder impact probe force – dummy EG-0792

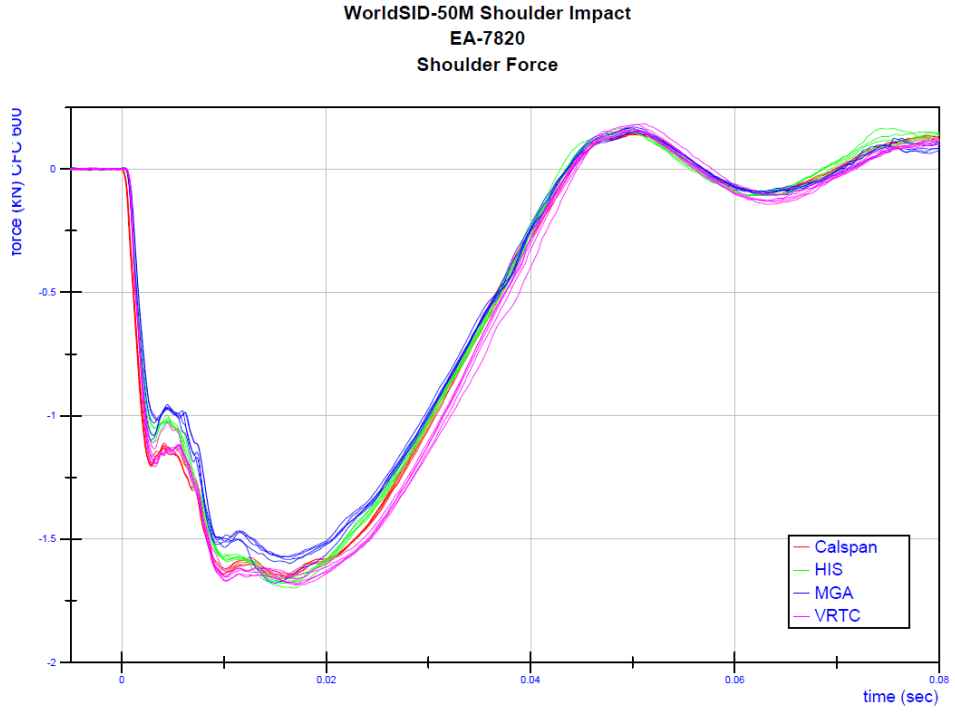

Figure A-4. Shoulder impact shoulder force – dummy EA-7820

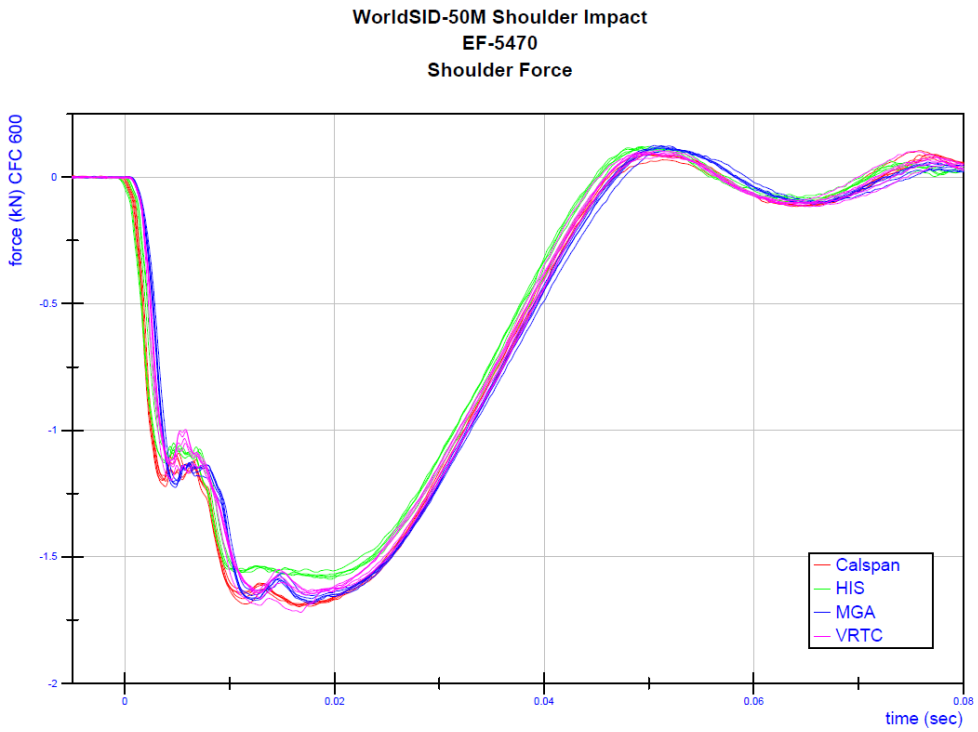

Figure A-5. Shoulder impact shoulder force – dummy EF-5470

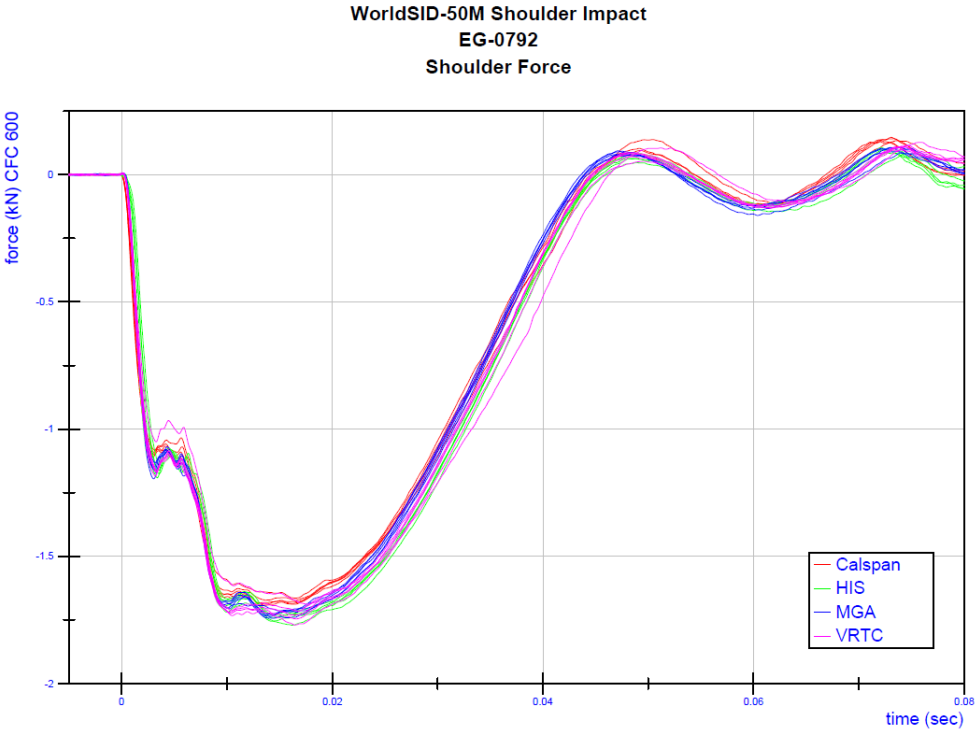

Figure A-6. Shoulder impact shoulder force – dummy EG-0792

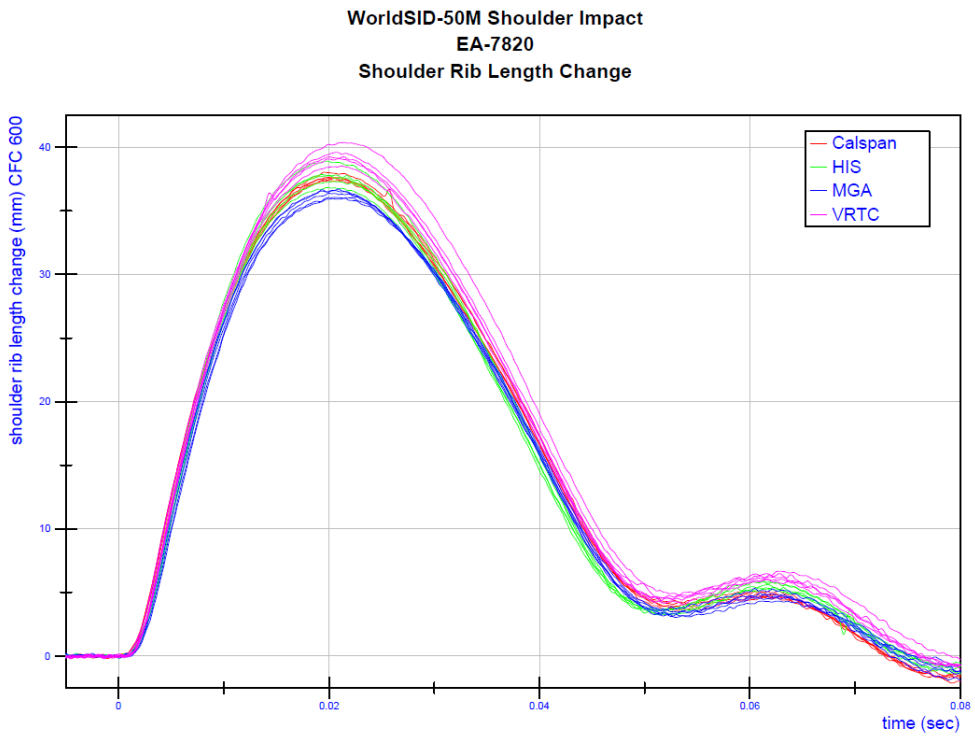

Figure A-7. Shoulder impact shoulder rib length change – dummy EA-7820

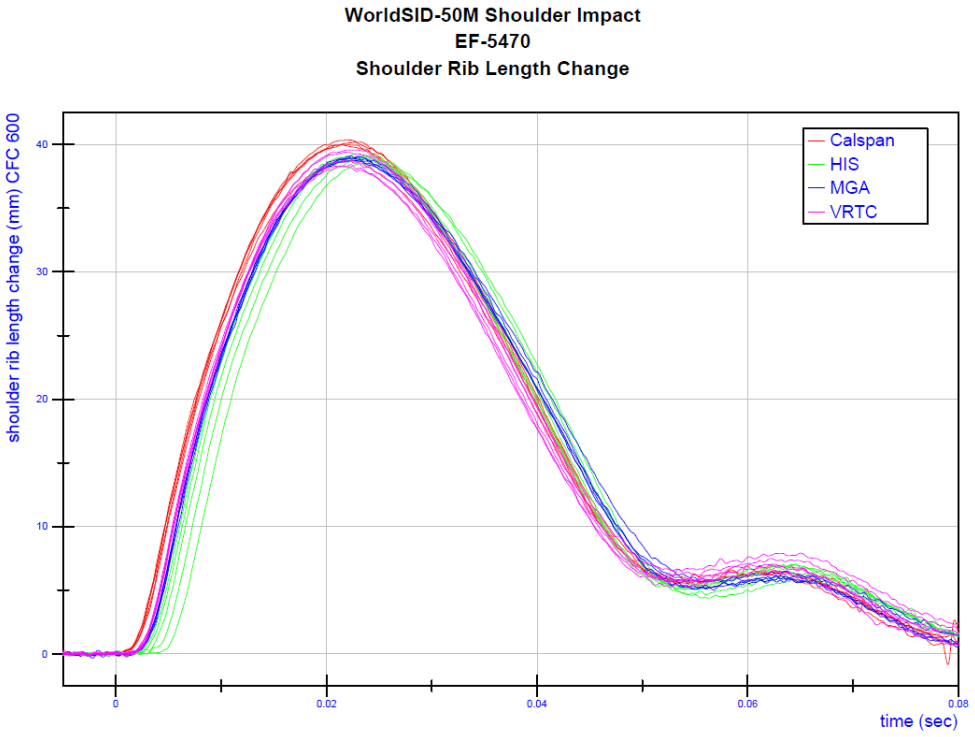

Figure A-8. Shoulder impact shoulder rib length change – dummy EF-5470

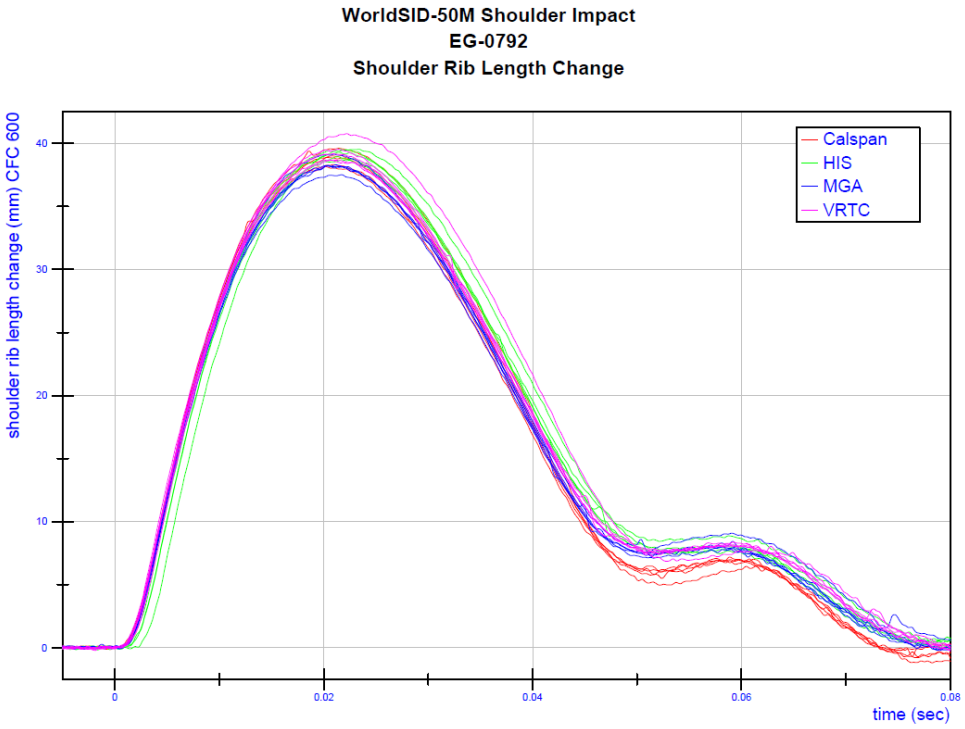

Figure A-9. Shoulder impact shoulder rib length change – dummy EG-0792

Thorax With Arm Impacts

Table A-4. Thorax with arm impact tests – dummy EA-7820

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	°C	kN	g	g	mm	mm	mm
EA-7820	VRTC	221027-1	1	6.71	21.3	6.27	33.4	26.4	40.8	43.5	34.8
		221027-2	2	6.70	23.0	6.13	33.1	25.4	42.1	45.0	37.1
		221027-3	3	6.70	22.5	6.05	32.8	24.5	42.0	44.1	36.0
		221027-4	4	6.71	21.6	6.06	32.4	25.3	42.0	44.3	36.3
		221027-5	5	6.71	21.8	6.08	32.7	26.7	42.5	43.9	35.8
	Humanetics	230110-1	1	6.69	20.8	6.43	35.0	25.6	40.4	43.8	34.7
		230110-2	2	6.69	20.9	6.45	34.6	25.2	41.2	44.5	35.4
		230110-3	3	6.69	22.0	6.37	34.7	25.3	41.5	44.6	35.4
		230110-4	4	6.69	21.4	6.36	34.4	25.1	41.5	44.7	35.6
		230110-5	5	6.69	21.5	6.33	34.6	24.9	41.5	44.3	35.2
	MGA	230214-1	1	6.68	21.6	6.35	35.1	25.2	40.4	41.7	34.0
		230214-2	2	6.73	21.3	6.30	35.3	25.3	41.7	42.4	34.0
		230214-3	3	6.73	21.5	6.26	35.5	25.7	42.5	42.1	33.4
		230214-4	4	6.73	21.6	6.21	34.9	25.1	41.6	42.0	33.7
		230214-5	5	6.68	21.7	6.19	35.2	24.4	41.8	42.1	33.8
	Calspan	230308-5	1	6.70	21.8	6.38	35.5	27.2	40.6	42.5	34.1
		230309-1	2	6.70	21.1	6.27	34.1	27.4	42.3	43.2	34.7
		230309-2	3	6.70	22.1	6.25	33.3	27.1	42.5	43.4	35.1
		230309-3	4	6.70	22.1	6.29	33.2	25.8	42.7	43.6	35.2
		230309-4	5	6.70	21.5	6.34	33.3	26.5	42.4	43.4	34.8
All Tests EA-7820			Mean			6.27	34.1	25.7	41.7	43.4	35.0
			Std Dev			0.12	1.03	0.89	0.72	1.02	0.95
			CV			1.88%	3.00%	3.44%	1.74%	2.35%	2.71%

Table A-5. Thorax with arm impact tests – dummy EF-5470

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	ºC	kN	g	g	mm	mm	mm
EF-5470	VRTC	221115-5	1	6.71	21.9	5.98	33.8	25.9	40.6	47.6	39.5
		221115-6	2	6.72	22.1	5.95	33.8	25.0	40.6	47.7	39.5
		221115-7	3	6.72	21.4	5.93	34.5	24.6	40.8	45.9	38.1
		221115-8	4	6.71	21.4	5.93	32.9	25.1	41.2	48.3	39.6
		221115-9	5	6.72	21.5	5.61	32.6	25.4	42.3	48.8	39.9
	Calspan	230120-2	1	6.70	21.9	6.12	36.3	26.6	39.9	47.1	38.5
		230120-3	2	6.70	21.7	6.09	36.0	27.0	39.9	46.5	38.1
		230120-4	3	6.70	21.6	6.10	36.2	27.5	39.9	46.7	38.0
		230120-5	4	6.70	21.9	6.11	36.0	26.8	39.9	47.0	38.2
		230120-6	5	6.71	21.6	6.13	36.9	27.7	39.6	46.1	37.5
	Humanetics	230307-1	1	6.70	20.5	6.36	33.7	27.2	40.1	47.2	38.3
		230307-2	2	6.70	21.0	6.40	32.5	28.4	39.3	46.0	38.1
		230307-3	3	6.70	21.0	6.45	33.0	28.1	39.3	46.6	38.4
		230307-4	4	6.71	21.7	6.33	33.7	27.5	39.9	46.9	38.6
		230307-5	5	6.70	20.6	6.36	31.5	28.4	40.5	48.2	39.1
	MGA	230328-1	1	6.68	21.4	6.29	35.3	25.1	39.8	44.6	36.6
		230328-2	2	6.73	21.5	6.23	36.1	26.5	40.3	44.6	36.4
		230328-3	3	6.68	21.6	6.30	37.7	27.8	40.8	44.2	36.0
		230328-4	4	6.73	21.6	6.21	34.9	25.5	40.9	44.4	36.5
		230328-5	5	6.69	21.8	6.21	34.6	25.3	40.8	45.3	36.9
All Tests EF-5470			Mean			6.16	34.6	26.6	40.3	46.5	38.1
			Std Dev			0.21	1.67	1.25	0.72	1.35	1.15
			CV			3.34%	4.83%	4.71%	1.78%	2.91%	3.01%

Table A-6. Thorax with arm impact tests – dummy EG-0792

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	ºC	kN	g	g	mm	mm	mm
EG-0792	VRTC	221125-1	1	6.71	21.3	5.98	37.0	27.4	42.3	44.3	36.2
		221125-2	2	6.71	22.2	6.05	34.7	26.3	40.6	45.9	37.5
		221128-1	3	6.71	21.1	5.87	36.1	27.1	42.4	44.7	37.0
		221128-2	4	6.71	21.7	5.96	33.6	26.2	40.5	46.9	38.4
		221128-4	5	6.72	21.2	5.98	35.0	26.8	40.8	45.5	38.1
	Calspan	230228-4	1	6.70	22.2	6.34	35.7	27.4	40.7	44.0	35.3
		230228-5	2	6.70	21.8	6.21	37.3	27.4	42.2	44.5	35.6
		230228-6	3	6.70	22.1	6.14	37.2	25.7	42.3	44.2	35.7
		230301-1	4	6.70	21.5	6.21	36.7	26.0	41.2	44.3	36.0
		230301-2	5	6.70	22.0	6.21	36.4	27.0	41.5	44.8	36.5
	Humanetics	230410-7	1	6.70	21.9	6.22	35.0	25.9	41.7	43.3	36.5
		230411-1	2	6.69	20.8	6.35	35.9	28.1	40.5	43.8	35.5
		230411-2	3	6.69	21.0	6.32	34.0	27.2	39.8	43.9	no data
		230411-3	4	6.69	21.1	6.24	35.0	26.4	40.2	44.2	36.5
		230411-4	5	6.70	21.4	6.17	35.2	25.5	41.2	44.7	37.6
	MGA	230510-1	1	6.73	20.9	6.24	34.6	26.1	39.3	43.8	35.0
		230510-2	2	6.73	21.1	6.24	34.5	26.3	40.3	44.5	35.8
		230510-3	3	6.73	21.2	6.26	36.3	26.3	40.3	45.1	35.6
		230510-4	4	6.73	21.4	6.20	35.2	25.7	40.3	45.3	36.4
		230510-5	5	6.73	20.7	6.26	35.3	26.0	40.4	45.4	36.3
All Tests EG-0792			Mean			6.17	35.5	26.5	40.9	44.7	36.4
			Std Dev			0.13	1.05	0.71	0.88	0.84	0.95
			CV			2.18%	2.95%	2.69%	2.16%	1.89%	2.61%

