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Evaluation of Hybrid-III 6YO ATD Chest Jacket Shape and Position

Sheila M. Ebert-Hamilton
Matthew P. Reed
University of Michigan Transportation Research Institute

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16. Abstract

In previous work, belt fit on the Hybrid-III six-year-old (6YO) anthropomorphic test device (ATD) was found to depend on the positioning of the chest jacket of the ATD. Moreover, differences were noted between jackets manufactured by Denton-ATD and First Technology Safety Systems (FTSS). The objective of this study was to quantify differences between the manufacturers' jackets by detailed measurements of exemplar jackets and to assess the effects of jacket installation procedure on jacket position.

A custom fixture was designed to hold rigidly the thorax, pelvis, and head of a 6YO ATD while allowing the chest jacket to be installed and removed. Testing was conducted with two jackets from FTSS and one from Denton. In pilot testing, jacket position was affected by the installation procedure and by the initial position of the shoulder components. Detailed measurements were made using a portable surface measurement device (laser scanner) with each jacket in six conditions defined by initial shoulder position and the manner in which the jacket was installed. Quantitative comparisons in jacket position and shape were conducted in software using the laser-scan data.

Notable differences in jacket shape were observed between the FTSS and Denton jackets, with the FTSS jacket having a wider, flatter profile in the lateral shoulder area and the Denton jacket extending more forward in the upper chest area. However, the effects of jacket positioning were much larger than differences between manufacturers in jacket shape. Pulling the jacket down firmly resulted in jacket shoulder positions relative to the spine differing by more than 25 mm from those obtained by pulling the jacket down lightly, with results dependent on the initial positions of the shoulder components.

The results of this study indicate that careful attention to jacket positioning is needed to obtain a consistent relationship between the chest and shoulder surfaces and the ATD skeleton. Pulling the jacket down firmly after initially placing the shoulder components in a downward/rearward position is suggested. Monitoring and adjusting the location of reference points on the jacket relative to specified hard points on the ATD skeleton provides a means for ensuring that the jacket is consistently placed for static or dynamic testing.

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Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
In	inches	25.4	millimeters	mm
Ft	feet	0.305	meters	m
Yd	yards	0.914	meters	m
Mi	miles	1.61	kilometers	km
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
Ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce	6.89	kilopascals	kPa

	per square inch			
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ACKNOWLEDGMENTS

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CONTENTS

EXECUTIVE SUMMARY

In previous work, belt fit on the Hybrid-III six-year-old (6YO) anthropomorphic test device (ATD) was found to depend on the positioning of the chest jacket of the ATD. Moreover, differences were noted between jackets manufactured by Denton-ATD and First Technology Safety Systems (FTSS). The objectives of this study were to quantify differences between the manufacturers' jackets by detailed measurements of exemplar jackets and to assess the effects of jacket installation procedure on jacket position.

A custom fixture was designed to hold rigidly the thorax, pelvis, and head of a 6YO ATD while allowing the chest jacket to be installed and removed. Testing was conducted with two jackets from FTSS and one from Denton using a single FTSS ATD. In pilot testing, jacket position was affected by the installation procedure and by the initial position of the shoulder components. Detailed measurements were made using a portable surface measurement device (laser scanner) with each jacket in six conditions defined by initial shoulder position and the manner in which the jacket was installed. Quantitative comparisons in jacket position and shape were conducted in software using the laser-scan data.

Notable differences in jacket shape were observed between the FTSS and Denton jackets, with the FTSS jacket having a wider, flatter profile in the lateral shoulder area and the Denton jacket extending more forward in the upper chest area. However, the effects of jacket positioning were much larger than differences between manufacturers in jacket shape. Installing the jacket with the ATD shoulder components initially in an "up" position, and pulling the jacket down only lightly, resulted in jacket shoulder positions relative to the spine differing by more than 25 mm from those obtained by pulling the jacket down firmly after initially placing the shoulder components in a downward/rearward configuration.

The results of this study indicate that careful attention to jacket positioning is needed to obtain a consistent relationship between the chest and shoulder surfaces and the ATD skeleton. Jacket positioning consistency can be improved by pulling the jacket down firmly after initially placing the shoulder components in a downward/rearward position. Monitoring and adjusting the location of the jacket relative to specified hard points on the ATD skeleton provides a means for ensuring that the jacket is consistently placed for static or dynamic testing. Further research is needed to develop and test a complete jacket installation procedure for use in dynamic testing.