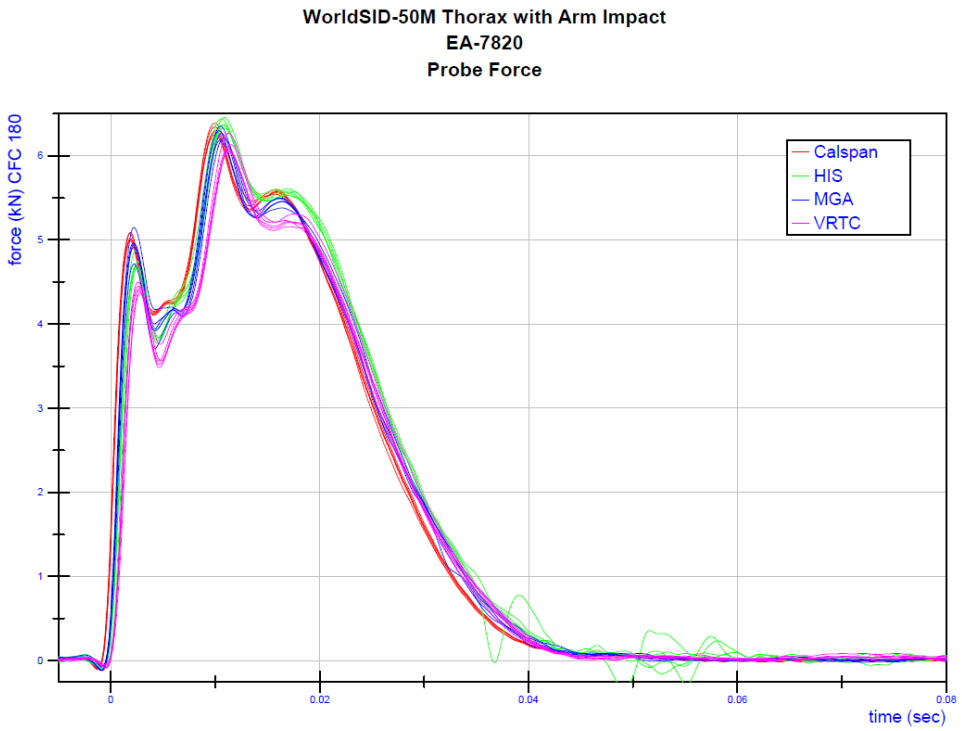

Figure A-10. Thorax with arm impact probe force – dummy EA-7820

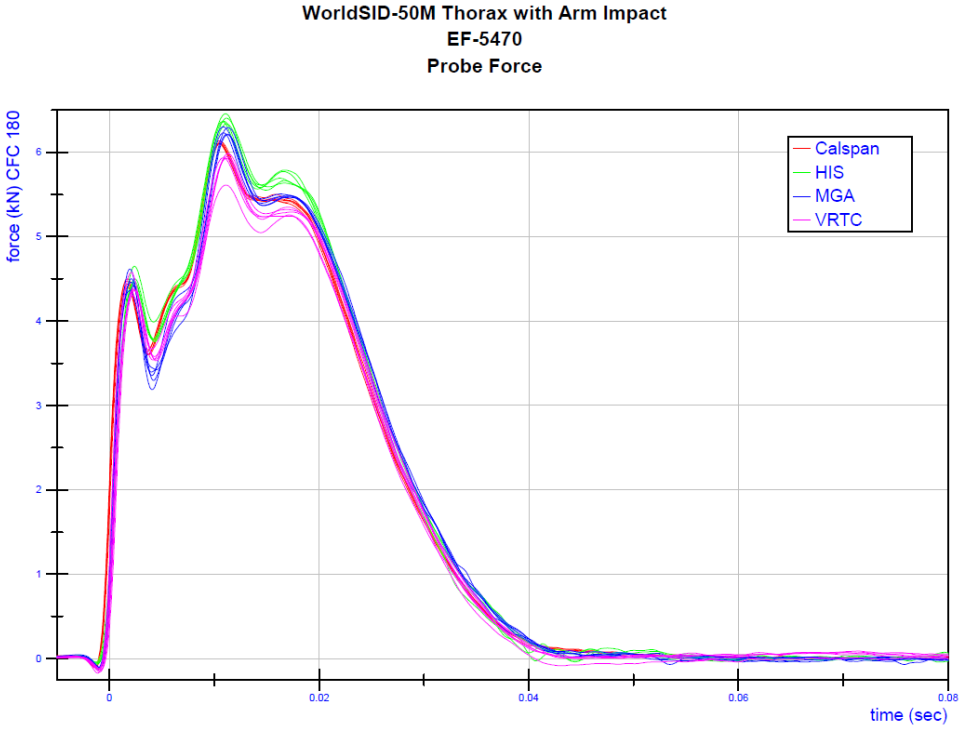

Figure A-11. Thorax with arm impact probe force – dummy EF-5470

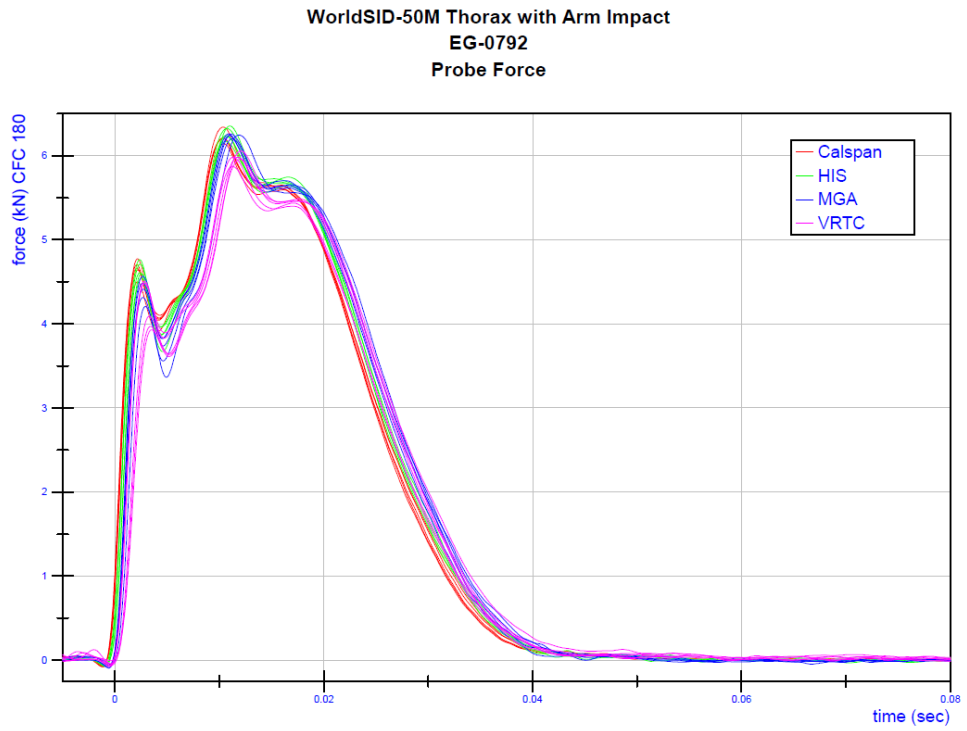

Figure A-12. Thorax with arm impact probe force – dummy EG-0792

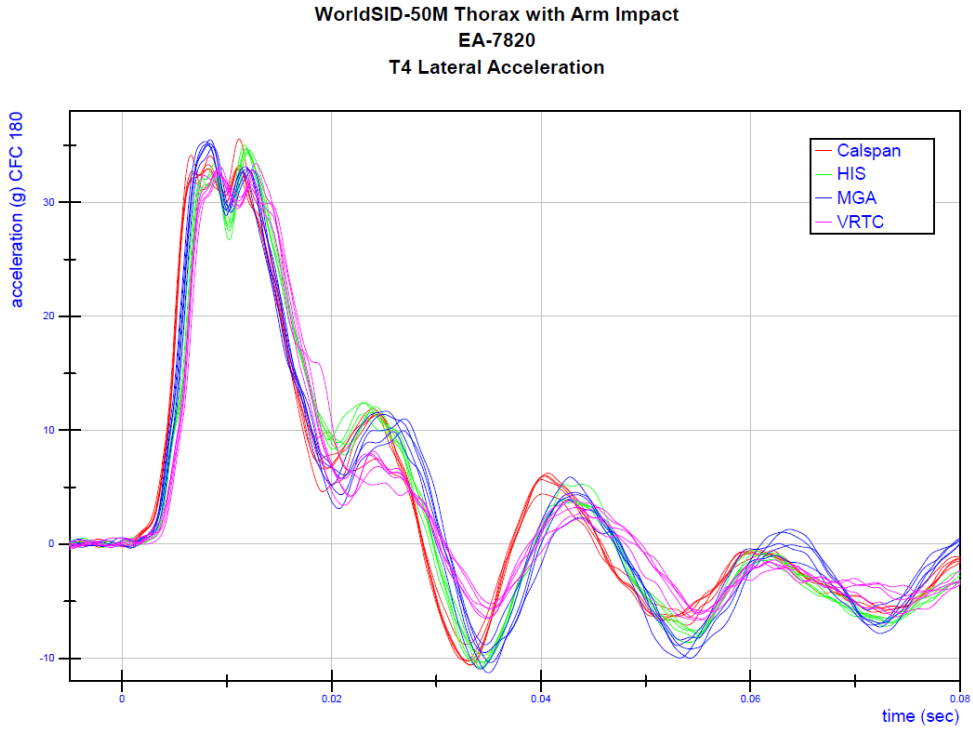

Figure A-13. Thorax with arm impact T4 lateral acceleration – dummy EA-7820

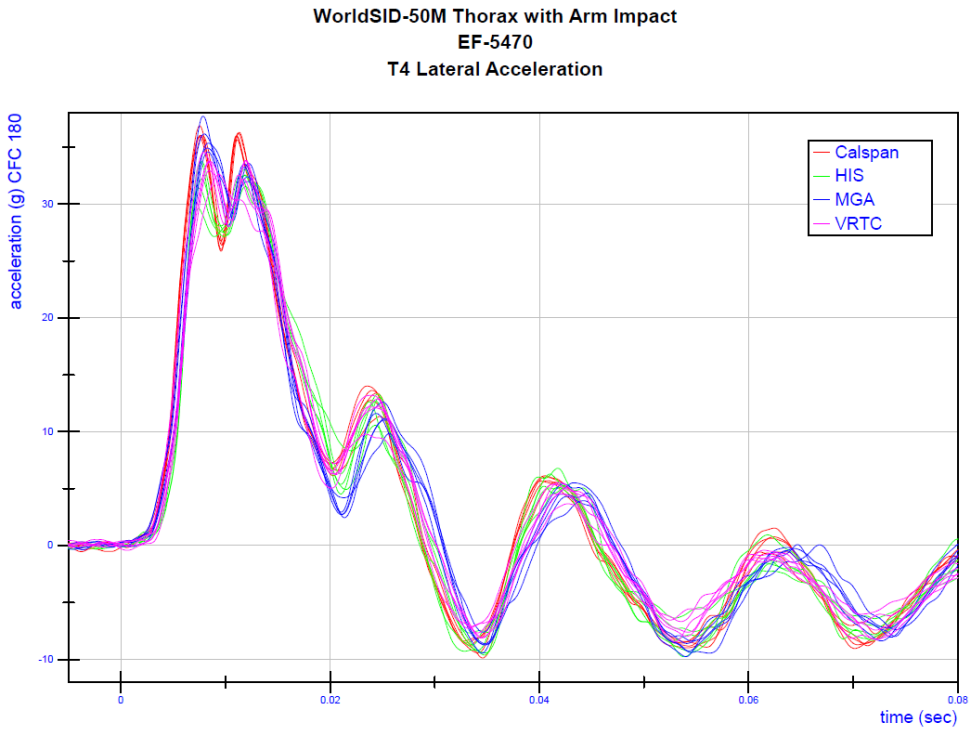

Figure A-14. Thorax with arm impact T4 lateral acceleration – dummy EF-5470

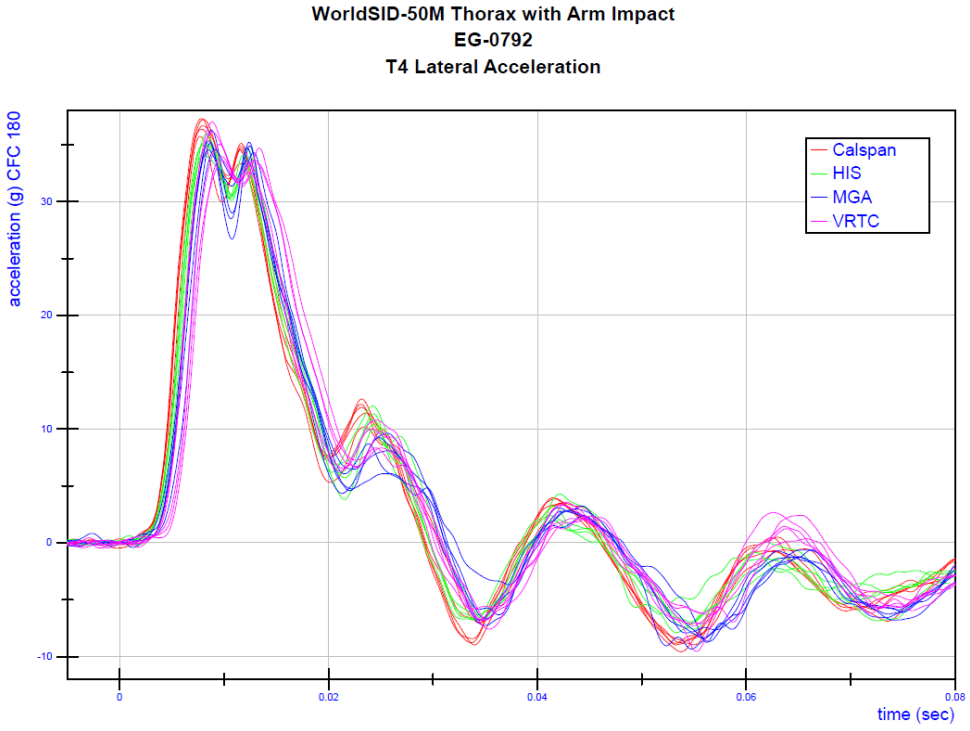

Figure A-15. Thorax with arm impact T4 lateral acceleration – dummy EG-0792

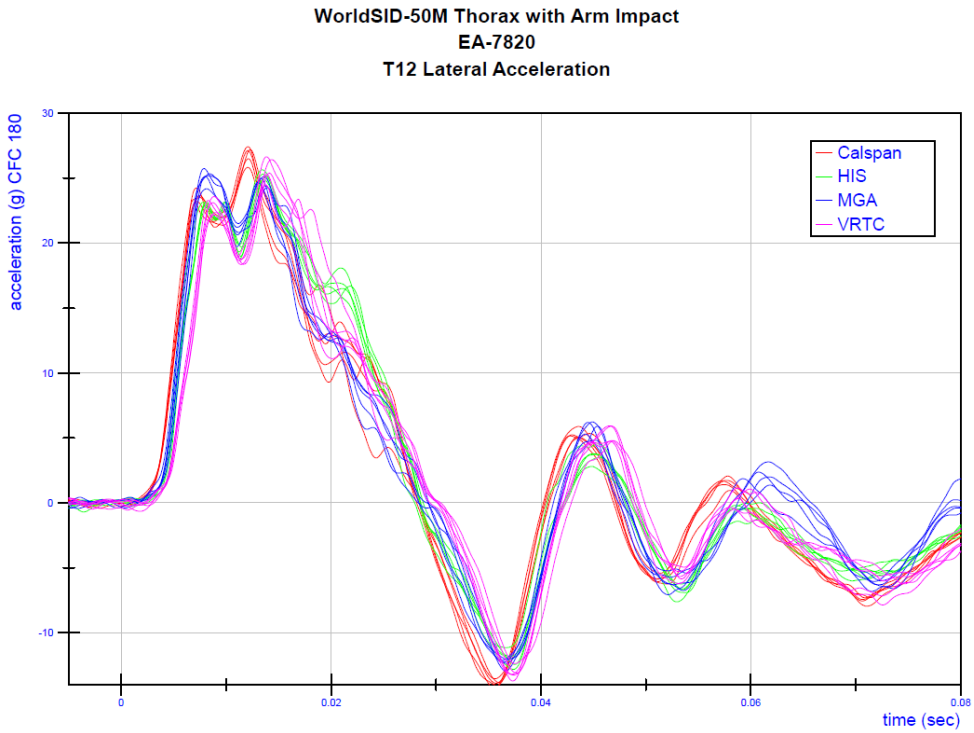

Figure A-16. Thorax with arm impact T12 lateral acceleration – dummy EA-7820

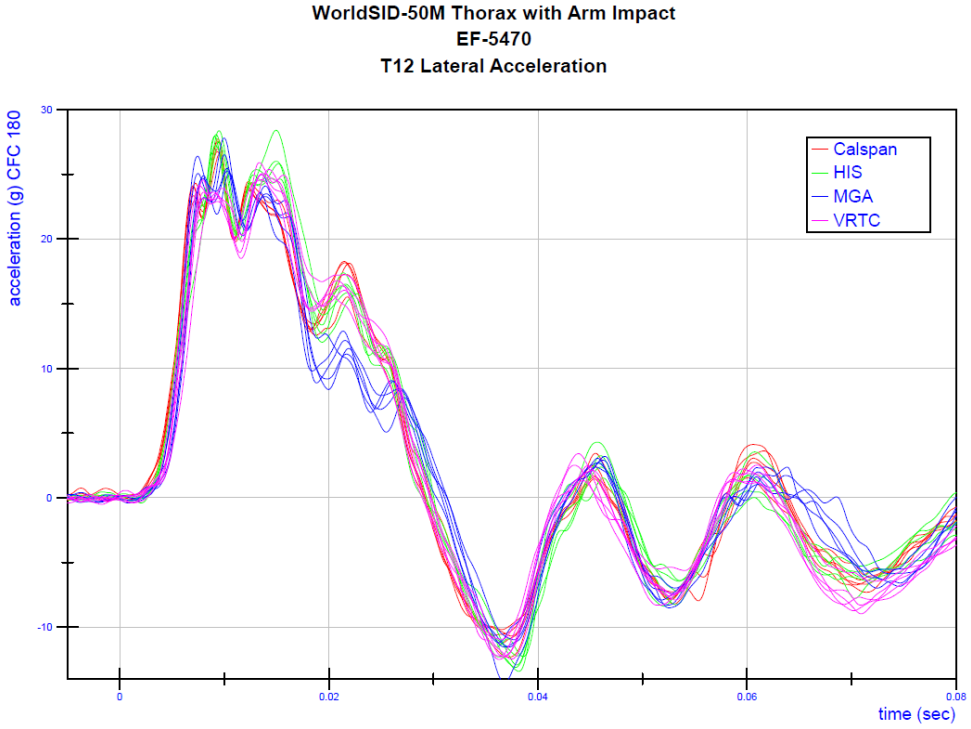

Figure A-17. Thorax with arm impact T12 lateral acceleration – dummy EF-5470

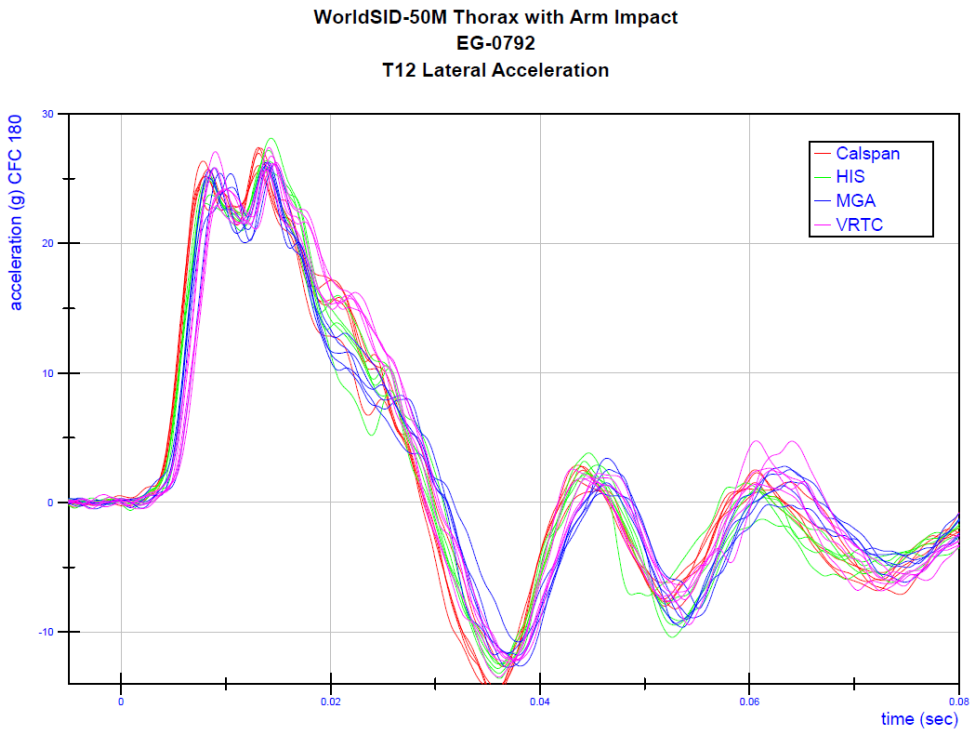

Figure A-18. Thorax with arm impact T12 lateral acceleration – dummy EG-0792

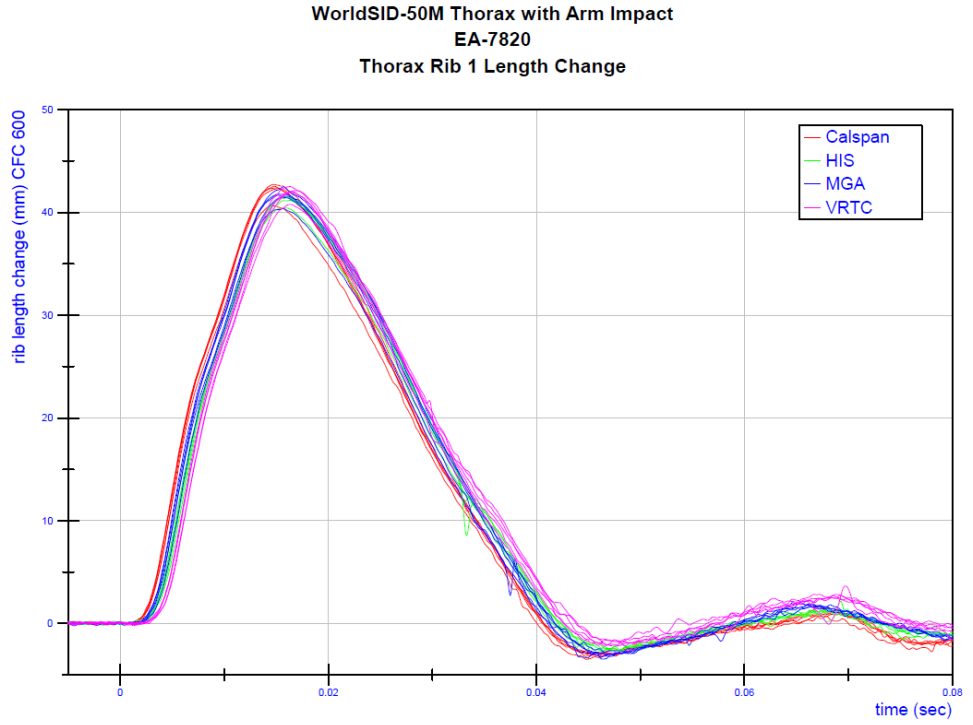

Figure A-19. Thorax with arm impact thorax rib 1 length change – dummy EA-7820

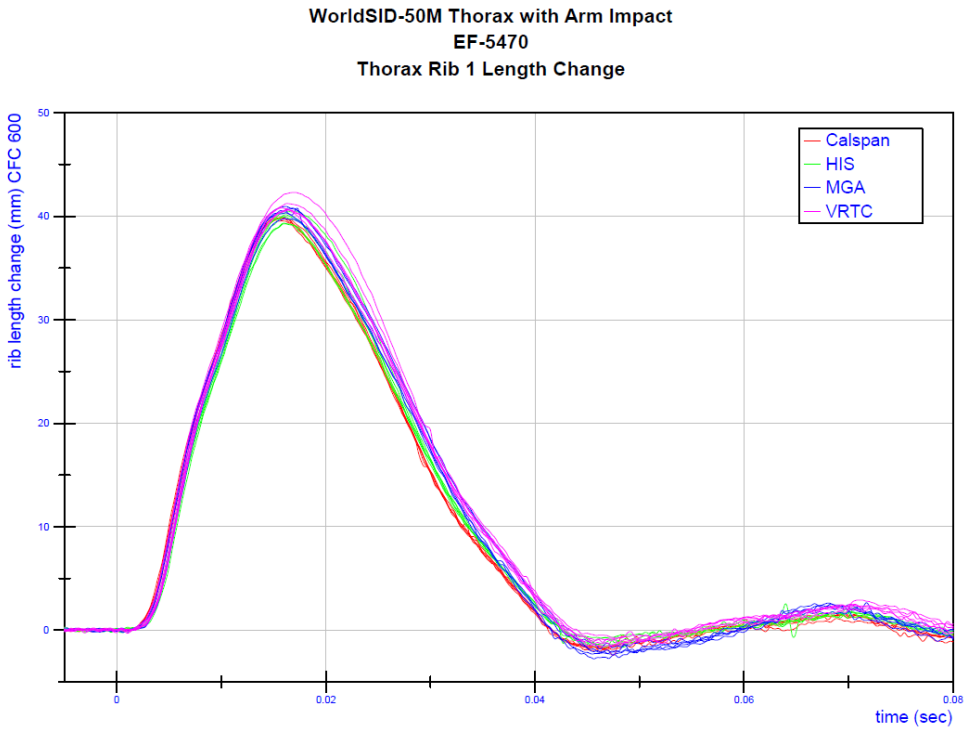

Figure A-20. Thorax with arm impact thorax rib 1 length change – dummy EF-5470

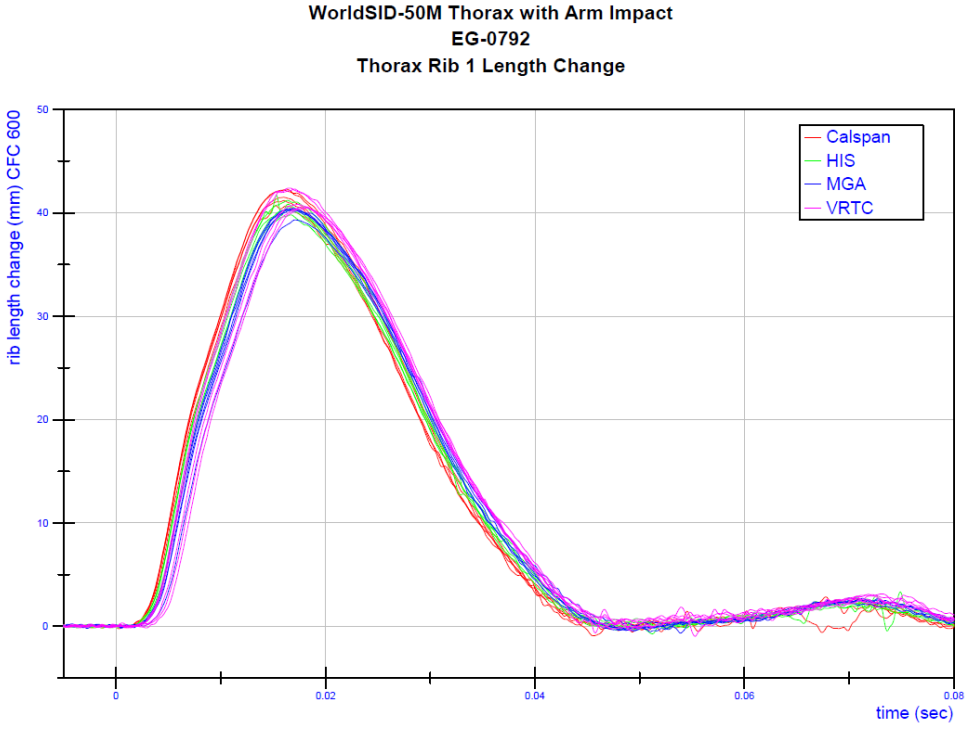

Figure A-21. Thorax with arm impact thorax rib 1 length change – dummy EG-0792

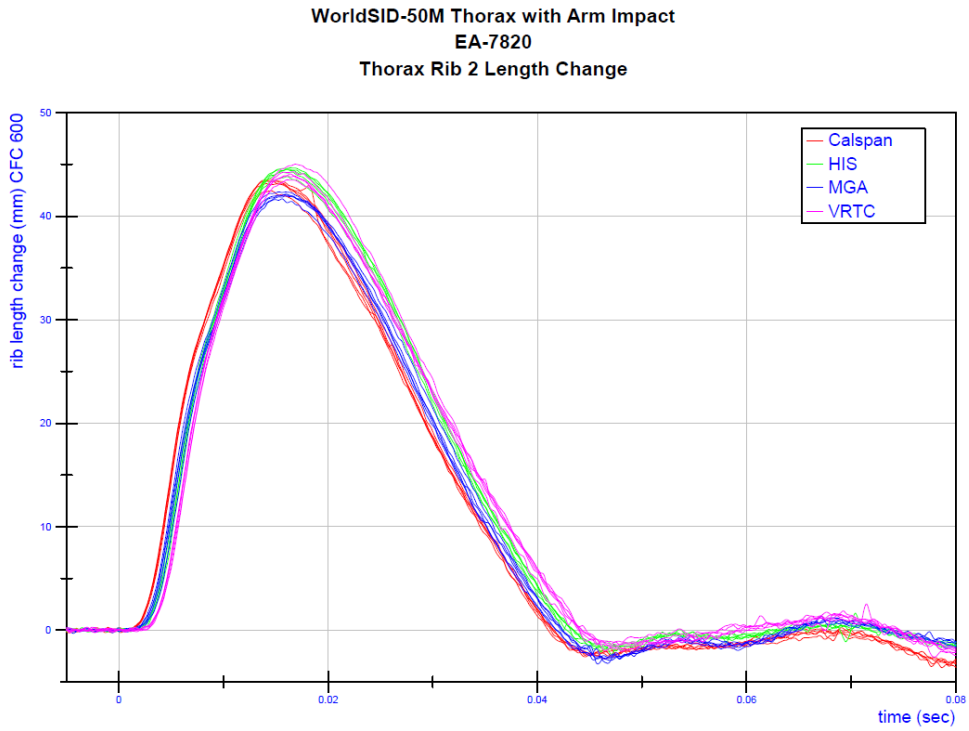

Figure A-22. Thorax with arm impact thorax rib 2 length change – dummy EA-7820

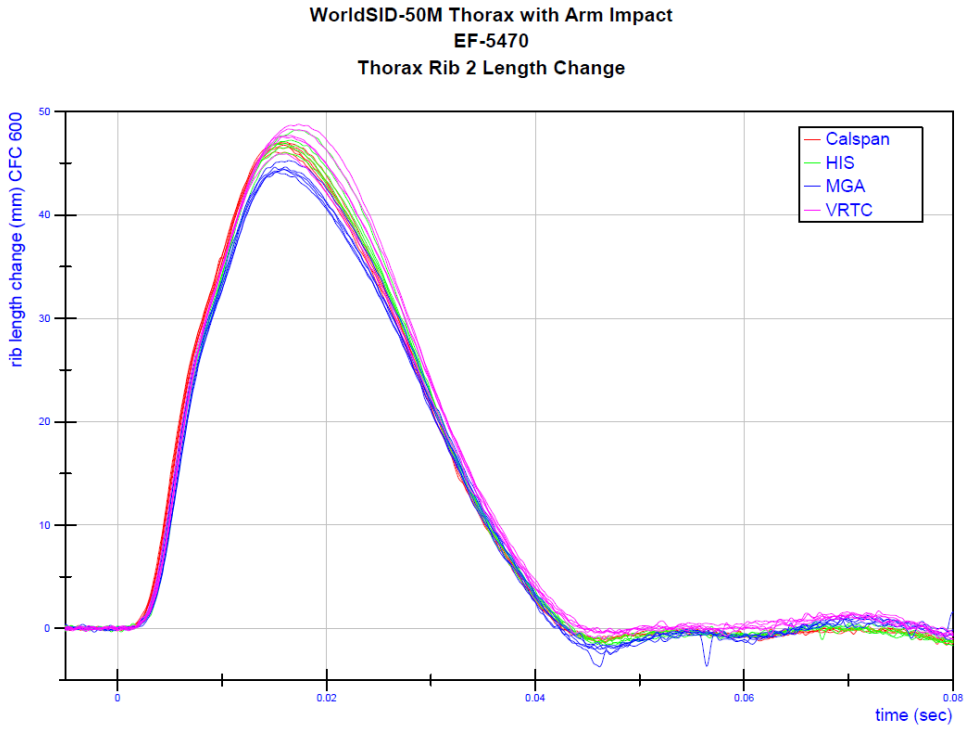

Figure A-23. Thorax with arm impact thorax rib 2 length change – dummy EF-5470

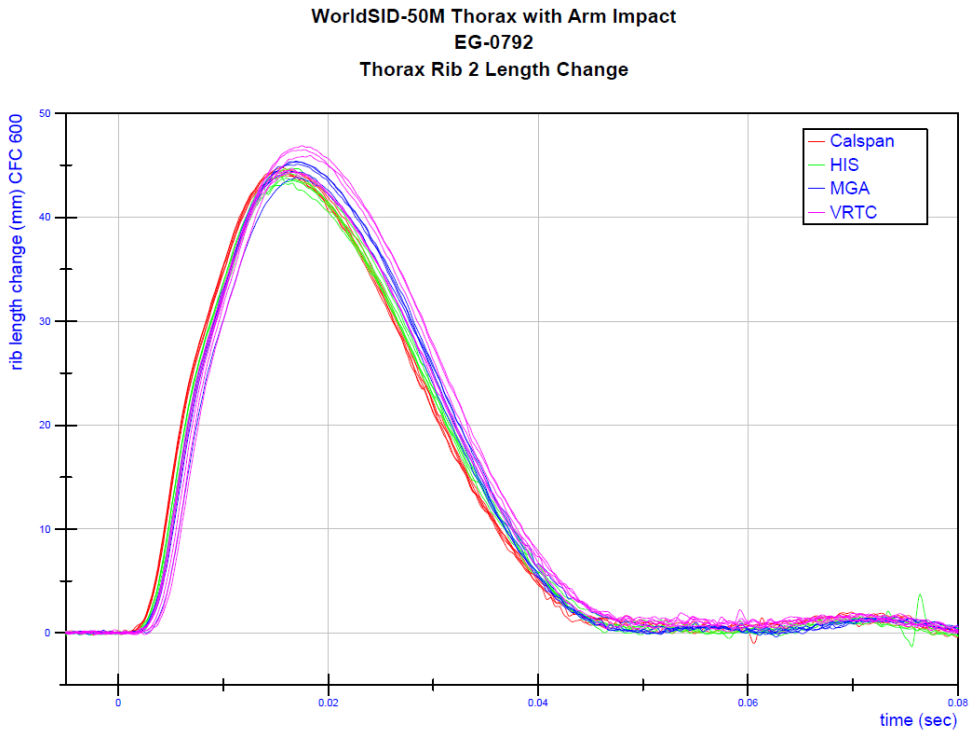

Figure A-24. Thorax with arm impact thorax rib 2 length change – dummy EG-0792

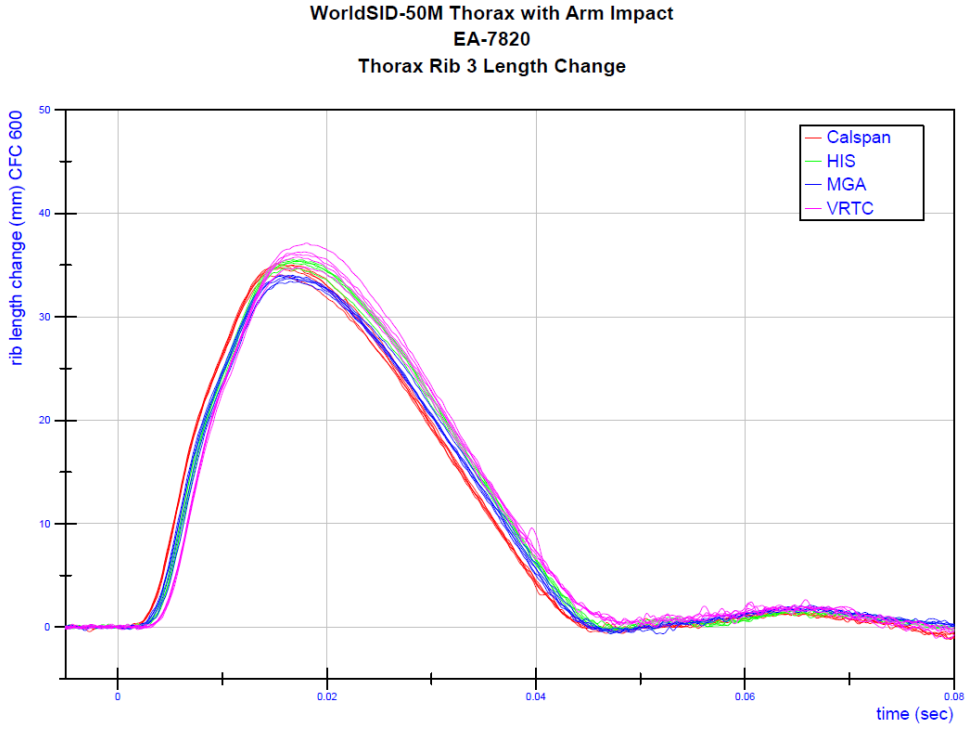

Figure A-25. Thorax with arm impact thorax rib 3 length change – dummy EA-7820

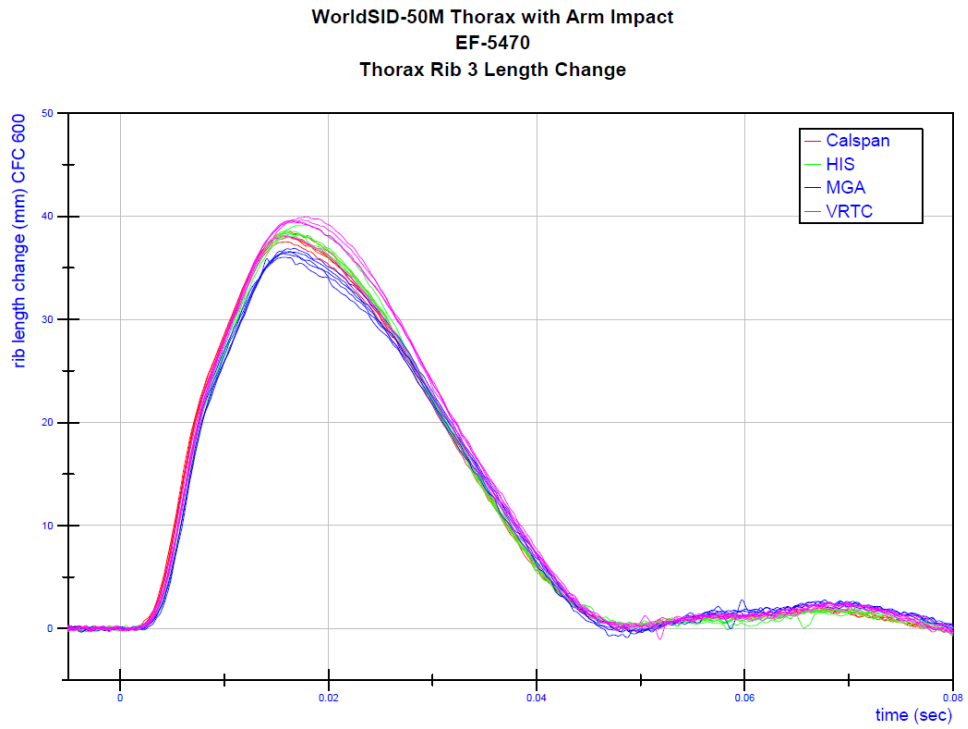

Figure A-26. Thorax with arm impact thorax rib 3 length change – dummy EF-5470

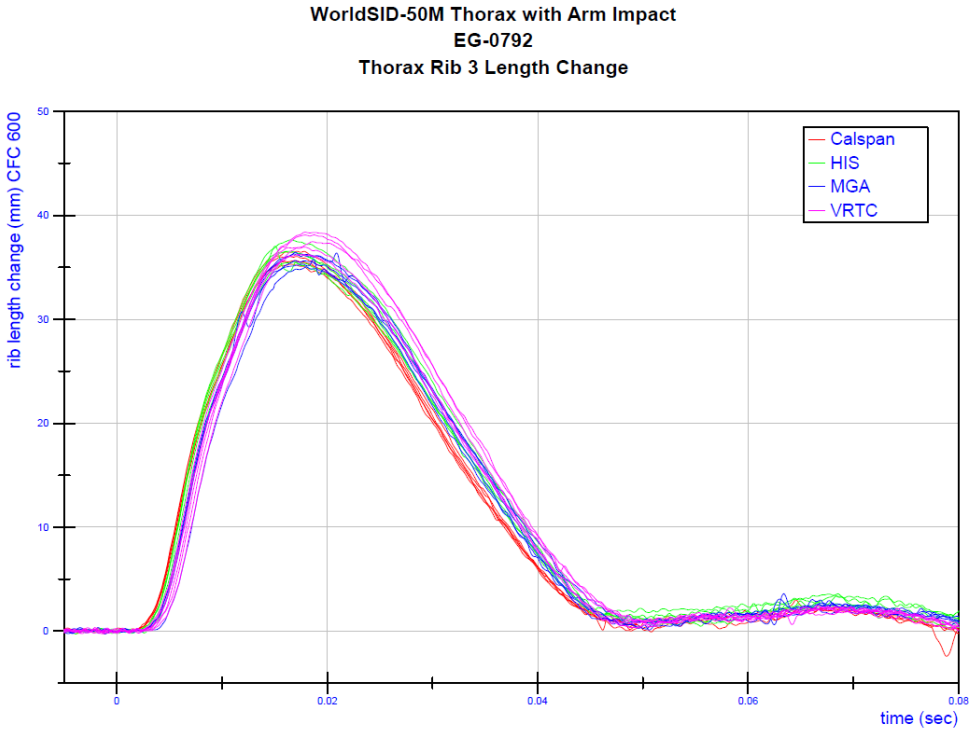

Figure A-27. Thorax with arm impact thorax rib 3 length change – dummy EG-0792

Thorax Without Arm Impacts

Table A-7. Thorax without arm impact tests – dummy EA-7820

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	ºC	kN	g	g	mm	mm	mm
EA-7820	VRTC	221027-7	1	4.30	22.1	3.61	13.2	13.6	37.6	39.2	33.9
		221027-11	2	4.30	21.1	3.59	13.2	13.1	37.5	39.3	33.9
		221027-13	3	4.30	22.2	3.59	13.5	13.1	37.9	39.6	34.5
		221031-1	4	4.30	21.0	3.60	15.5	13.6	37.5	38.9	33.4
		221031-3	5	4.29	21.4	3.62	13.8	13.3	37.0	39.3	34.5
	Humanetics	230109-6	1	4.30	21.8	3.76	14.3	14.2	36.5	38.6	34.2
		230109-7	2	4.30	21.9	3.72	14.1	13.7	37.5	39.1	34.4
		230109-8	3	4.30	22.0	3.73	14.3	13.3	37.5	39.4	34.6
		230109-9	4	4.30	21.5	3.71	14.1	13.6	37.7	39.5	34.7
		230109-10	5	4.30	21.4	3.70	14.1	13.6	37.7	39.4	34.1
	MGA	230211-2	1	4.32	21.1	3.71	14.1	14.6	37.0	38.9	33.6
		230213-1	2	4.31	21.4	3.67	14.1	15.1	36.6	38.1	33.2
		230213-2	3	4.32	21.5	3.70	14.4	14.7	37.6	39.3	32.4
		230213-3	4	4.31	21.4	3.71	15.0	15.1	37.2	39.2	32.7
		230213-4	5	4.32	21.5	3.67	14.6	14.9	37.8	39.2	32.1
	Calspan	230310-1	1	4.30	21.1	3.63	15.0	16.2	38.2	38.7	32.7
		230310-2	2	4.30	21.3	3.64	15.4	16.2	37.8	38.9	33.2
		230310-4	3	4.30	21.9	3.63	15.3	16.3	38.0	39.1	33.3
		230313-1	4	4.30	22.4	3.63	15.4	16.7	38.1	38.9	33.0
		230313-2	5	4.30	21.9	3.63	15.3	16.6	38.3	38.7	33.1
All Tests EA-7820			Mean			3.66	14.4	14.6	37.5	39.1	33.6
			Std Dev			0.05	0.72	1.25	0.48	0.37	0.79
			CV			1.41%	5.01%	8.55%	1.29%	0.94%	2.37%

Table A-8. Thorax without arm impact tests – dummy EF-5470

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	ºC	kN	g	g	mm	mm	mm
EF-5470	VRTC	221116-2	1	4.31	21.2	3.48	13.8	14.4	40.2	44.2	37.1
		221116-4	2	4.31	22.0	3.48	13.9	14.3	40.8	44.7	37.5
		221116-5	3	4.31	21.3	3.49	13.4	13.9	40.1	44.3	37.0
		221116-6	4	4.31	21.4	3.50	14.4	14.4	39.5	44.5	38.0
		221116-7	5	4.31	21.9	3.48	14.5	14.3	40.1	44.9	38.4
	Calspan	230111-1	1	4.31	22.9	3.57	16.2	15.4	39.7	44.2	36.7
		230112-1	2	4.30	22.0	3.62	16.5	15.3	38.7	43.4	37.3
		230112-2	3	4.31	22.0	3.64	16.7	16.0	38.3	43.5	37.6
		230112-3	4	4.31	22.0	3.57	15.9	14.6	40.0	43.5	37.5
		230112-4	5	4.30	22.0	3.58	15.4	14.7	39.9	43.4	38.3
	Humanetics	230303-1	1	4.30	21.3	3.63	16.4	16.1	37.9	42.3	36.2
		230303-2	2	4.30	21.0	3.60	15.6	15.7	37.5	42.1	36.4
		230303-3	3	4.30	21.1	3.63	16.0	15.5	37.7	42.6	36.1
		230303-4	4	4.31	20.9	3.66	15.9	15.6	38.0	43.2	36.8
		230303-5	5	4.30	21.1	3.64	15.5	15.7	38.0	43.0	36.9
	MGA	230327-2	1	4.31	21.8	3.53	16.2	15.8	38.2	41.5	35.2
		230327-3	2	4.31	21.3	3.54	16.3	16.2	37.1	40.9	35.4
		230327-4	3	4.31	21.3	3.52	17.0	16.6	36.8	40.4	34.9
		230327-5	4	4.31	21.2	3.50	17.0	16.5	37.0	40.6	34.6
		230327-6	5	4.31	21.3	3.51	16.2	16.3	37.9	41.0	35.0
All Tests EF-5470			Mean			3.56	15.6	15.4	38.7	42.9	36.6
			Std Dev			0.06	1.08	0.83	1.24	1.43	1.14
			CV			1.74%	6.88%	5.38%	3.20%	3.32%	3.12%

Table A-9. Thorax without arm impact tests – dummy EG-0792

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T4 Y-axis Accel	Peak T12 Y-axis Accel	Peak Length Change		
									Thorax Rib 1	Thorax Rib 2	Thorax Rib 3
				m/s	ºC	kN	g	g	mm	mm	mm
EG-0792	VRTC	221128-6	1	4.31	21.9	3.58	14.9	14.5	37.1	40.3	36.8
		221128-7	2	4.31	21.3	3.60	16.1	16.1	39.0	40.8	35.8
		221129-1	3	4.31	21.3	3.60	16.1	16.5	38.8	40.6	35.4
		221129-2	4	4.31	21.3	3.51	15.3	15.4	39.2	39.7	34.3
		221129-3	5	4.31	21.3	3.56	15.7	15.8	38.6	40.4	35.8
	Calspan	230301-3	1	4.31	21.5	3.58	16.4	16.0	38.0	39.5	34.9
		230301-4	2	4.30	22.9	3.53	16.0	16.0	38.0	39.5	34.2
		230301-5	3	4.30	22.2	3.56	16.3	16.6	38.5	40.0	35.1
		230301-6	4	4.30	21.9	3.57	16.9	16.9	38.4	40.0	35.5
		230301-7	5	4.31	22.2	3.55	16.8	17.3	38.4	40.1	35.7
	Humanetics	230406-1	1	4.30	21.3	3.61	16.0	16.4	37.2	39.7	35.3
		230410-1	2	4.32	20.7	3.73	15.1	15.5	36.8	39.9	35.8
		230410-2	3	4.30	20.6	3.65	13.8	14.7	36.6	39.2	34.4
		230410-3	4	4.31	21.4	3.66	13.7	14.5	37.9	40.4	35.6
		230410-4	5	4.30	21.4	3.64	14.8	15.5	37.1	40.3	35.6
	MGA	230505-1	1	4.34	21.0	3.63	15.3	17.4	35.7	37.6	33.0
		230509-1	2	4.27	21.0	3.60	14.7	14.7	36.0	38.6	34.0
		230509-2	3	4.32	20.6	3.65	15.7	16.4	36.8	38.8	33.9
		230509-3	4	4.32	21.0	3.62	16.4	15.8	36.3	38.8	34.6
		230509-4	5	4.27	20.8	3.63	15.8	16.8	36.1	38.4	34.2
All Tests EG-0792			Mean			3.60	15.6	15.9	37.5	39.6	35.0
			Std Dev			0.05	0.89	0.88	1.09	0.83	0.90
			CV			1.40%	5.68%	5.53%	2.90%	2.10%	2.58%