INTRODUCTION

The University of Michigan Transportation Research Institute (UMTRI) recently developed systematic procedures to measure belt fit on children and similar methods (Reed et al. 2008) for use with the 6YO and 10YO Hybrid-III anthropomorphic test devices (ATDs). The methods have been used by the Insurance Institute for Highway Safety (IIHS) to quantify the effects of booster and belt configurations on child belt fit and to survey the belt fit provided by a wide range of boosters (IIHS, 2009). Efforts to apply the methods on the FMVSS 213 bench and in other laboratories have documented higher levels of variability in the measurements than were observed in the original laboratory development of the procedures.

The current study was part of a larger effort to understand and control the sources of variance in the belt fit measurement procedure. Based on experience at the IIHS, variability in belt fit measurements across laboratories may be due in part to differences in contour between the 6YO chest jackets manufactured by Denton-ATD and First Technology Safety Systems (FTSS). Jackets from the two manufacturers differ visibly in contour, particularly in the shoulder area.

Hence, the original research plan called for measuring a sample of jackets from each manufacturer to establish differences between and consistency within the two designs. However, preliminary measurements used to establish the test procedures demonstrated that jacket installation variability could easily swamp the variability due to the jacket shape. Indeed, IIHS addressed differences in measurements between UMTRI and IIHS by shimming the jacket on the IIHS ATD to match the jacket location measured at UMTRI. These findings made an understanding of the jacket positioning issues more important than detailed quantification of the differences between manufacturers. Moreover, discussions with the manufacturers indicated that potentially important changes in jacket fit could occur over time as the material shrunk, suggesting that a quantification of new jackets would not adequately represent the population of jackets. Finally, Denton-ATD and FTSS merged into a single company (Humanetics) during the conduct of this study. We expect that Humanetics will manufacture only a single 6YO jacket design going forward, but the results of the jacket comparison remain important due to the number of jackets from both original manufacturers that are still in use.

Consequently, this report represents a preliminary effort to: (1) quantify shape differences between manufacturers using exemplar jackets, (2) identify the contribution of jacket positioning to variability in shoulder location, (3) assess ways to reduce the influence of jacket variability on ATD-based belt-fit measurement.

METHODS

All testing was conducted with a single Hybrid-III 6YO ATD supplied by the National Highway Traffic Safety Administration (NHTSA) Vehicle Research and Test Center (VRTC). The ATD was manufactured by FTSS and was generally in good condition. The ATD was mounted to a custom built fixture (Figure 1) so that the head, spine box and pelvis did not move during testing. Appendix A contains detailed information on the preparation of the ATD for measurement.

Two FTSS jackets and one Denton jacket were measured. Each jacket was in generally good condition. The Denton jacket and one FTSS jacket (FTSS 1) had previously been used in both static (belt fit) and dynamic testing. The other FTSS jacket (FTSS 2) was new. As shown in Figure 2, the FTSS jacket has more prominent contours in the shoulder area. Each of the jackets was prepared for testing as described in Appendix A.