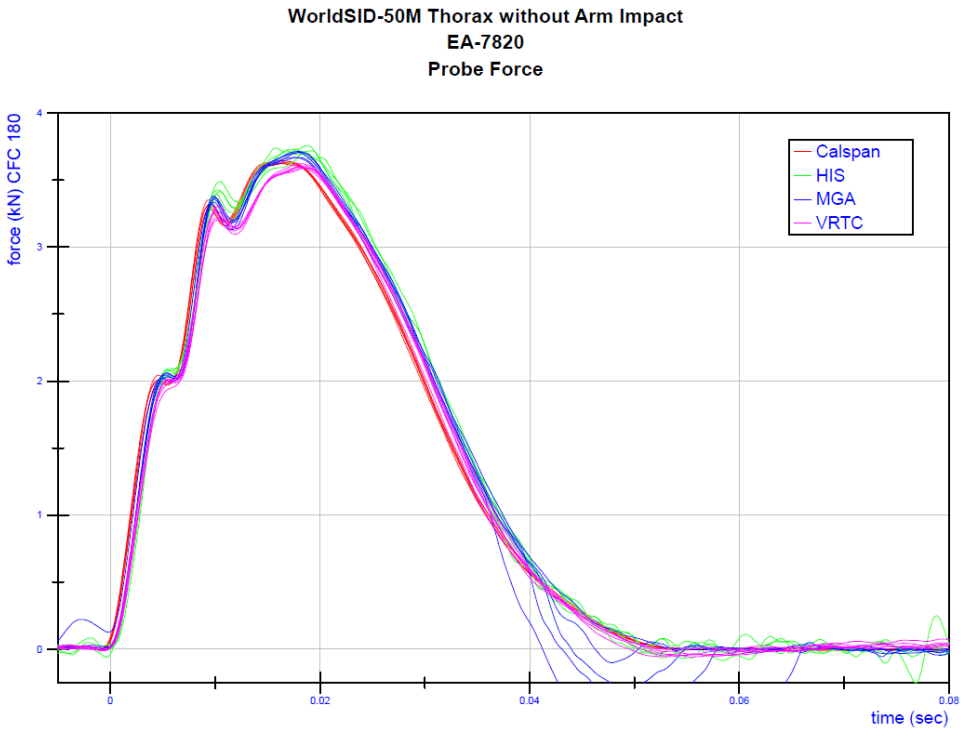

Figure A-28. Thorax without arm impact probe force – dummy EA-7820

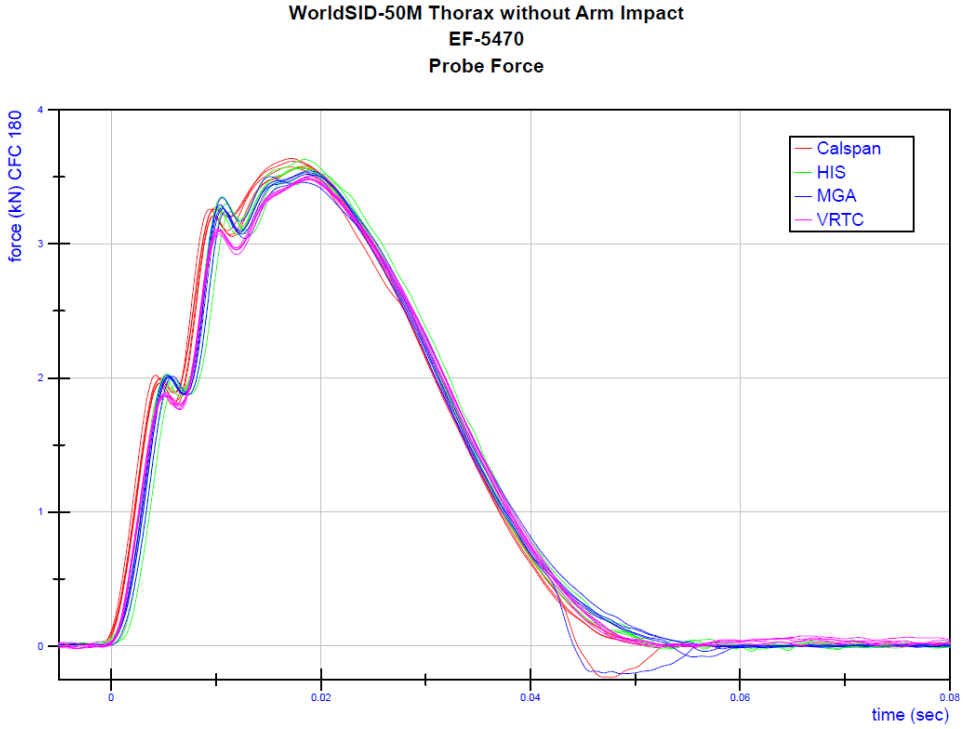

Figure A-29. Thorax without arm impact probe force – dummy EF-5470

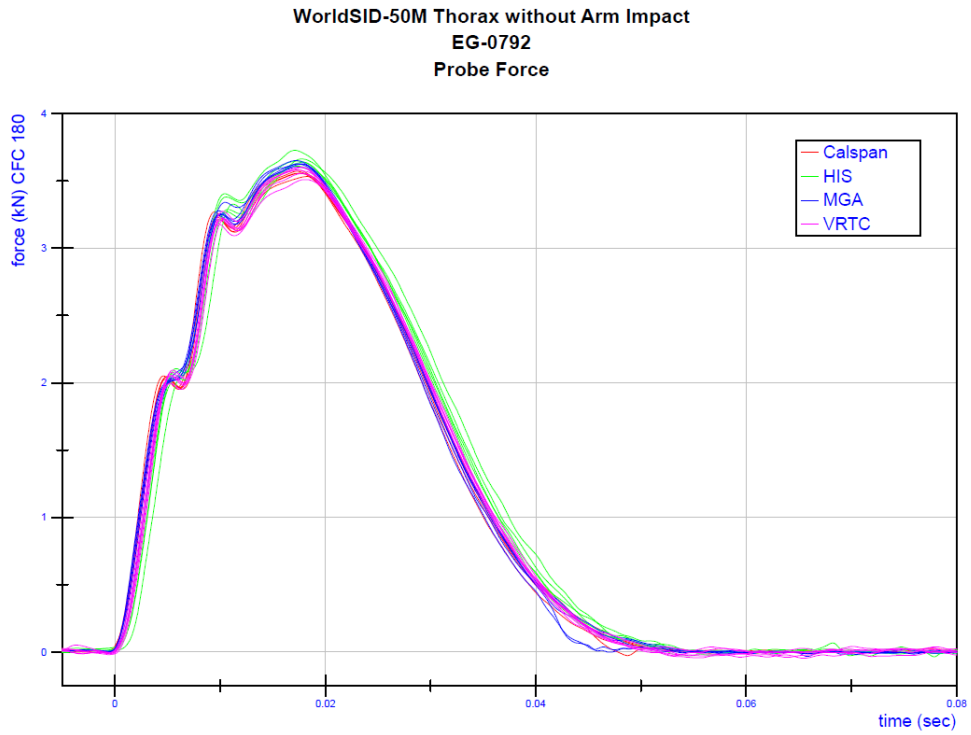

Figure A-30. Thorax without arm impact probe force – dummy EG-0792

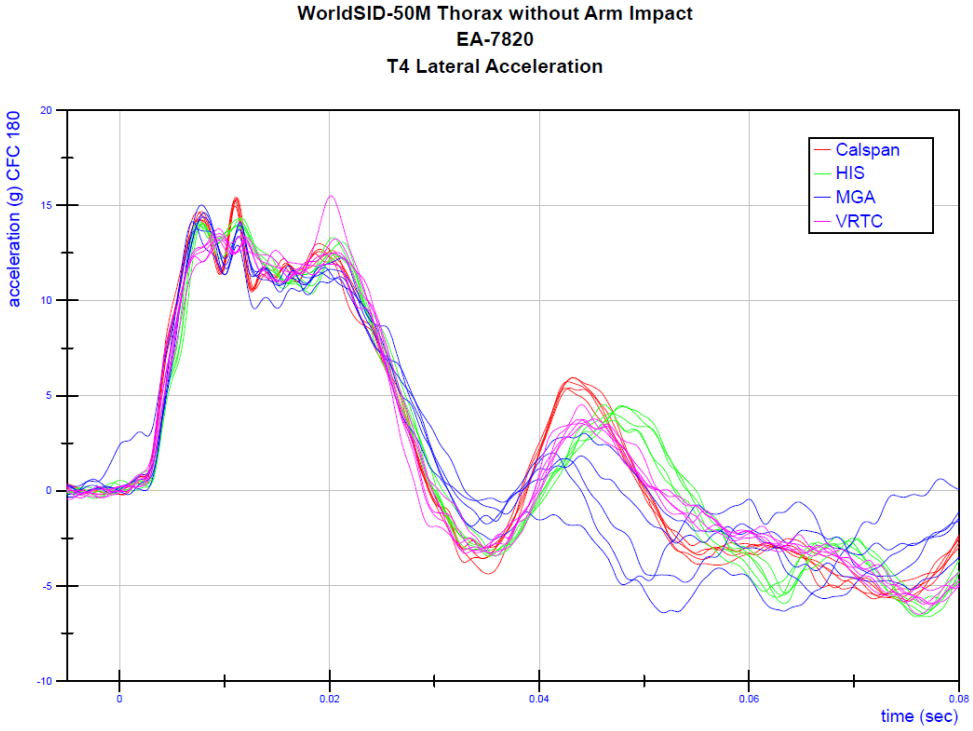

Figure A-31. Thorax without arm impact T4 lateral acceleration – dummy EA-7820

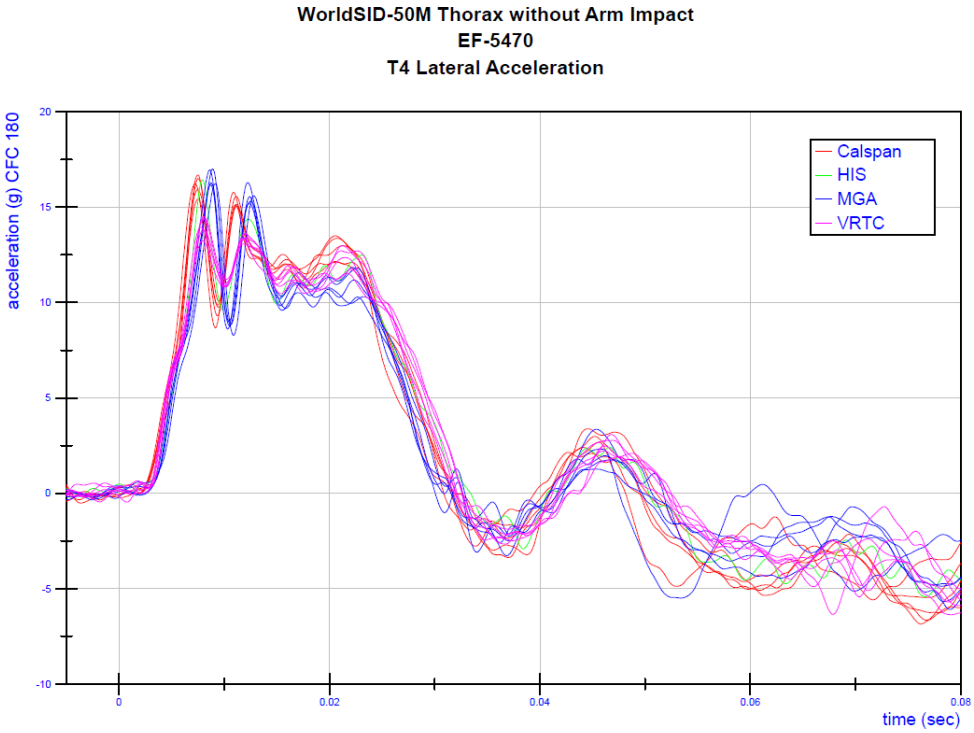

Figure A-32. Thorax without arm impact T4 lateral acceleration – dummy EF-5470

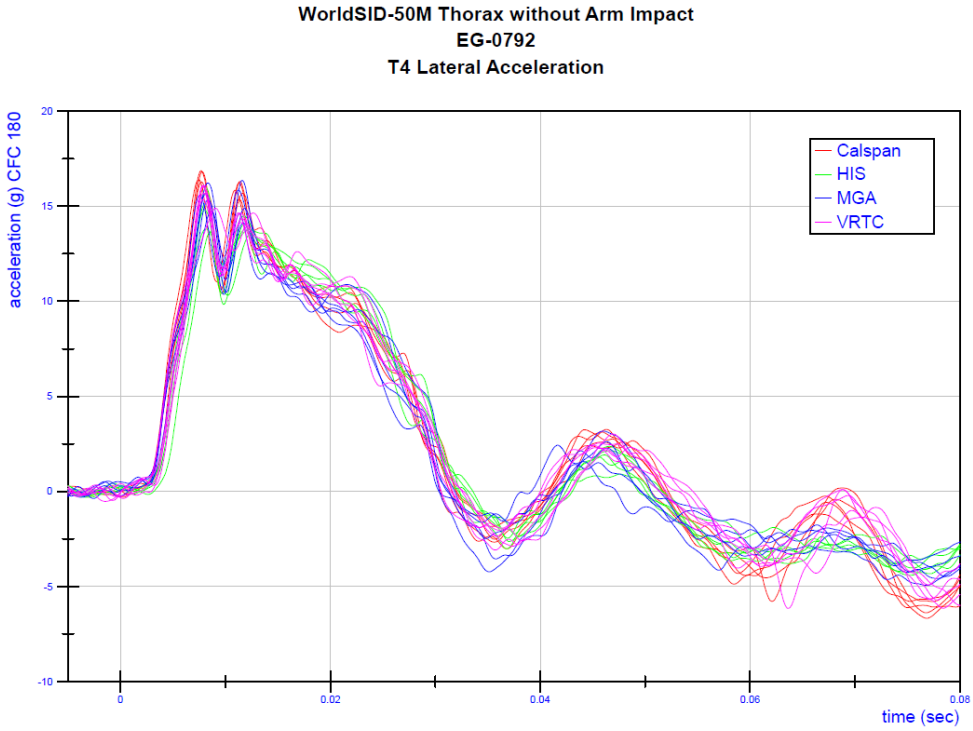

Figure A-33. Thorax without arm impact T4 lateral acceleration – dummy EG-0792

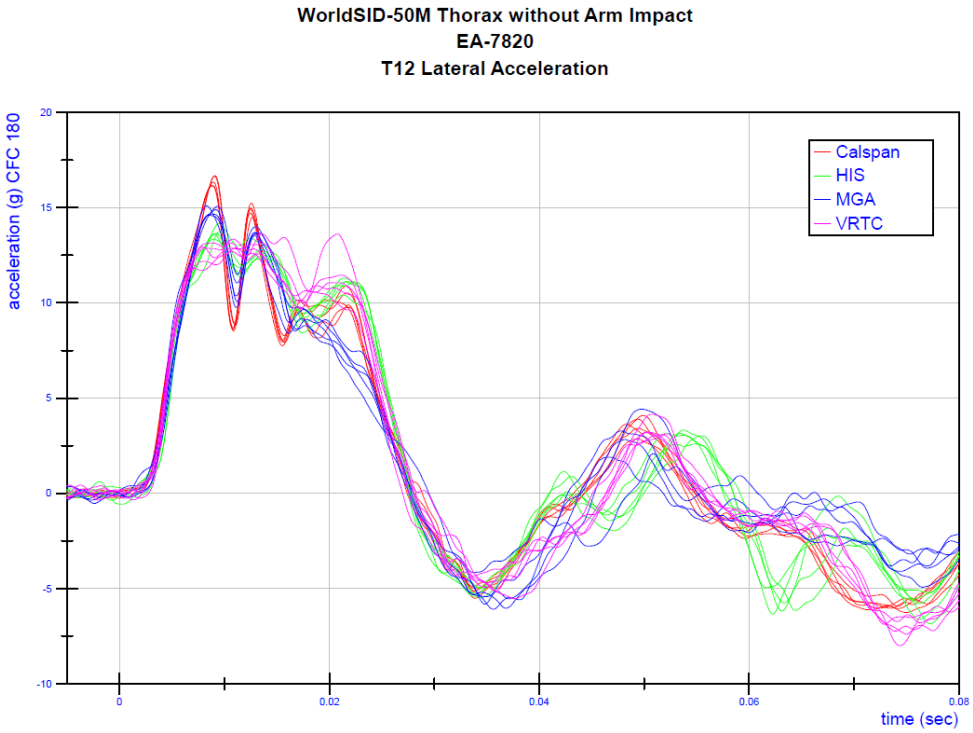

Figure A-34. Thorax without arm impact T12 lateral acceleration – dummy EA-7820

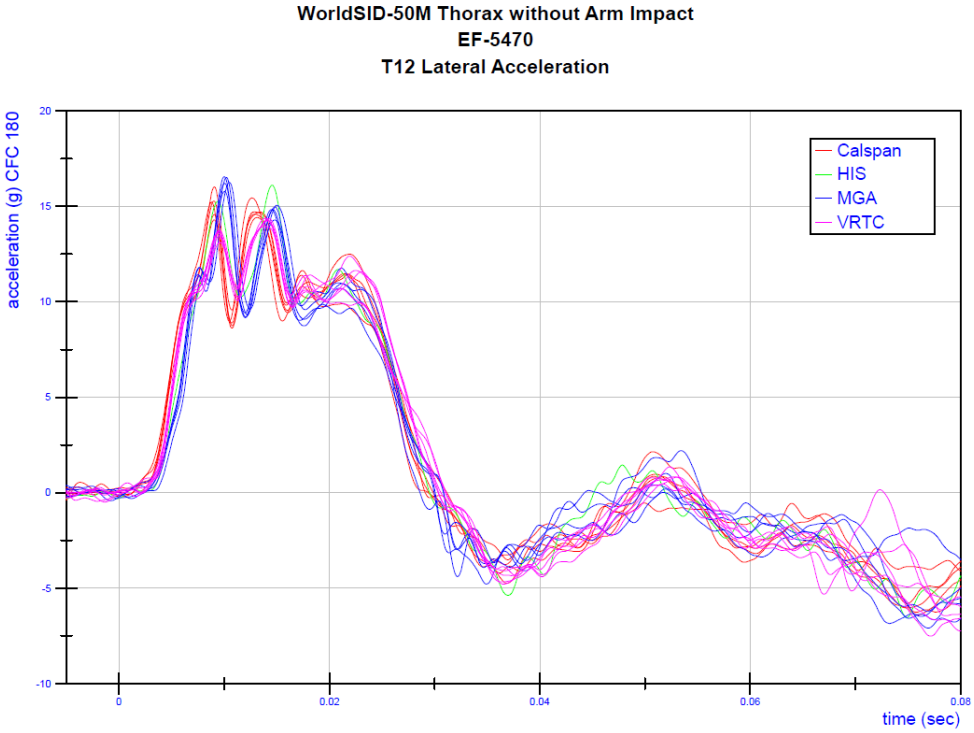

Figure A-35. Thorax without arm impact T12 lateral acceleration – dummy EF-5470

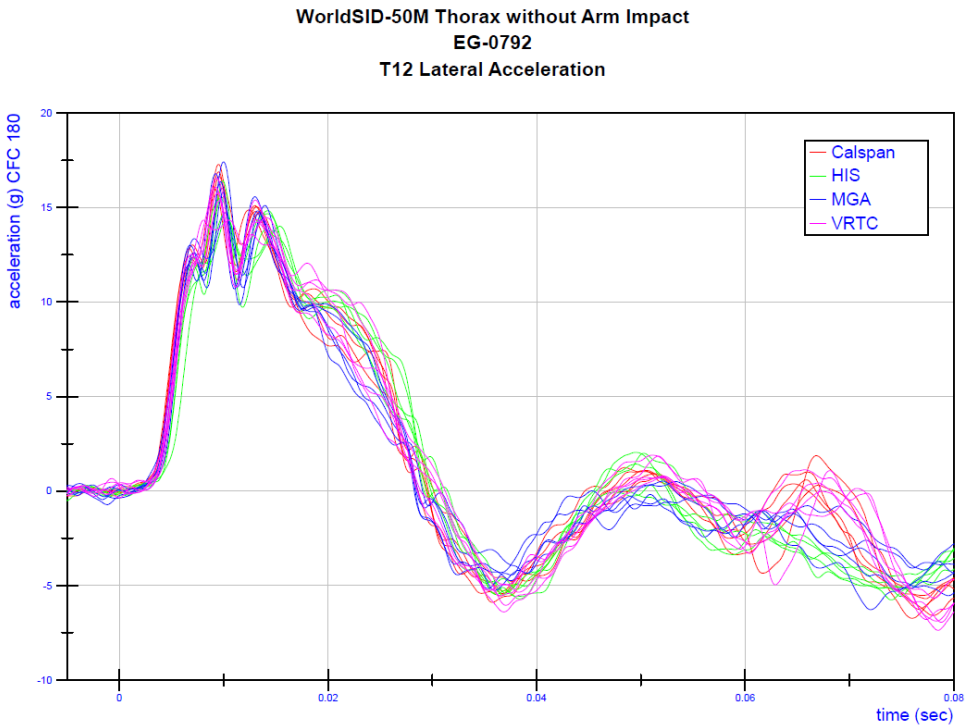

Figure A-36. Thorax without arm impact T12 lateral acceleration – dummy EG-0792

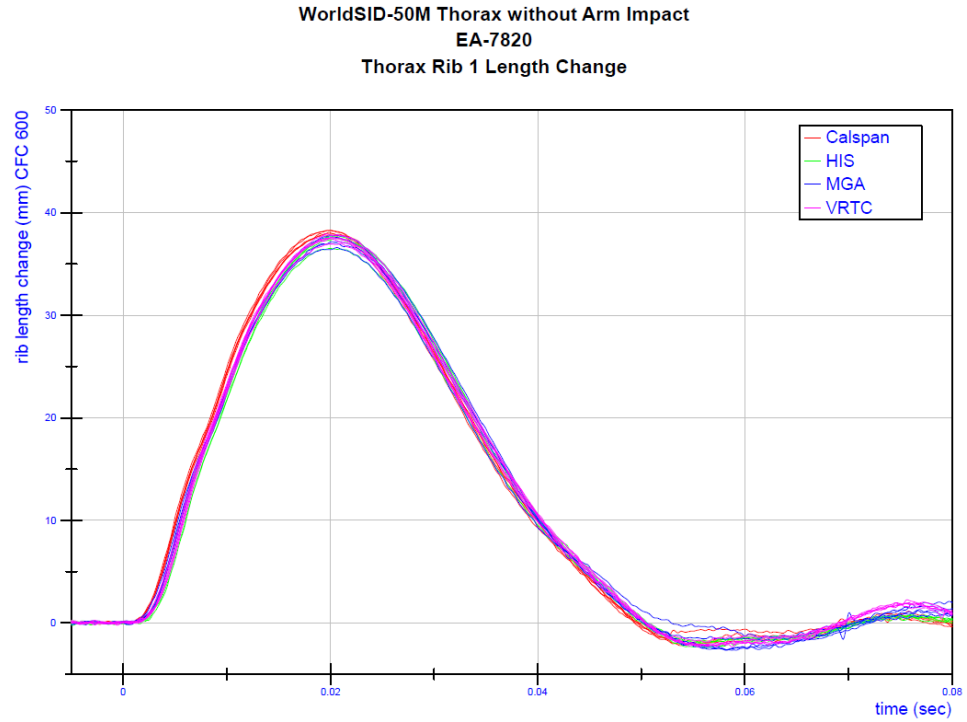

Figure A-37. Thorax without arm impact thorax rib 1 length change – dummy EA-7820

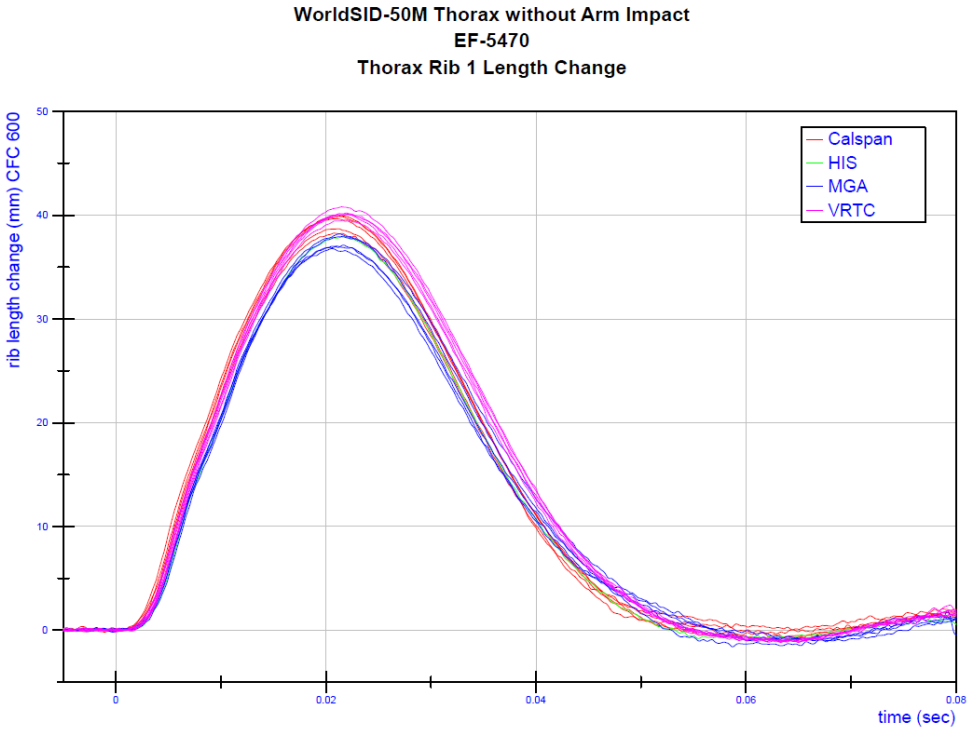

Figure A-38. Thorax without arm impact thorax rib 1 length change – dummy EF-5470

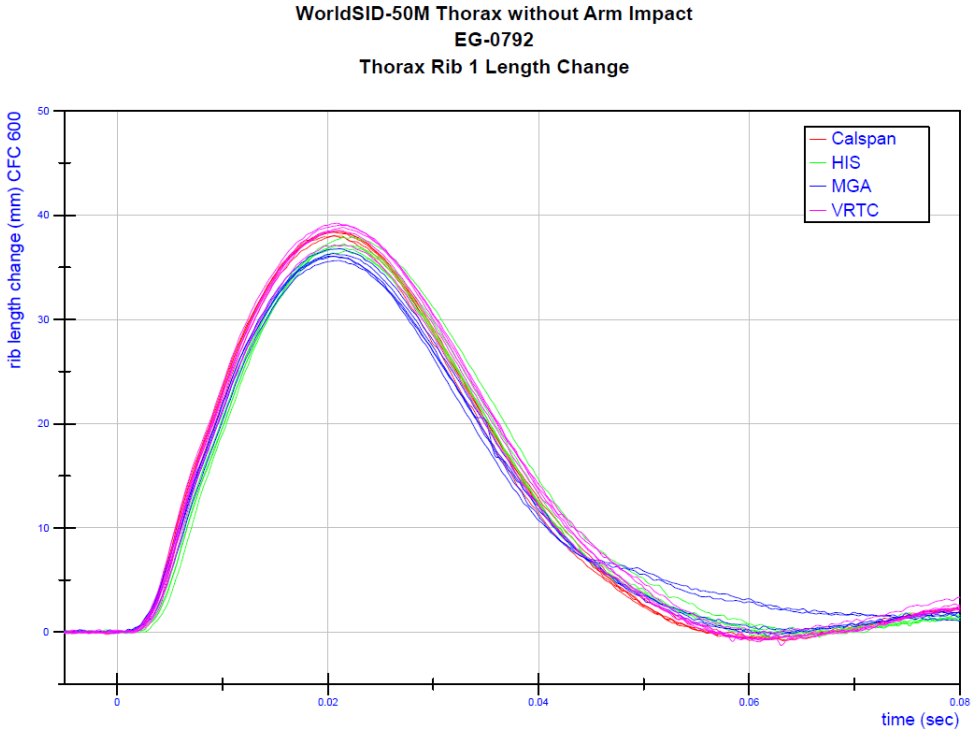

Figure A-39. Thorax without arm impact thorax rib 1 length change – dummy EG-0792

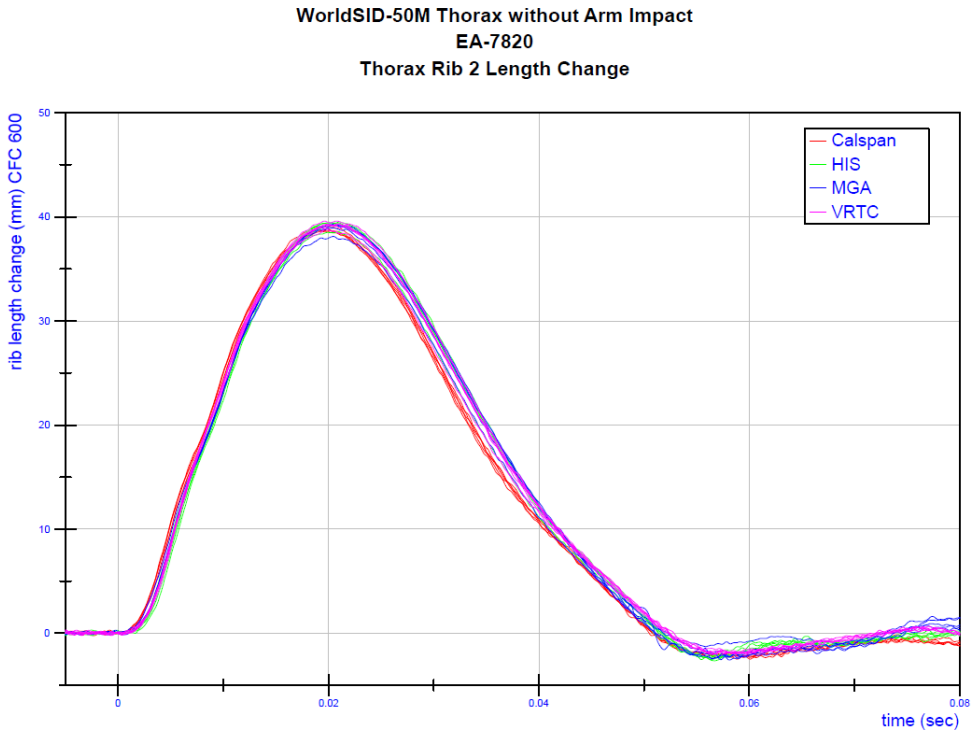

Figure A-40. Thorax without arm impact thorax rib 2 length change – dummy EA-7820

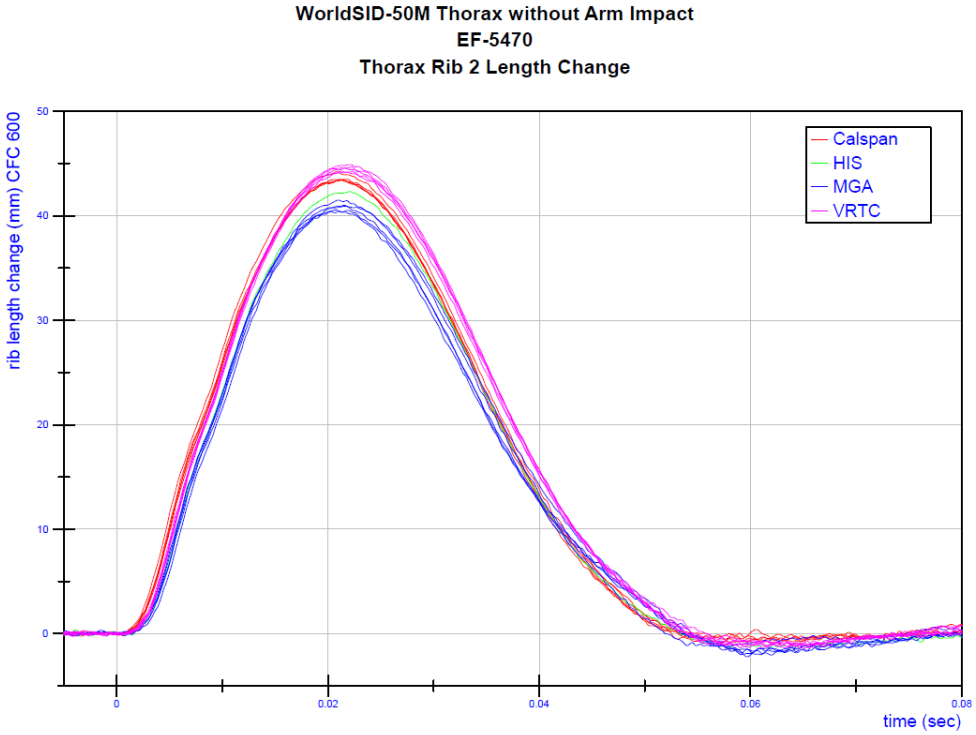

Figure A-41. Thorax without arm impact thorax rib 2 length change – dummy EF-5470

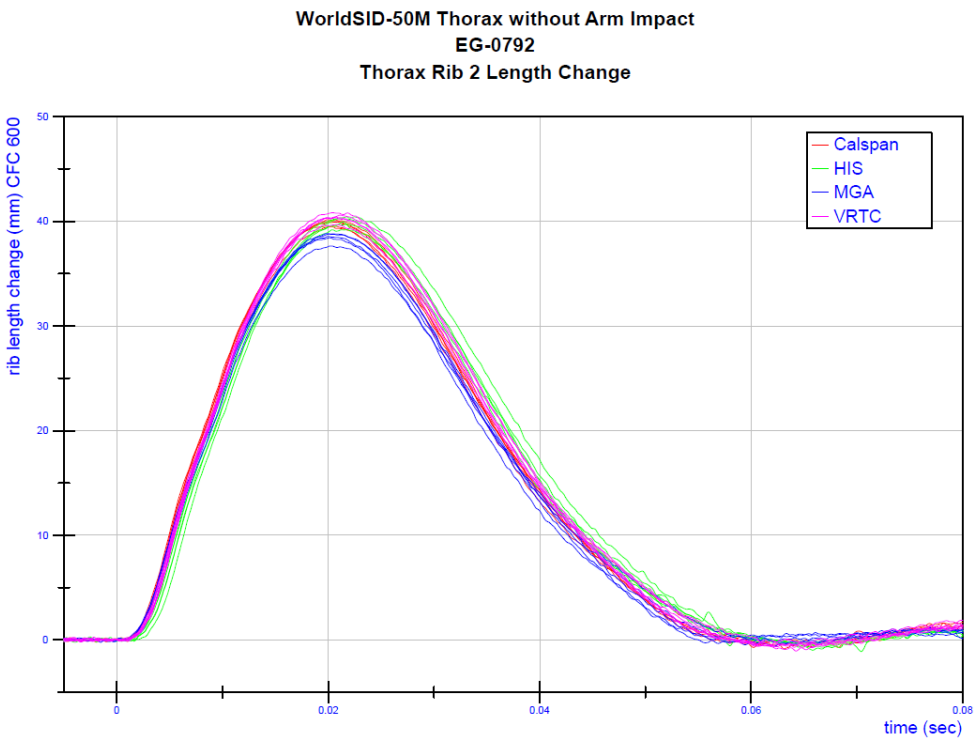

Figure A-42. Thorax without arm impact thorax rib 2 length change – dummy EG-0792

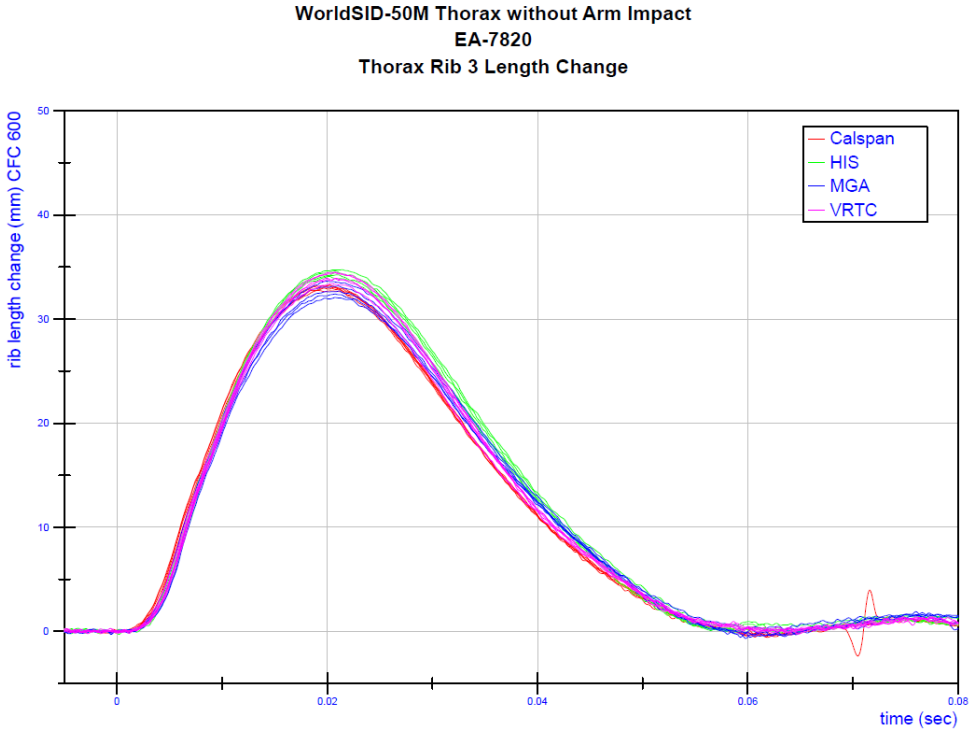

Figure A-43. Thorax without arm impact thorax rib 3 length change – dummy EA-7820

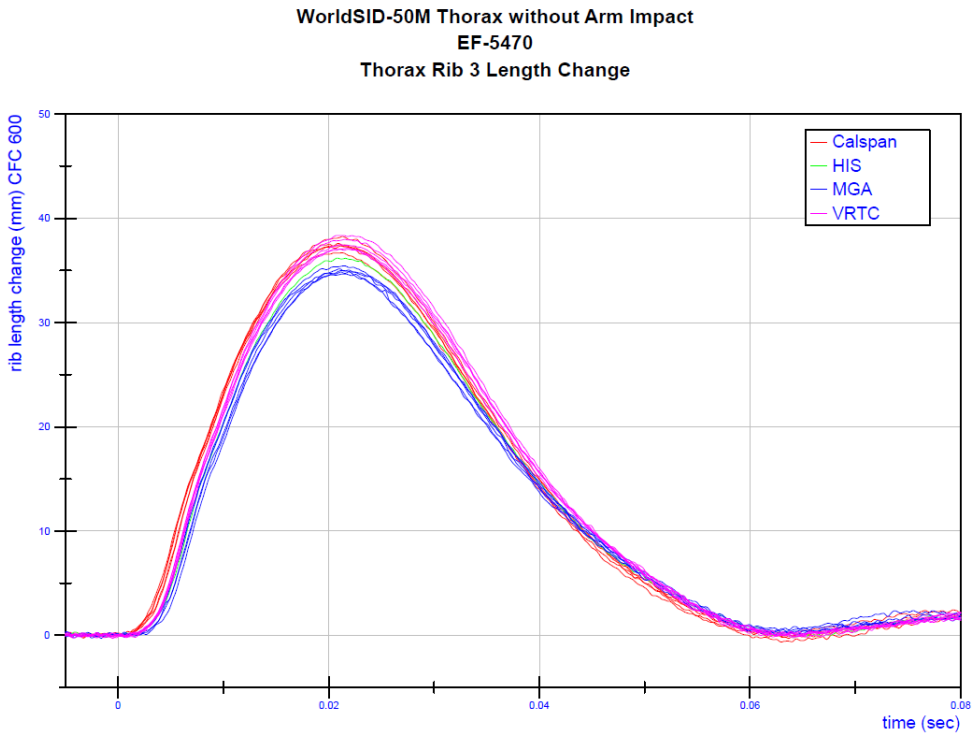

Figure A-44. Thorax without arm impact thorax rib 3 length change – dummy EF-5470

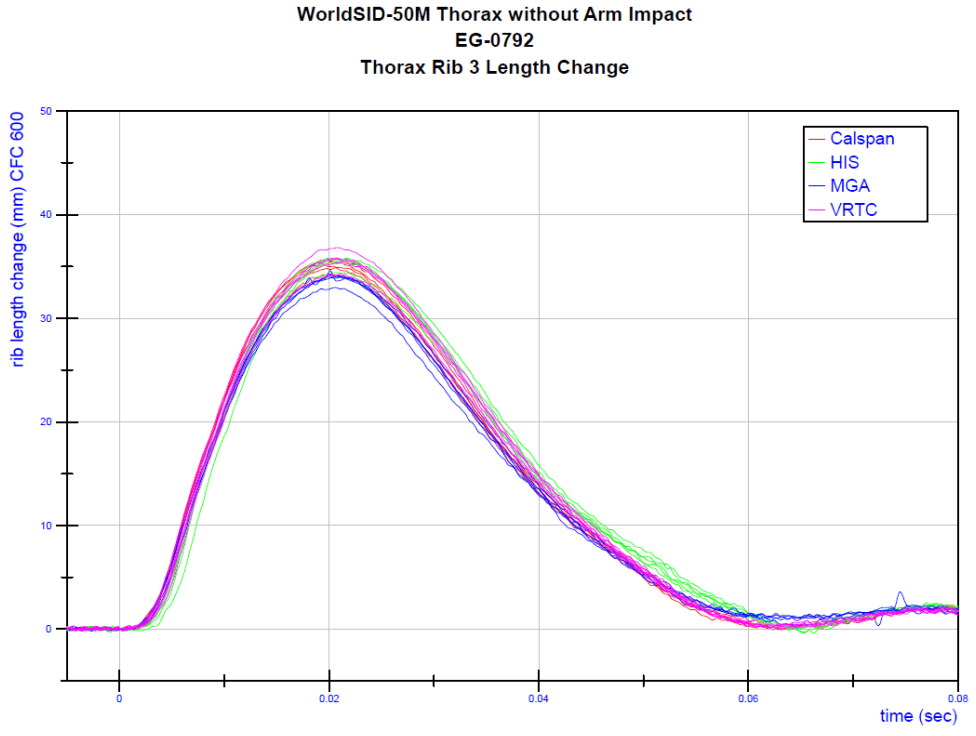

Figure A-45. Thorax without arm impact thorax rib 3 length change – dummy EG-0792

Abdomen Impacts

Table A-10. Abdomen impact tests – dummy EA-7820

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T12 Y-axis Accel	Peak Length Change	
								Abdomen Rib 1	Abdomen Rib 2
				m/s	ºC	kN	g	mm	mm
EA-7820	VRTC	221031-9	1	4.28	21.8	3.16	15.9	34.7	35.4
		221031-10	2	4.29	21.5	3.17	16.5	35.3	34.4
		221031-13	3	4.29	21.5	3.17	16.5	34.9	34.5
		221101-1	4	4.28	21.0	3.16	16.8	34.9	34.9
		221101-2	5	4.29	21.3	3.14	15.9	35.4	35.7
	Humanetics	230110-6	1	4.31	21.3	3.36	16.3	34.1	34.5
		230110-7	2	4.31	21.7	3.36	16.2	34.4	34.5
		230110-8	3	4.31	22.0	3.33	16.9	34.8	34.5
		230110-9	4	4.31	21.5	3.36	17.0	34.8	34.6
		230110-10	5	4.31	21.5	3.34	16.7	34.6	34.7
	MGA	230215-1	1	4.31	21.3	3.34	17.3	32.2	33.2
		230216-1	2	4.31	21.2	3.29	16.5	32.6	33.2
		230216-2	3	4.31	21.6	3.28	16.7	33.4	33.5
		230216-3	4	4.31	21.4	3.31	16.9	33.1	33.3
		230216-4	5	4.31	21.3	3.31	17.1	33.2	33.5
	Calspan	230313-3	1	4.30	22.1	3.32	16.7	33.7	33.4
		230313-4	2	4.30	21.2	3.31	17.0	34.2	32.7
		230313-5	3	4.30	22.2	3.28	16.3	34.4	33.8
		230313-6	4	4.30	21.5	3.29	16.7	34.5	33.3
		230313-7	5	4.30	22.3	3.29	16.5	34.6	33.8
All Tests EA-7820			Mean			3.28	16.6	34.2	34.1
			Std Dev			0.07	0.37	0.88	0.80
			CV			2.28%	2.25%	2.57%	2.36%

Table A-11. Abdomen impact tests – dummy EF-5470

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T12 Y-axis Accel	Peak Length Change	
								Abdomen Rib 1	Abdomen Rib 2
				m/s	ºC	kN	g	mm	mm
EF-5470	VRTC	221116-10	1	4.32	21.6	3.12	18.0	35.9	35.7
		221116-11	2	4.31	22.2	3.06	17.6	36.4	36.6
		221116-13	3	4.31	21.7	3.08	18.1	36.6	35.2
		221116-14	4	4.31	21.7	3.02	17.7	36.6	36.9
		221116-16	5	4.31	22.2	3.07	17.3	37.1	37.0
	Calspan	230116-1	1	4.31	22.6	3.29	18.4	36.7	34.1
		230117-1	2	4.31	20.9	3.24	17.6	36.3	34.2
		230117-2	3	4.31	21.6	3.22	17.6	36.8	34.8
		230117-3	4	4.31	20.9	3.23	17.7	36.6	34.5
		230117-4	5	4.31	21.1	3.25	17.4	37.1	35.2
	Humanetics	230306-1	1	4.30	20.7	3.27	18.7	36.1	34.1
		230306-2	2	4.30	21.0	3.21	18.3	36.8	34.7
		230306-3	3	4.31	21.1	3.24	17.8	36.9	34.6
		230306-4	4	4.29	21.2	3.20	18.5	36.8	34.4
		230306-5	5	4.29	21.4	3.20	17.8	36.8	34.3
	MGA	230328-6	1	4.29	21.5	3.19	17.6	34.7	34.1
		230328-7	2	4.29	21.2	3.19	17.4	34.8	34.2
		230328-8	3	4.31	21.2	3.19	17.6	34.7	34.2
		230328-9	4	4.31	21.3	3.19	17.6	35.1	34.3
		230328-10	5	4.32	21.2	3.13	17.6	35.0	34.7
All Tests EF-5470			Mean			3.18	17.8	36.2	34.9
			Std Dev			0.07	0.40	0.84	0.95
			CV			2.35%	2.23%	2.32%	2.72%

Table A-12. Abdomen impact tests – dummy EG-0792

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Rib Temp	Peak Impactor Force	Peak T12 Y-axis Accel	Peak Length Change	
								Abdomen Rib 1	Abdomen Rib 2
				m/s	ºC	kN	g	mm	mm
EG-0792	VRTC	221129-4	1	4.30	21.3	3.13	17.1	34.5	35.7
		221129-7	2	4.29	21.3	3.12	17.2	34.7	35.7
		221129-10	3	4.30	21.4	3.07	17.5	34.6	35.7
		221129-11	4	4.30	21.5	3.10	17.7	35.2	34.8
		221129-14	5	4.30	21.4	3.08	16.9	35.1	36.3
	Calspan	230302-1	1	4.30	21.5	3.22	17.9	33.4	33.5
		230302-2	2	4.30	21.5	3.20	17.6	34.4	34.3
		230302-3	3	4.30	22.1	3.16	17.3	34.6	34.3
		230302-4	4	4.31	21.5	3.18	17.4	34.4	34.2
		230302-5	5	4.30	22.0	3.17	17.3	34.7	34.7
	Humanetics	230411-6	1	4.30	21.7	3.20	17.3	33.2	34.3
		230412-1	2	4.30	21.7	3.24	17.9	33.5	35.0
		230412-2	3	4.29	21.9	3.15	17.9	34.0	35.0
		230412-3	4	4.29	21.9	3.15	17.7	33.9	35.1
		230412-4	5	4.29	21.4	3.17	17.2	33.9	34.5
	MGA	230511-1	1	4.27	21.3	3.14	17.2	32.9	34.6
		230511-2	2	4.32	21.0	3.16	17.3	33.2	34.1
		230511-3	3	4.31	21.1	3.17	17.7	33.3	34.3
		230511-4	4	4.32	21.2	3.17	17.5	33.5	34.9
		230511-5	5	4.32	21.2	3.16	17.9	33.4	34.7
All Tests EG-0792			Mean			3.16	17.5	34.0	34.8
			Std Dev			0.04	0.30	0.69	0.67
			CV			1.35%	1.71%	2.04%	1.94%