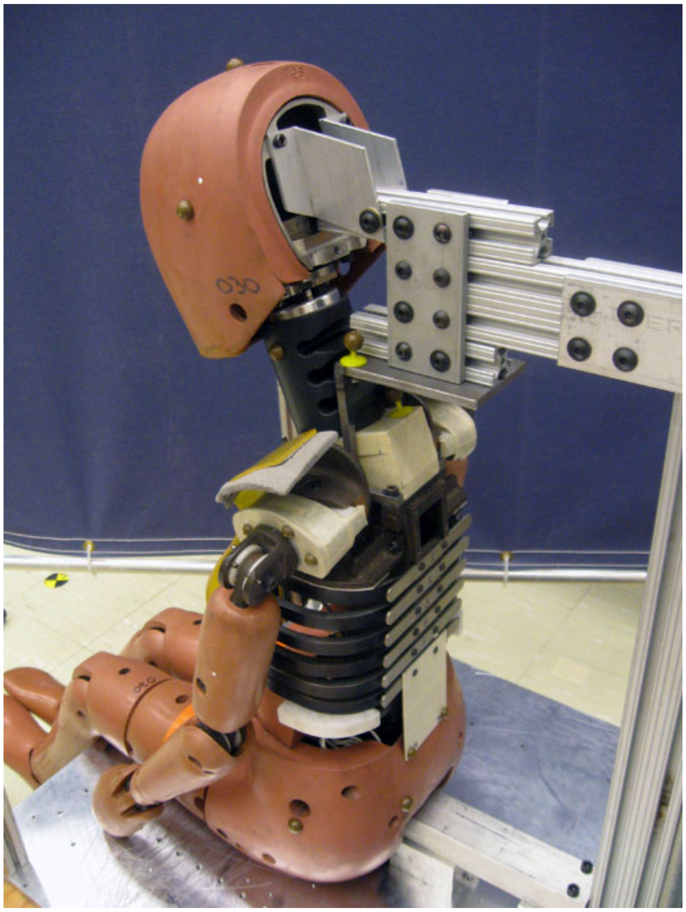


Figure 1. 6YO ATD attached to measurement fixture

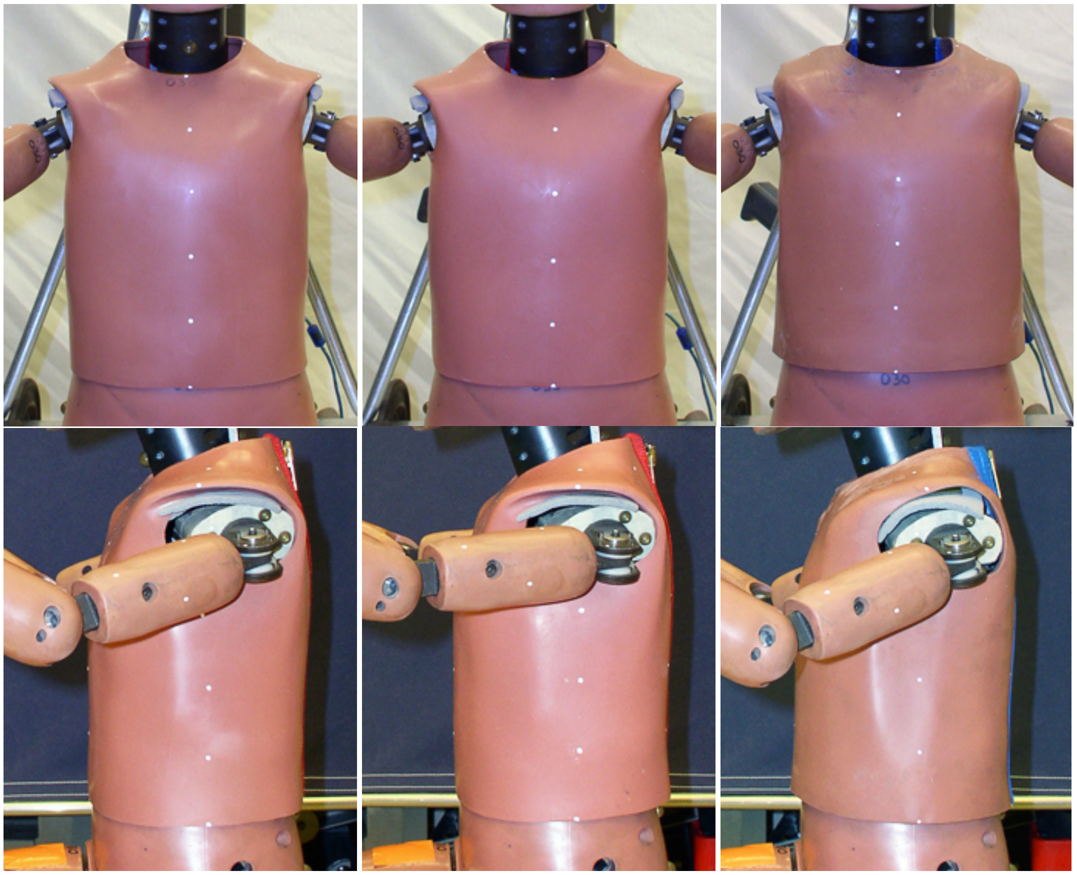


Figure 2. 6YO ATD jackets tested (from left to right): FTSS 1, FTSS 2, and Denton