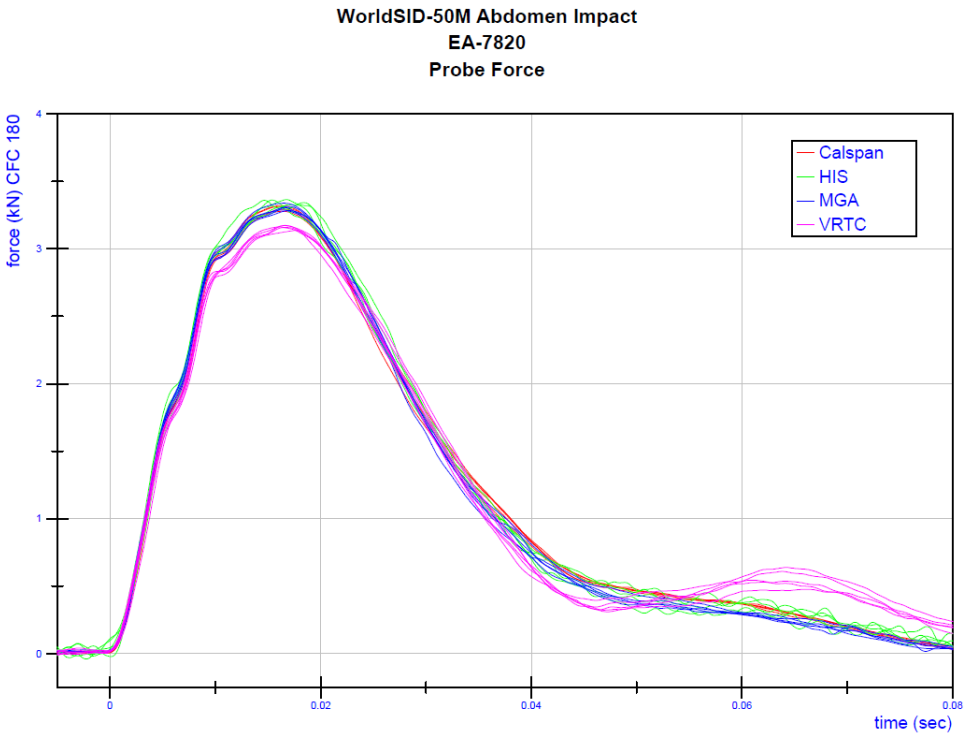

Figure A-46. Abdomen impact probe force – dummy EA-7820

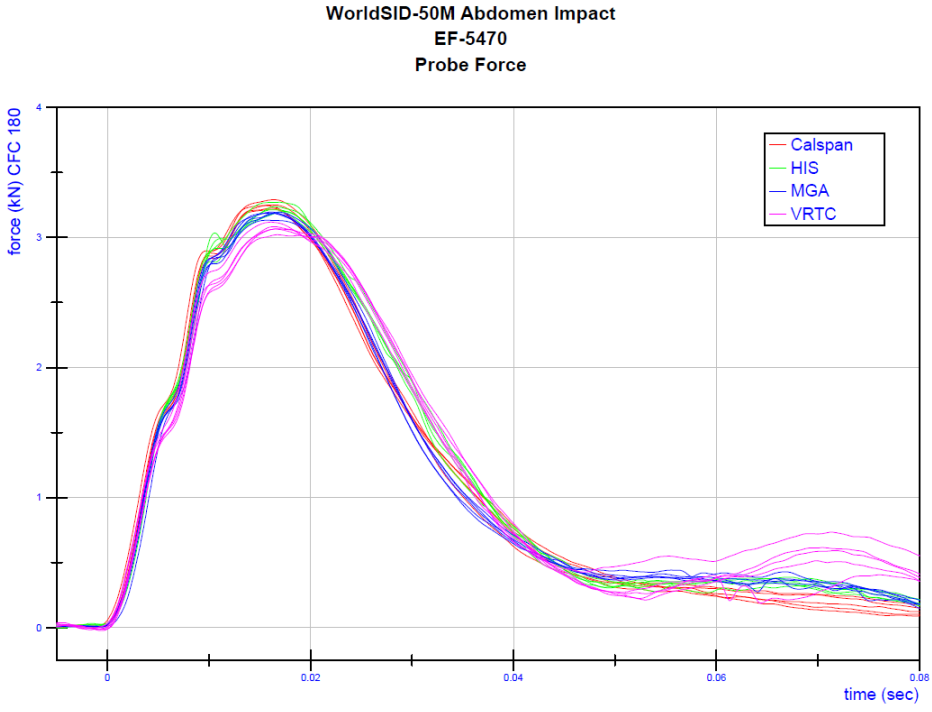

Figure A-47. Abdomen impact probe force – dummy EF-5470

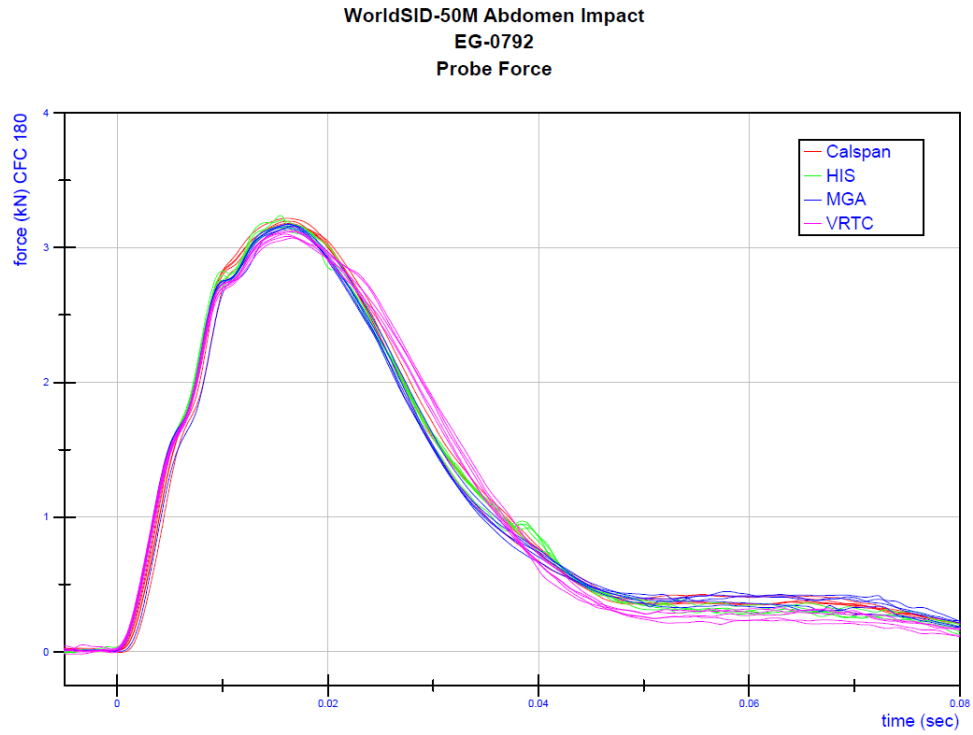

Figure A-48. Abdomen impact probe force – dummy EG-0792

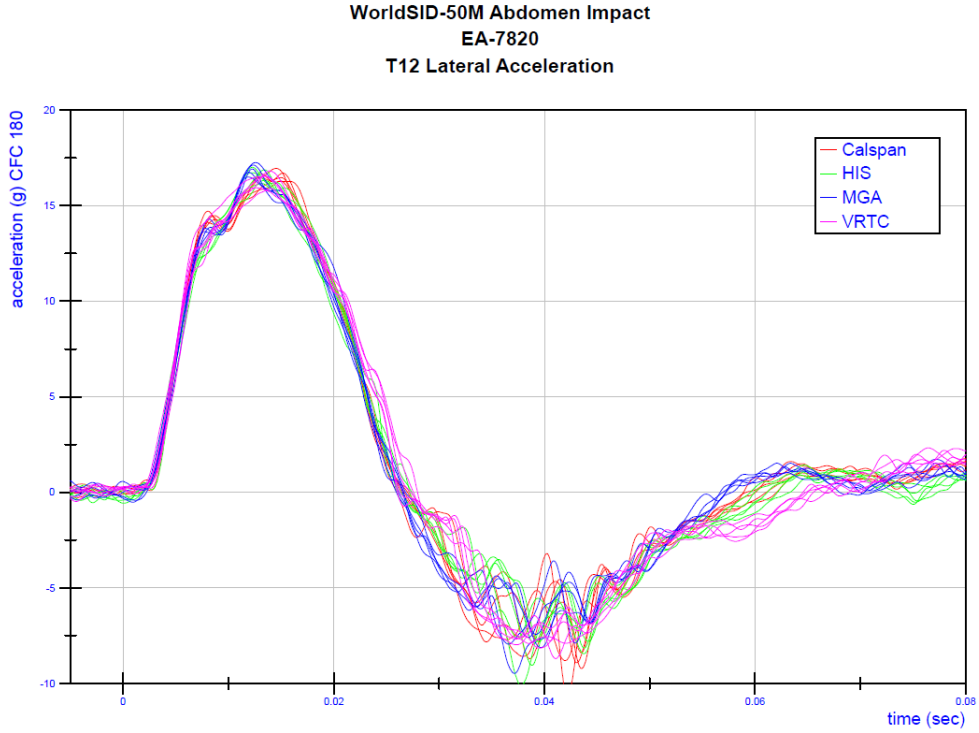

Figure A-49. Abdomen impact T12 lateral acceleration – dummy EA-7820

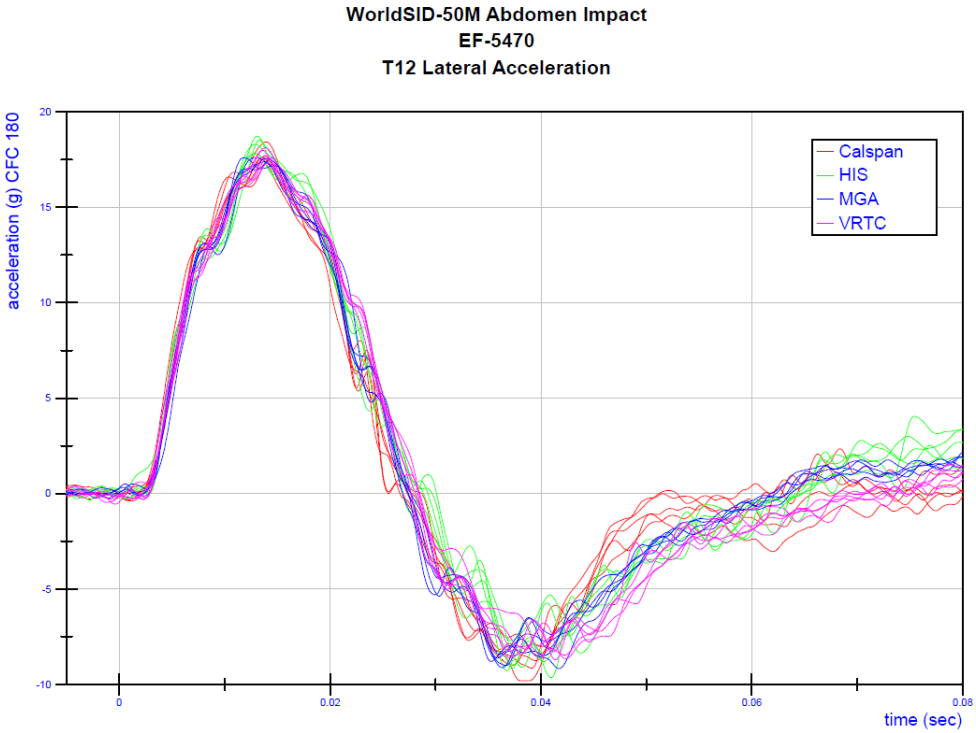

Figure A-50. Abdomen impact T12 lateral acceleration – dummy EF-5470

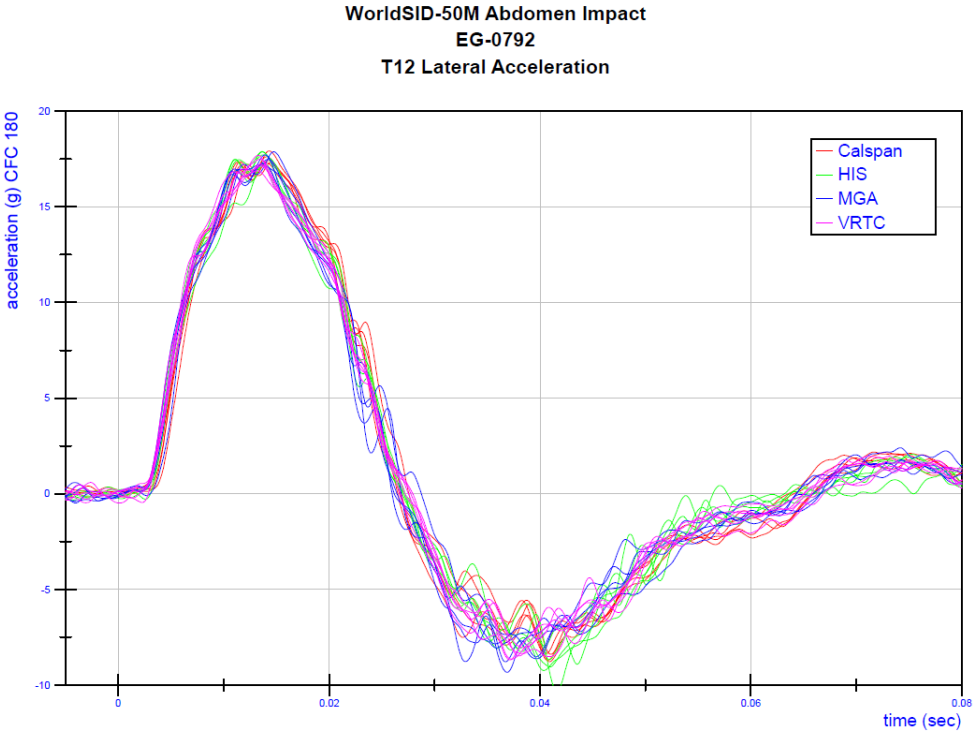

Figure A-51. Abdomen impact T12 lateral acceleration – dummy EG-0792

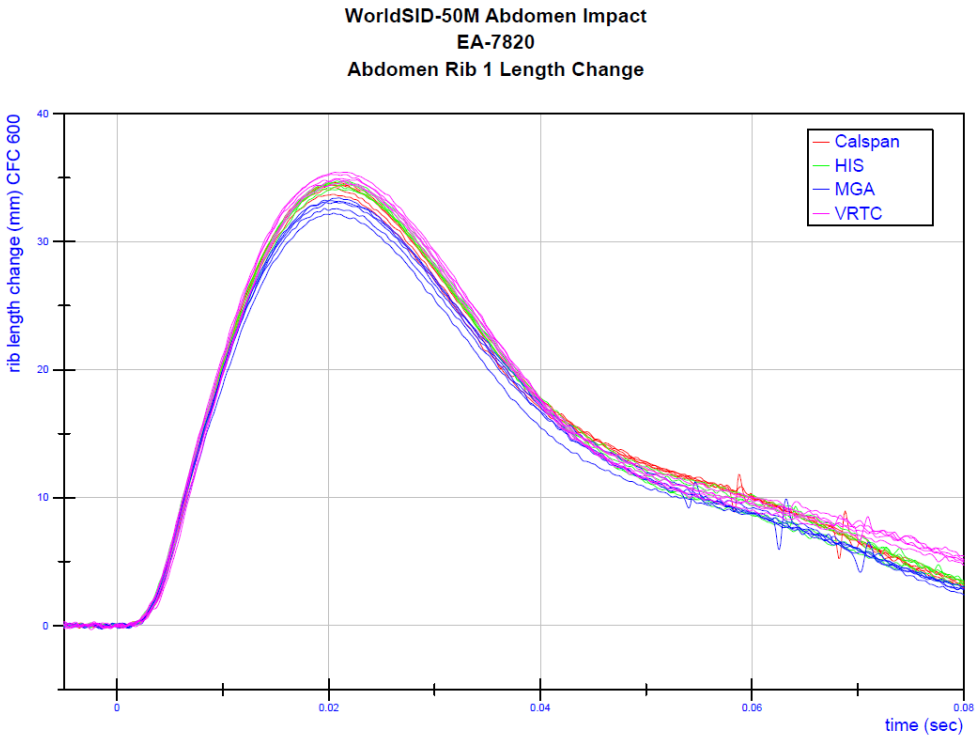

Figure A-52. Abdomen impact abdomen rib 1 length change – dummy EA-7820

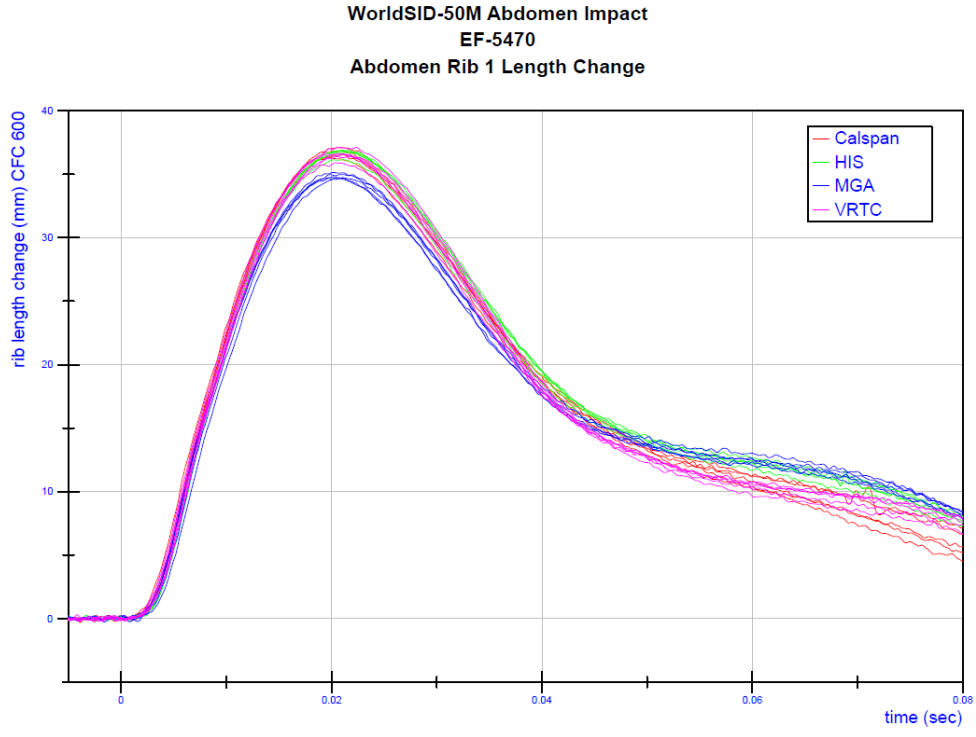

Figure A-53. Abdomen impact abdomen rib 1 length change – dummy EF-5470

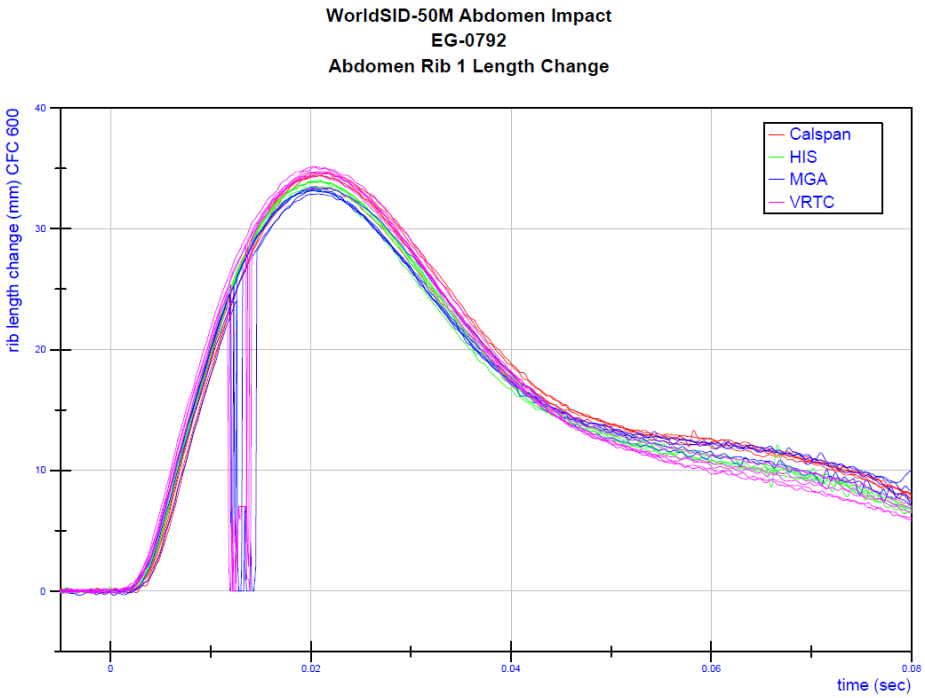

Figure A-54. Abdomen impact abdomen rib 1 length change – dummy EG-0792. Note: vertical lines in plot were attributed to intermittent and loose LEDs. Peak response values were not affected.

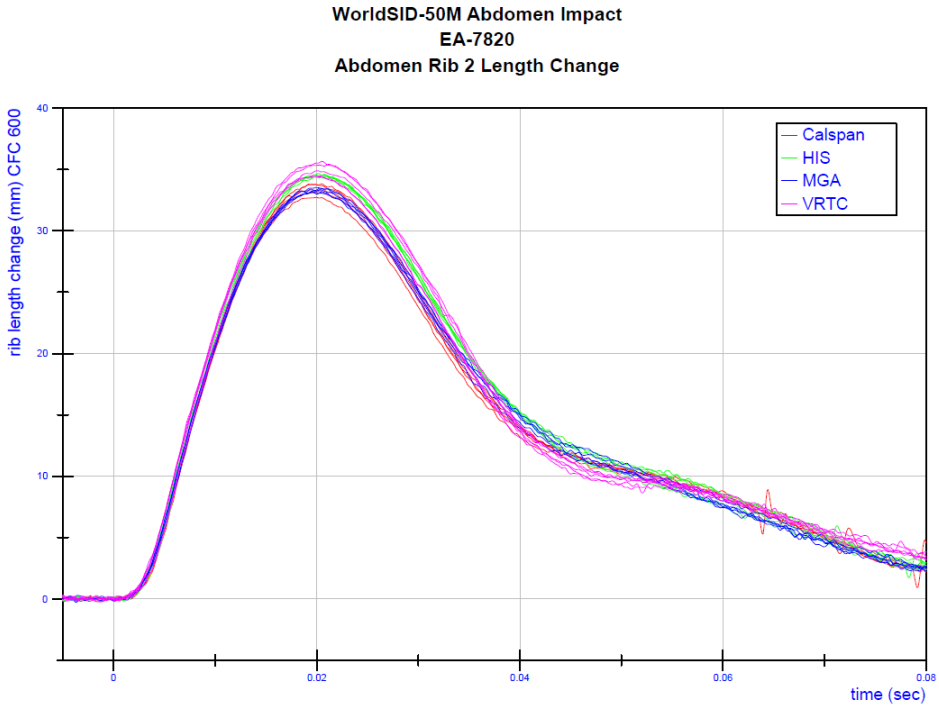

Figure A-55. Abdomen impact abdomen rib 2 length change – dummy EA-7820

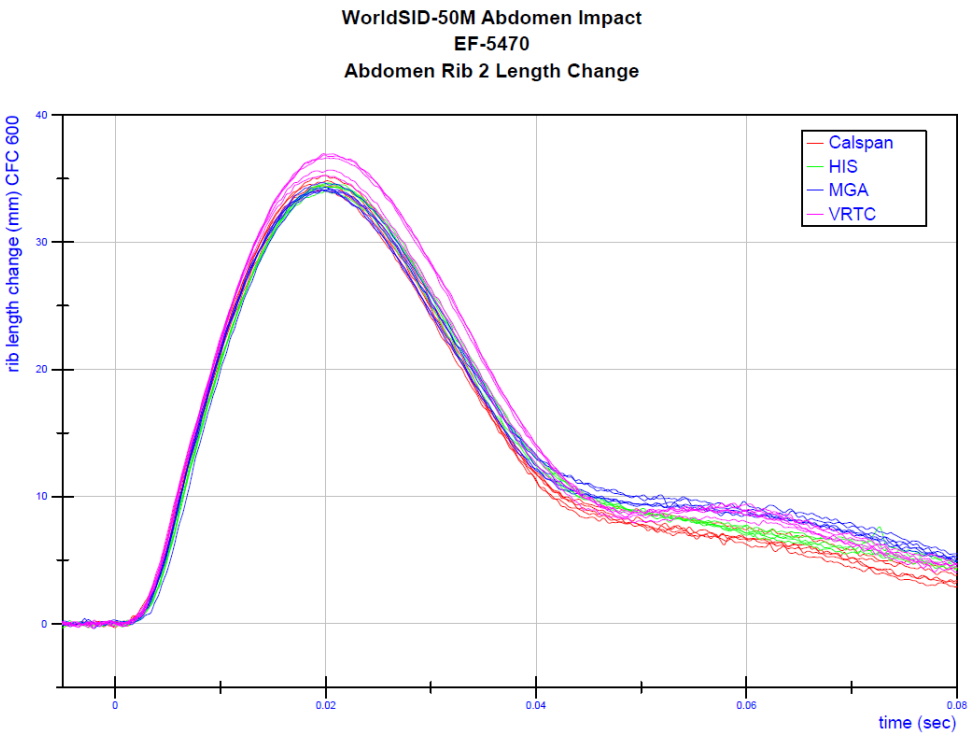

Figure A-56. Abdomen impact abdomen rib 2 length change – dummy EF-5470

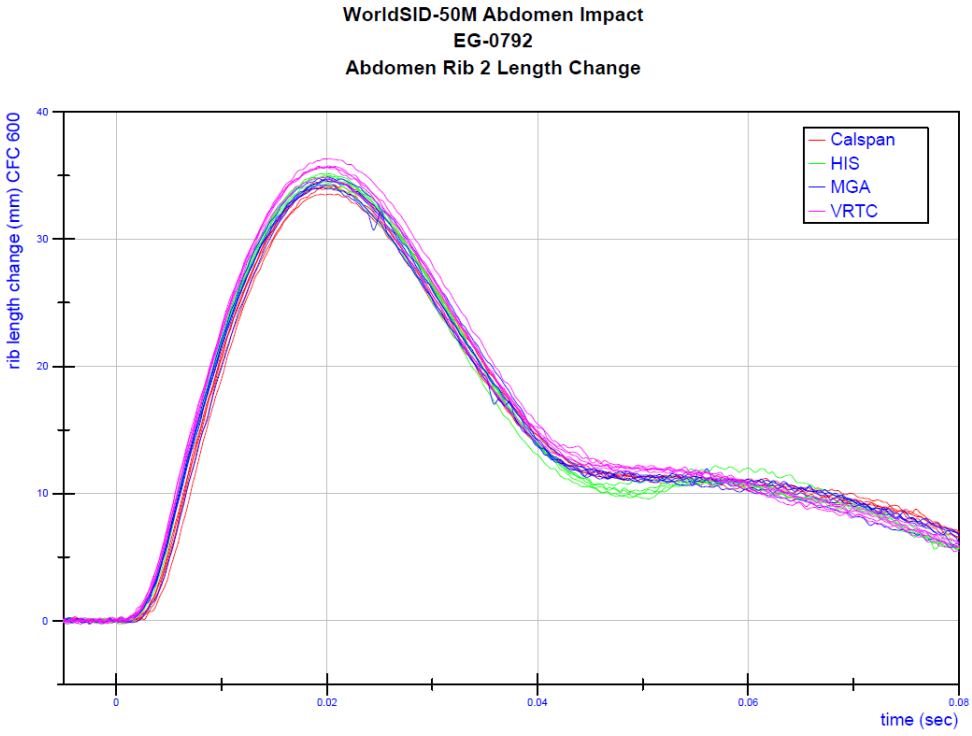

Figure A-57. Abdomen impact abdomen rib 2 length change – dummy EG-0792

Pelvis Impacts

Table A-13. Pelvis impact tests – dummy EA-7820

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Peak Impactor Force	Peak Pubic Y-force	Peak Sacroiliac Y-force	Peak T12 Y-accel	Peak Pelvis Y-accel
				m/s	kN	kN	kN	g	g
EA-7820	VRTC	221121-1	1	6.71	7.99	-1.47	-2.45	13.3	42.5
		221121-2	2	6.72	8.10	-1.49	-2.43	12.3	43.3
		221122-1	3	6.72	7.93	-1.41	-2.48	13.1	39.8
		221122-2	4	6.72	8.07	-1.46	-2.44	12.4	41.6
		221122-3	5	6.71	7.92	-1.45	-2.48	12.7	40.9
	Humanetics	230111-1	1	6.69	8.19	-1.50	-2.36	13.9	41.4
		230111-2	2	6.69	8.10	-1.51	-2.39	14.9	40.9
		230111-3	3	6.68	7.98	-1.48	-2.43	14.2	40.6
		230111-4	4	6.69	8.09	-1.53	-2.38	14.4	39.9
		230111-5	5	6.69	8.02	-1.53	-2.37	14.7	39.4
	MGA	230216-6	1	6.71	8.08	-1.51	-2.34	13.2	40.0
		230216-7	2	6.71	8.01	-1.49	-2.35	12.6	41.6
		230216-8	3	6.71	8.05	-1.51	-2.31	13.1	40.6
		230216-9	4	6.71	7.97	-1.51	-2.41	12.4	41.5
		230216-10	5	6.71	7.95	-1.51	-2.41	13.4	40.9
	Calspan	230314-1	1	6.70	8.11	-1.47	-2.38	14.1	39.8
		230314-2	2	6.71	8.10	-1.56	-2.45	14.5	42.8
		230314-3	3	6.71	8.15	-1.55	-2.41	14.6	41.6
		230314-4	4	6.71	8.15	-1.55	-2.42	14.1	41.0
		230314-5	5	6.70	8.15	-1.52	-2.39	14.5	41.4
All Tests EA-7820			Mean		8.06	-1.50	-2.40	13.61	41.07
			Std Dev		0.080	0.037	0.046	0.862	1.029
			CV		1.00%	2.46%	1.91%	6.33%	2.51%

Table A-14. Pelvis impact tests – dummy EF-5470

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Peak Impactor Force	Peak Pubic Y-force	Peak Sacroiliac Y-force	Peak T12 Y-accel	Peak Pelvis Y-accel
				m/s	kN	kN	kN	g	g
EF-5470	VRTC	221107-1	1	6.73	7.64	-1.25	-1.99	11.9	38.4
		221108-1	2	6.74	7.60	-1.24	-1.98	11.9	39.4
		221108-3	3	6.74	7.62	-1.27	-2.06	12.2	41.2
		221108-4	4	6.73	7.48	-1.23	-2.04	12.4	39.5
		221108-5	5	6.73	7.61	-1.28	-2.01	12.5	39.1
	Calspan	230118-1	1	6.70	7.80	-1.30	-2.13	13.4	44.8
		230118-2	2	6.70	7.76	-1.35	-2.08	12.4	42.4
		230123-1	3	6.71	7.71	-1.27	-2.09	12.7	41.4
		230123-2	4	6.70	7.78	-1.37	-2.01	13.7	42.5
		230124-1	5	6.70	7.74	-1.30	-2.02	13.3	40.6
	Humanetics	230308-1	1	6.70	7.73	-1.32	-2.02	12.5	40.9
		230308-2	2	6.70	7.76	-1.24	-2.19	12.1	43.5
		230308-3	3	6.71	7.68	-1.24	-2.20	12.0	43.9
		230308-4	4	6.71	7.66	-1.25	-2.26	12.7	44.0
		230308-5	5	6.70	7.64	-1.23	-2.26	13.8	44.7
	MGA	230329-1	1	6.73	7.82	-1.34	-2.00	13.0	39.9
		230329-2	2	6.73	7.70	-1.33	-1.98	13.7	43.1
		230329-3	3	6.68	7.48	-1.31	-2.03	12.5	38.6
		230329-4	4	6.73	7.55	-1.31	-2.13	12.4	43.3
		230329-5	5	6.73	7.64	-1.36	-2.04	11.5	40.8
All Tests EF-5470			Mean		7.67	-1.29	-2.08	12.63	41.59
			Std Dev		0.097	0.046	0.090	0.658	2.059
			CV		1.26%	3.58%	4.31%	5.21%	4.95%

Table A-15. Pelvis impact tests – dummy EG-0792

Dummy S/N	Lab	Test ID	Test #	Impact Speed	Peak Impactor Force	Peak Pubic Y-force	Peak Sacroiliac Y-force	Peak T12 Y-accel	Peak Pelvis Y-accel
				m/s	kN	kN	kN	g	g
EG-0792	VRTC	221201-2	1	6.70	7.78	-1.34	-2.13	12.9	42.2
		221201-3	2	6.70	7.82	-1.34	-2.02	12.7	44.7
		221202-1	3	6.72	7.96	-1.31	-2.06	11.6	45.1
		221202-2	4	6.72	7.87	-1.30	-2.02	11.8	43.1
		221202-3	5	6.72	7.77	-1.26	-2.05	11.7	43.1
	Calspan	230302-6	1	6.71	7.94	-1.35	-2.09	11.9	42.4
		230303-1	2	6.71	8.08	-1.44	-2.13	12.2	45.8
		230303-2	3	6.70	8.02	-1.43	-2.16	11.7	45.6
		230303-3	4	6.70	7.91	-1.42	-2.14	11.5	44.5
		230303-4	5	6.70	8.00	-1.43	-2.14	12.7	44.4
	Humanetics	230412-1	1	6.70	7.84	-1.31	-2.17	12.4	46.5
		230412-2	2	6.69	7.68	-1.35	-2.19	12.4	44.9
		230412-3	3	6.68	8.05	-1.34	-2.25	11.3	44.6
		230412-4	4	6.69	7.92	-1.39	-2.16	12.0	44.8
		230412-5	5	6.70	7.97	-1.42	-2.14	12.0	43.7
	MGA	230511-6	1	6.73	8.40	-1.49	-2.17	11.6	44.1
		230511-7	2	6.73	8.35	-1.36	-2.18	12.6	43.1
		230511-8	3	6.68	8.28	-1.38	-2.19	12.4	43.3
		230511-9	4	6.71	8.27	-1.37	-2.18	12.0	43.8
		230511-10	5	6.73	8.26	-1.40	-2.18	11.0	43.0
All Tests EG-0792			Mean		8.01	-1.37	-2.14	12.02	44.13
			Std Dev		0.21	0.06	0.06	0.51	1.16
			CV		2.56%	4.04%	2.86%	4.20%	2.64%