Based on initial investigations with various ATD settings and jacket installation methods, two primary factors affecting jacket position were identified. First, the initial configuration of the shoulder hardware was found to affect the jacket location. Second, the method of installing the jacket, in particular how forcefully the jacket is pulled downward over the shoulders, was found to affect the jacket positioning. Table 1 lists six test conditions developed from the combination of two shoulder positions (up and down) and three jacket installation levels (up, down, and resting). Each of the three jackets was tested in each of the six conditions, and one additional measurement was taken in the down/down condition (condition 6).

Table 1
Test Matrix

Condition Number, Name	ATD	Jacket	Condition Description
1 Up/Up	1	1	Clavicle link rotated **up** to maximum unsupported position Clavicle rotated **forward** Jacket in **highest** possible position (as limited by arm hole).
2 Up/Resting	1	2	Clavicle link rotated **up** to maximum unsupported position Clavicle rotated **forward** Jacket **resting lightly** on shoulders (not pulled down thus moving clavicle)
3 Up/Down	1	3	Clavicle link rotated **up** to maximum unsupported position Clavicle rotated **forward** Jacket **pulled down** as far as one can (if clavicle moves it is only by jacket contact)
4 Down/Up	2	1	Clavicle link rotated **down** Clavicle rotated **backward** Jacket in **highest** possible position (as limited by arm hole). May move clavicle up
5 Down/Resting	2	2	Clavicle link rotated **down** Clavicle rotated **backward** Jacket **resting lightly** on shoulders (not pulled down and moving clavicle)
6 Down/Down	2	3	Clavicle link rotated **down** Clavicle rotated **backward** Jacket **pulled down** as far as one can (if clavicle moves it is only by jacket contact)

Figure 3 shows the shoulder hardware referenced in Table 1. The clavicle link connects the shoulder to the spine with a pivot allowing vertical motion of the shoulder. The clavicle (part number 127-2090) is connected to the clavicle link (part number 127-2080) with a joint that allows fore-aft motion. Combined, these segments allow the proximal arm joint (analogous to the anatomical glenohumeral joint) to move vertically and fore-aft. For the current testing, two shoulder component positions were used. In the “shoulders up” position, the proximal arm joint was moved up and forward. In the “shoulders down” position, the proximal arm joint was moved down and rearward. In both cases, the shoulder segments were set firmly against the stops, i.e., at the end of the range of motion obtained with firm manual manipulation (see Figure 4). These two positions were chosen among the range of possible positions for these two segments because they produced the most extreme jacket positions and because they were readily replicable.

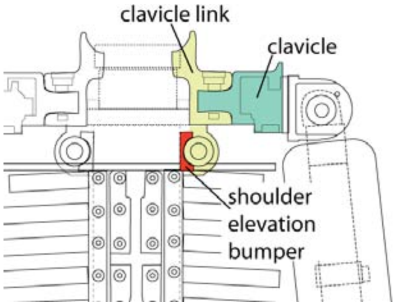


Figure 3. Schematic illustration of the shoulder hardware, showing the clavicle and clavicle link components.

The jackets were positioned relative to the ATD using three different methods: pulled as high as possible (up), pulled down as much as possible (down), or resting on the clavicle (resting). For the up and down conditions, movement of the clavicle and clavicle link as produced by jacket contact with the ATD was allowed. For the resting condition the clavicle and clavicle link were not allowed to move.

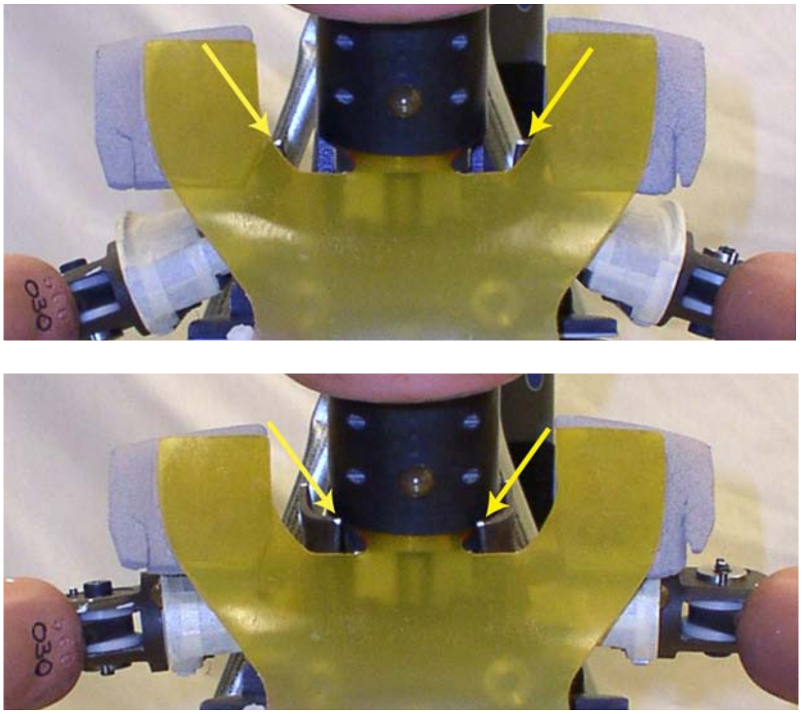


Figure 4. The two ATD shoulder condition positions. Top image: "*Down" condition* – clavicle pushed **down** and **rearward**. Bottom image: "*Up" Condition* – clavicle pulled **up** and **forward**. The arrows point to the positions of the most anterior/superior corner of the clavicle links.

After the ATD was positioned and the jacket applied, the ATD and jacket were digitized and scanned with a FARO Fusion Faro Arm (P/N 10456 8ft Rev 3, S/O 562521). Digitized points and scanned targets (hemispheres and raised marks) were used to track the vests, clavicles, clavicle links, shoulders, and upper arms and to check that the head, neck, spine box and pelvis did not move. The scan data were processed using reverseengineering software (Geomagic Studio 12 and Geomagic Qualify 12). The data processing steps included creating polygonal meshes from the laser scan points, cleaning of the scan surface to reduce noise, aligning the data, and creating files containing only the vest scans. Appendix C presents the details of the scan processing methodology. The number of polygons in the vest scans was reduced to 20,000 to reduce processing time. The coordinates of the raised targets on the vest were extracted from the scans.