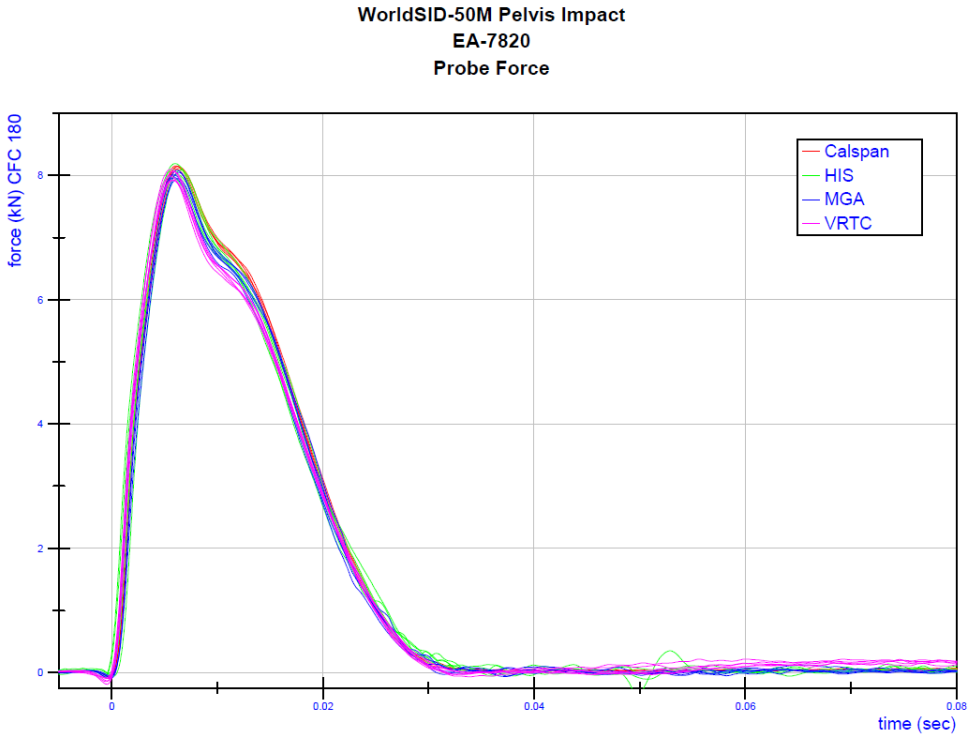

Figure A-58. Pelvis impact probe force – dummy EA-7820

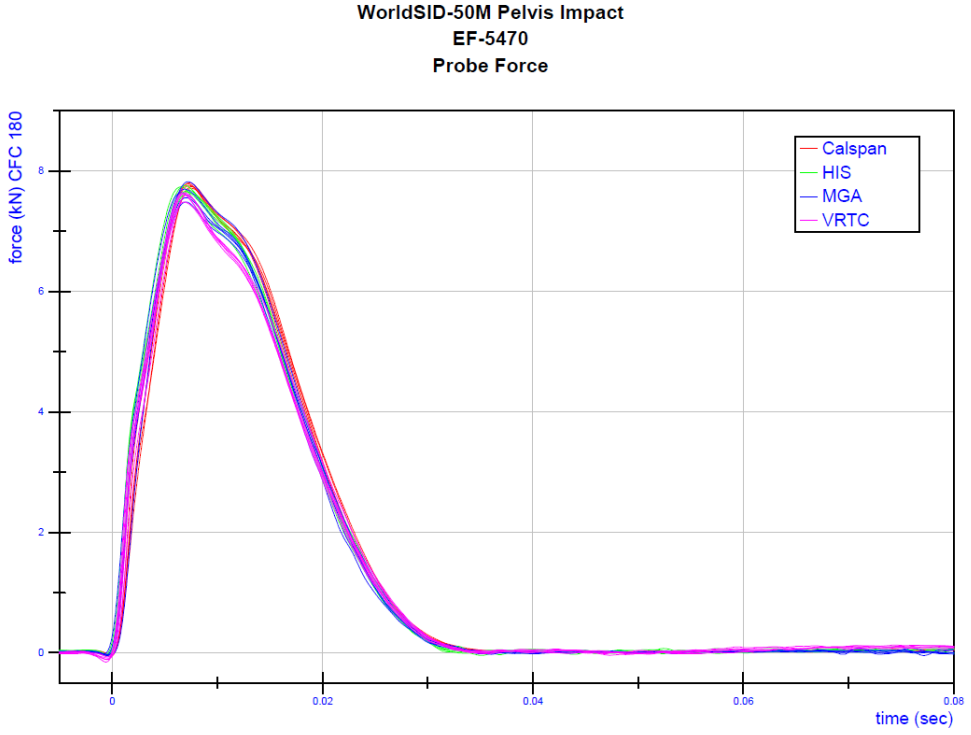

Figure A-59. Pelvis impact probe force – dummy EF-5470

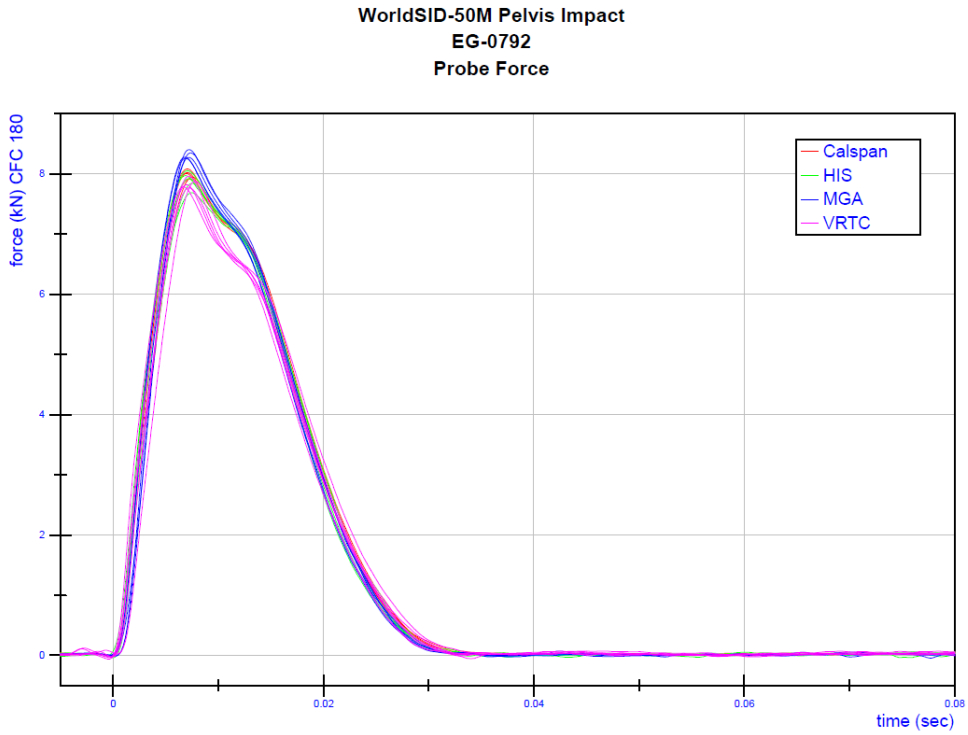

Figure A-60. Pelvis impact probe force – dummy EG-0792

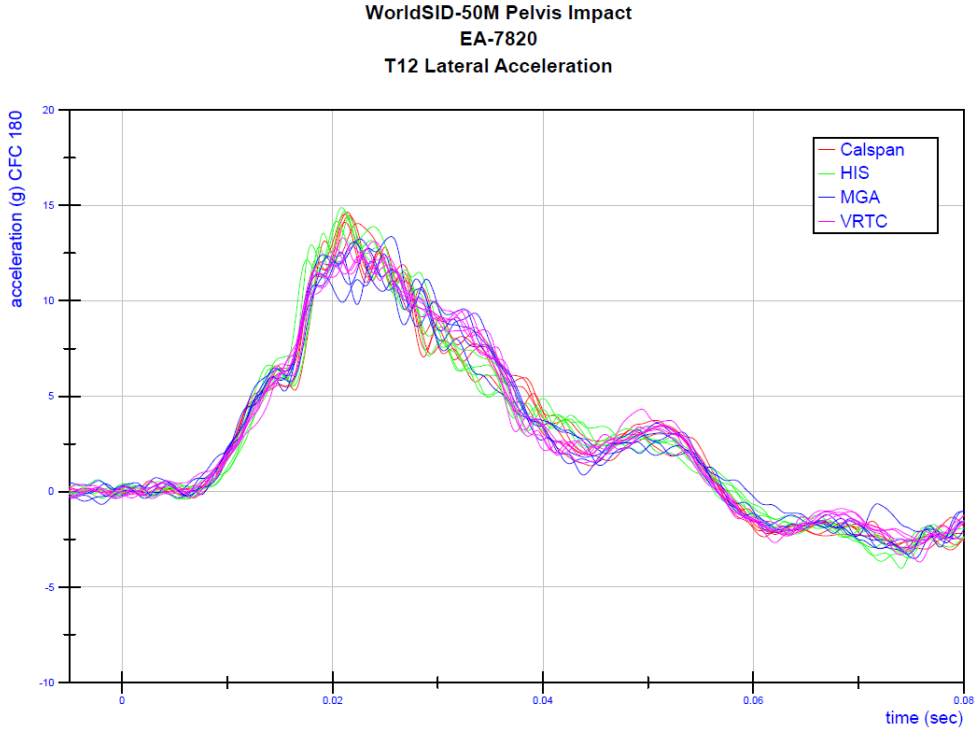

Figure A-61. Pelvis impact T12 lateral acceleration – dummy EA-7820

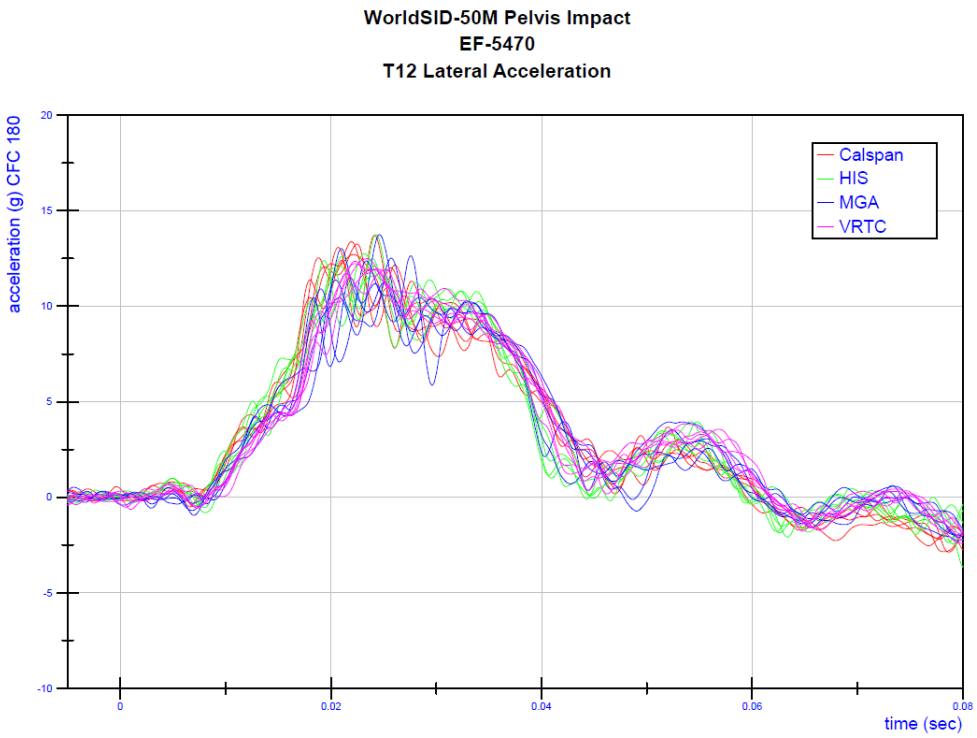

Figure A-62. Pelvis impact T12 lateral acceleration – dummy EF-5470

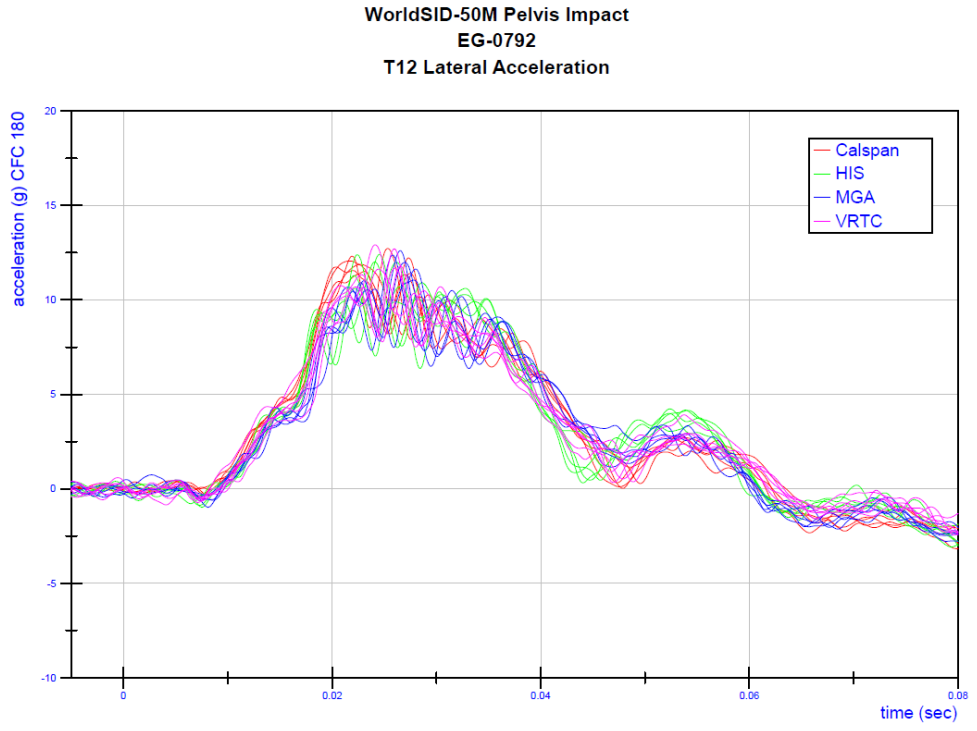

Figure A-63. Pelvis impact T12 lateral acceleration – dummy EG-0792

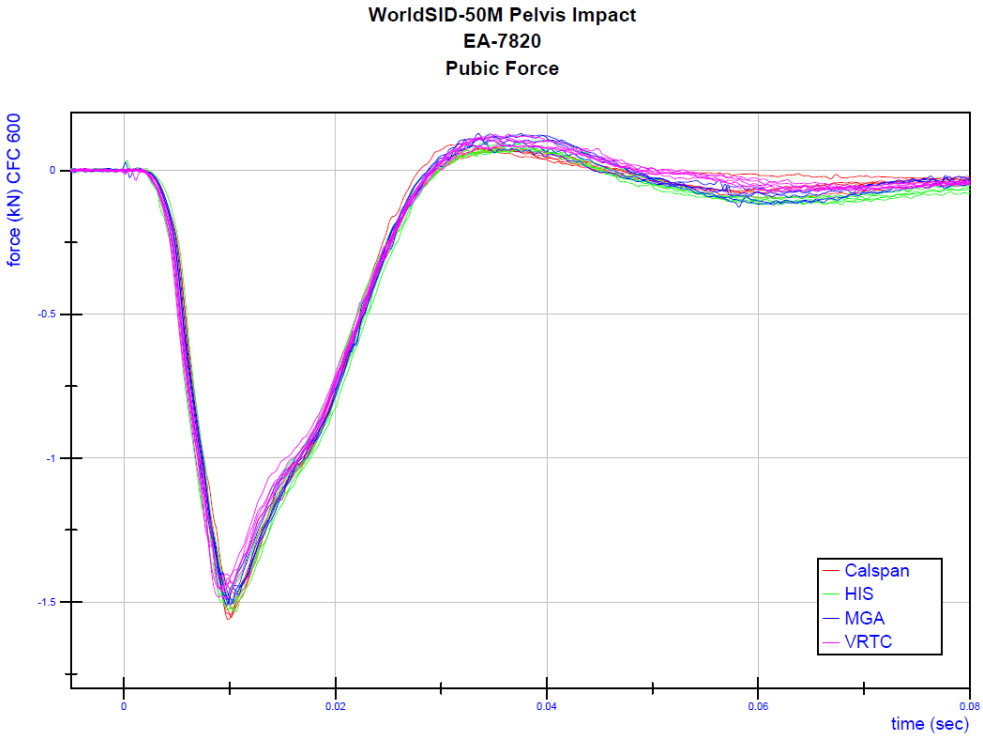

Figure A-64. Pelvis impact pubic force – dummy EA-7820

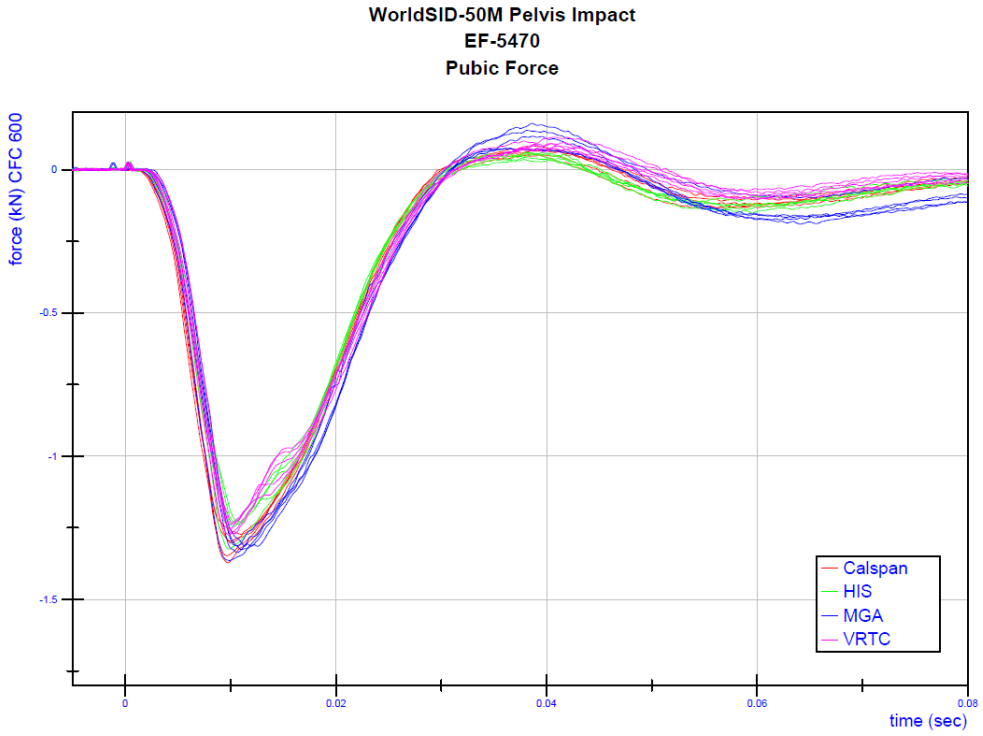

Figure A-65. Pelvis impact pubic force – dummy EF-5470

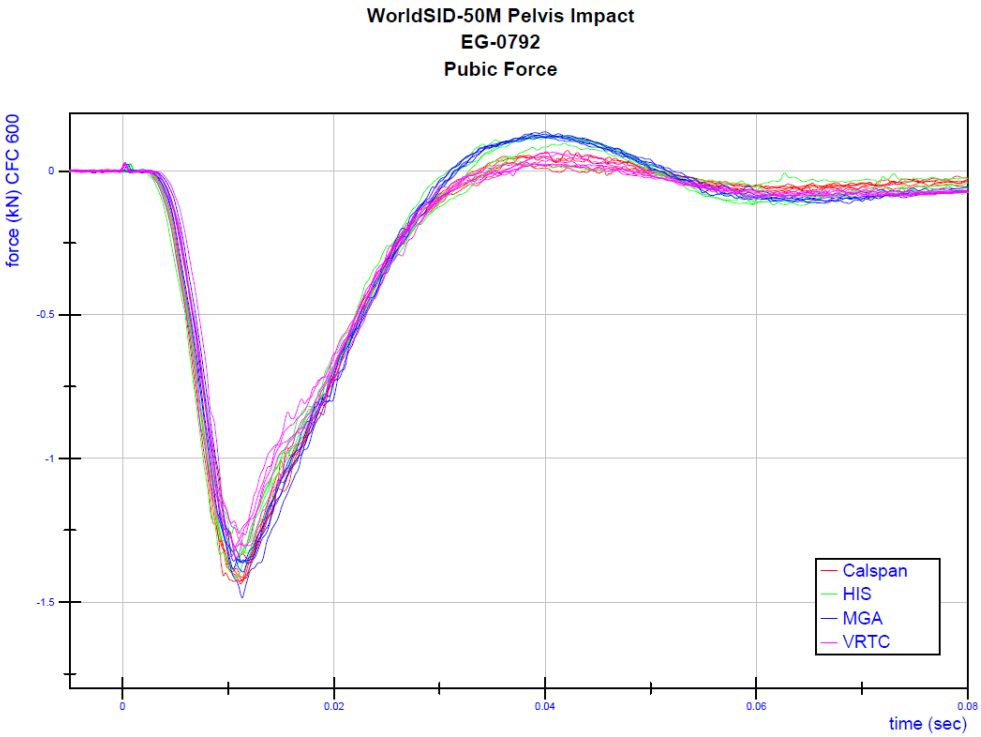

Figure A-66. Pelvis impact pubic force – dummy EG-0792

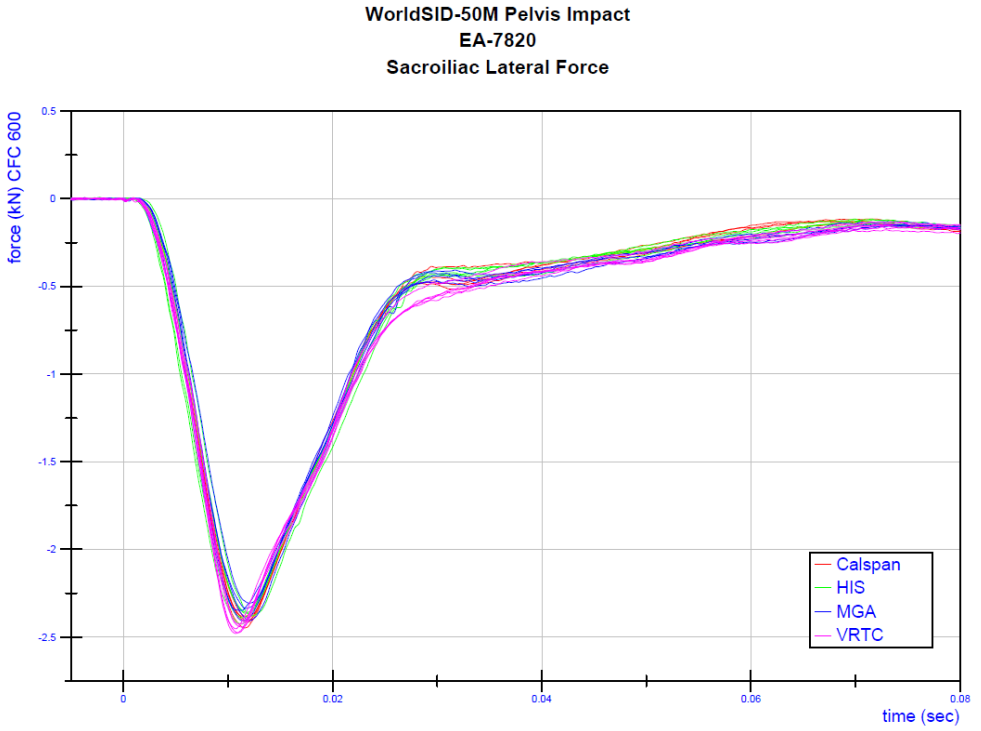

Figure A-67. Pelvis impact sacroiliac lateral force – dummy EA-7820

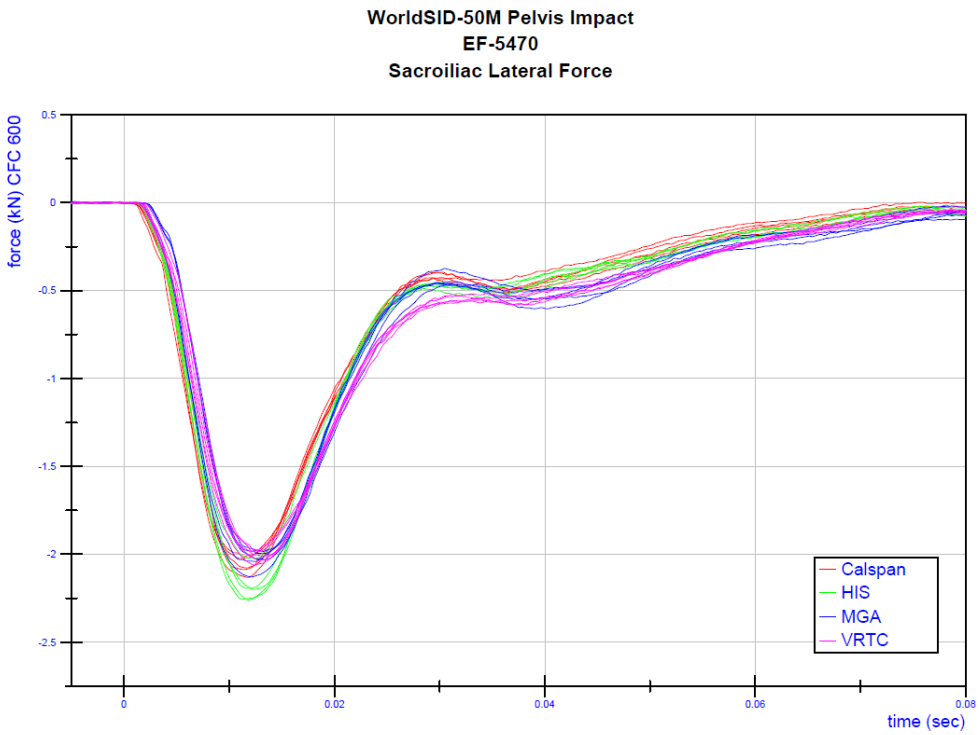

Figure A-68. Pelvis impact sacroiliac lateral force – dummy EF-5470

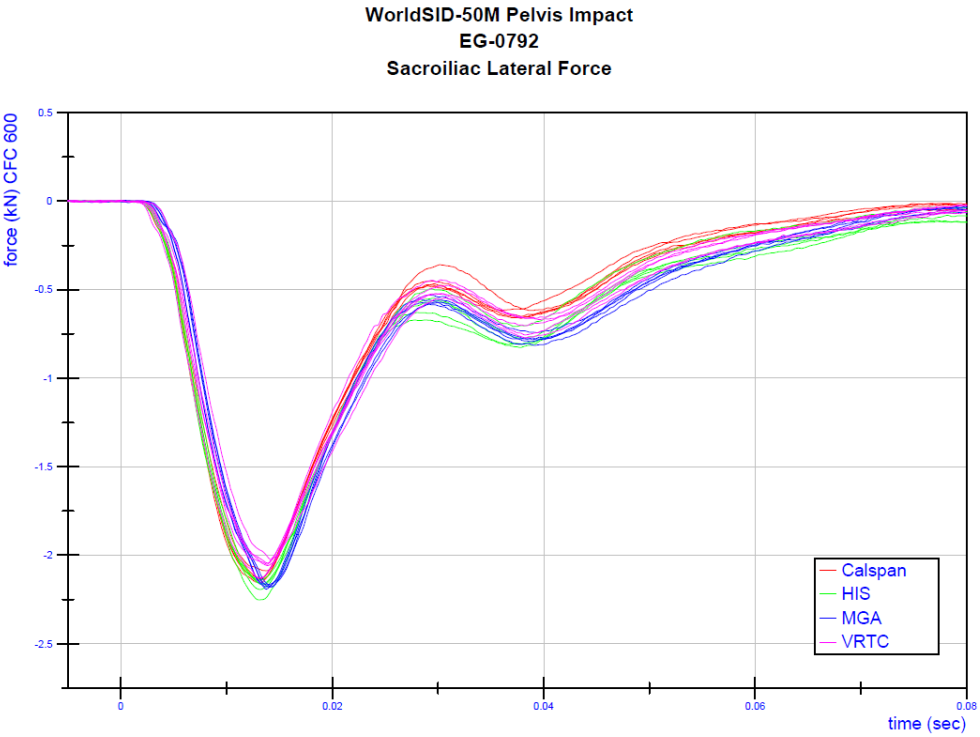

Figure A-69. Pelvis impact sacroiliac lateral force – dummy EG-0792

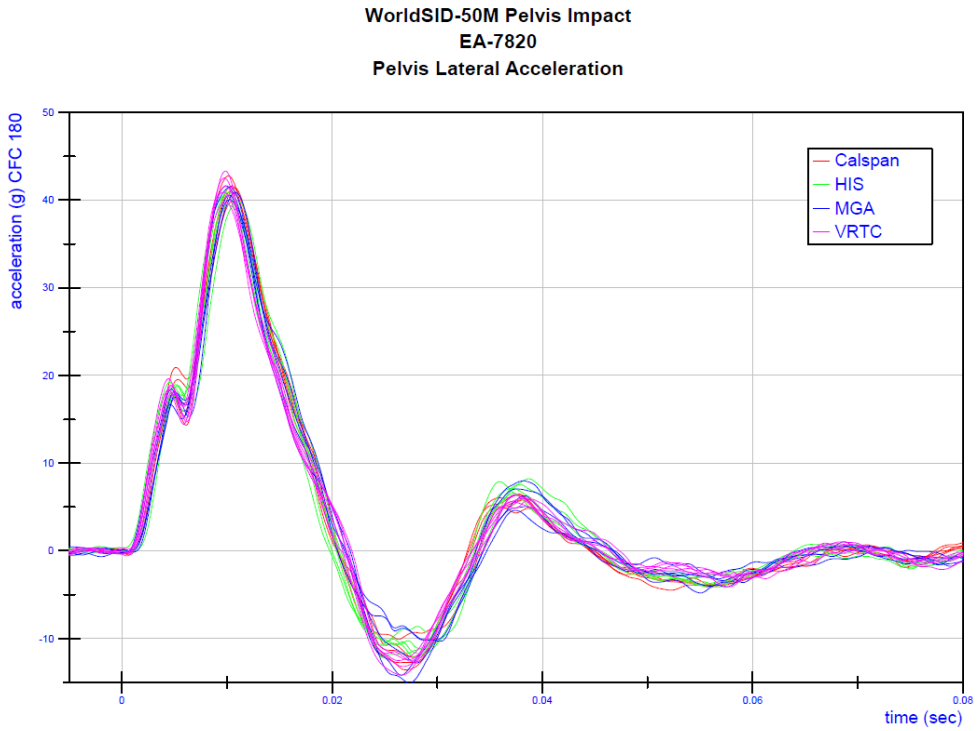

Figure A-70. Pelvis impact pelvis lateral acceleration – dummy EA-7820

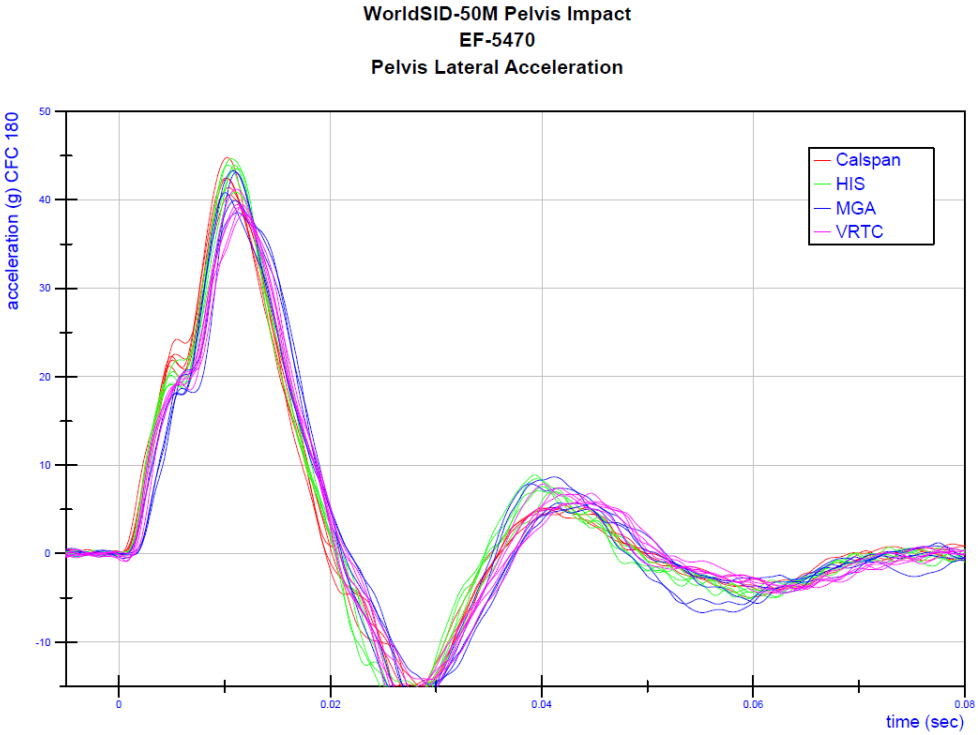

Figure A-71. Pelvis impact pelvis lateral acceleration – dummy EF-5470

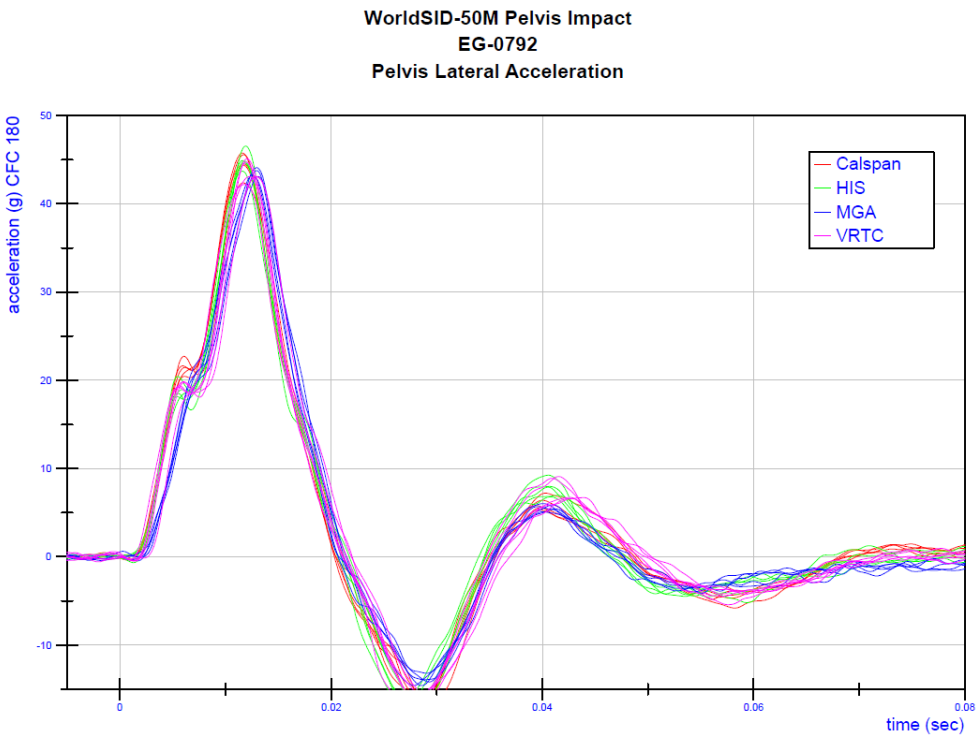

Figure A-72. Pelvis impact pelvis lateral acceleration – dummy EG-0792

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