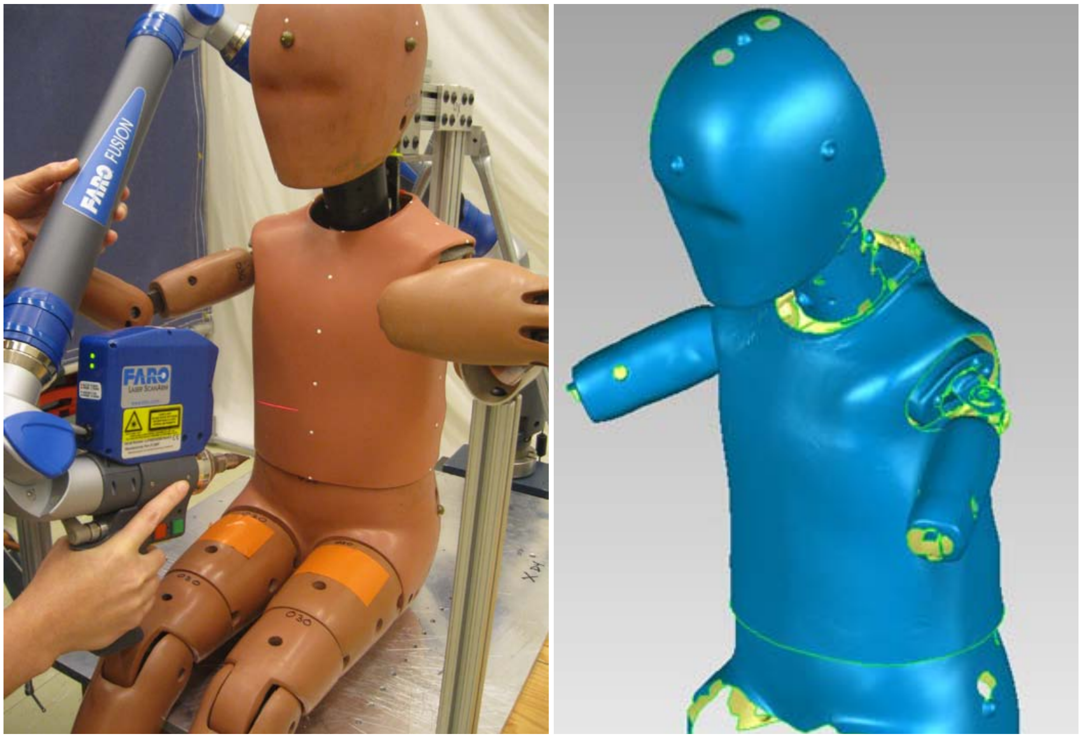


Figure 5. Vest being scanned (left) and an example of processed scan (right).

Differences in jacket position and shape were analyzed using both contour and point data. Pair-wise deviations in contour were generated in Geomagic Studio 12 (software settings: max deviation =100 mm and critical angle = 45 deg). In the IIHS Booster Seat Belt Fit Evaluation Protocol (IIHS 2009), the position of the jacket is measured in a coordinate system with the origin located on the posterior superior edge of the lower-neck load cell (or structural replacement), at the midline of the ATD with the X-Y plane parallel to the superior face of the load cell. The shoulder position is measured on the top surface of the jacket at the point (X, Y) = (53, 72) and the chest is measured on the anterior surface at the point (Y, Z) = (0,0). Figures 6 and 7 illustrate the procedure used to locate and measure the reference points.

Shoulder Point: From the origin at the posterior edge of the lower neck load cell, move along the positive X axis by 53 mm and along the positive Y axis by 72 mm. Move along the Z axis to the surface of the jacket. Report the Z value relative to the origin.

Chest Point: From the origin, move along the X axis until reaching the surface of the jacket. Report the distance from the origin.

The IIHS reference values for jacket position are Z = 10±5 mm at the shoulder and X = –110±5 mm at the chest. These values are used for the current analysis since no other reference values are available for jacket positioning, but they should not be construed as design targets.

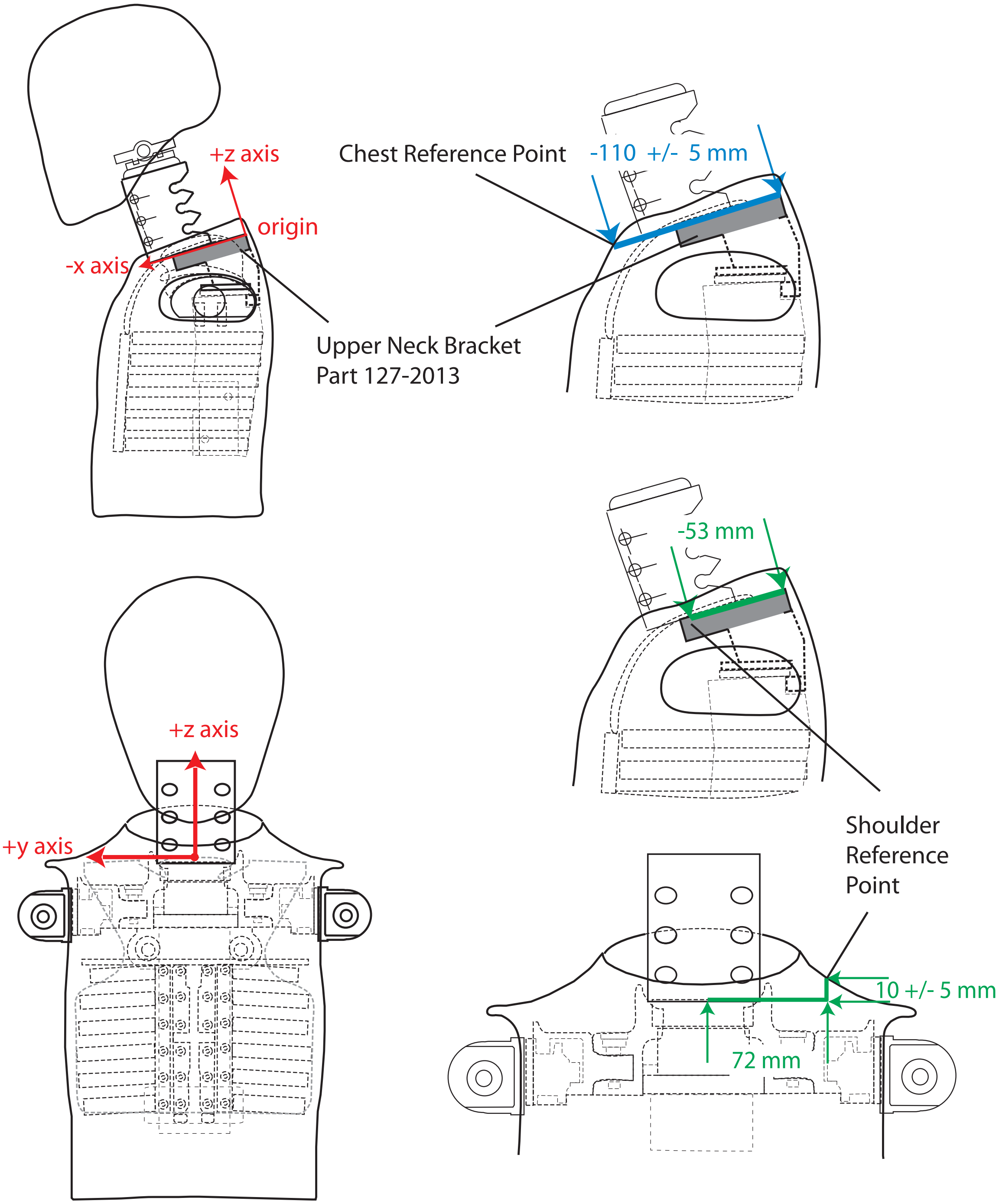


Figure 6. Establishing jacket reference points.

RESULTS

Tables 2 and 3 list the positions of the shoulder and chest reference points for all trials.

Table 2
Jacket Position Measured at Shoulder and Chest Reference Points

Jacket	Positioning			Shoulder Point Height Above Neck Block (mm)*			Chest Point Anterior to Neck Block (mm)**
	Shoulder	Jacket	Rep	Right	Left	Ave.	
FTSS 1	Up	max-up	1	18	19.5	19	-118
		resting	1	5.2	2.4	4	-101
		max-down	1	2.6	0.35	1	-99
	Down	max-up	1	8.8	9.4	9	-111
		resting	1	10	15	13	-110
		max-down	1	6.3	4.7	6	-106
		max-down	2	4.2	3.8	4	-106
FTSS 2	Up	max-up	1	19	20.7	20	-123
		resting	1	9	9.9	9	-118
		max-down	1	1.6	3.9	3	-108
	Down	max-up	1	13.7	14.4	14	-107
		resting	1	7	6.3	7	-112
		max-down	1	7.5	5.7	7	-112
		max-down	2	5.2	4.3	5	-100
Denton	Up	max-up	1	24	24	24	-129
		resting	1	6.5	5.4	6	-120
		max-down	1	0.3	1	1	-112
	Down	max-up	1	9.5	10.3	10	-122
		resting	1	6.5	6.6	7	-117
		max-down	1	7.4	5.4	6	-121
		max-down	2	7.1	5.5	6	-118

*Reference value is 10 ± 5 mm
** Reference value is -110 ± 5mm

Table 3
Descriptive Statistics Across All Conditions of Jacket Position Measured at Shoulder and Chest Reference Point Locations

	Average Shoulder Point Height Above Neck Block (mm)				Chest Point Anterior to Neck Block (mm)			
	Min	Max	Range	Mean	Min	Max	Range	Mean
FTSS 1	1	19	17	8	-118	-99	19	-107
FTSS 2	3	20	17	9	-123	-100	23	-111
Denton	1	24	23	9	-129	-112	17	-120

Comparison of Jacket Shapes in the Shoulder-Down/Jacket-Down Condition

Repeatability – The shoulder-down/jacket down condition was applied twice for each jacket. Contour comparisons are shown in Figure 7. The differences between repetitions, as measured at the shoulder and chest reference points, were less than 4 mm. The differences between contours were also below 4 mm for most of the surface area. The anterior shoulder area of both FTSS jackets had greater deviation than that of the Denton jacket, for which the greatest deviation occurred in the right anterior-lateral chest area.

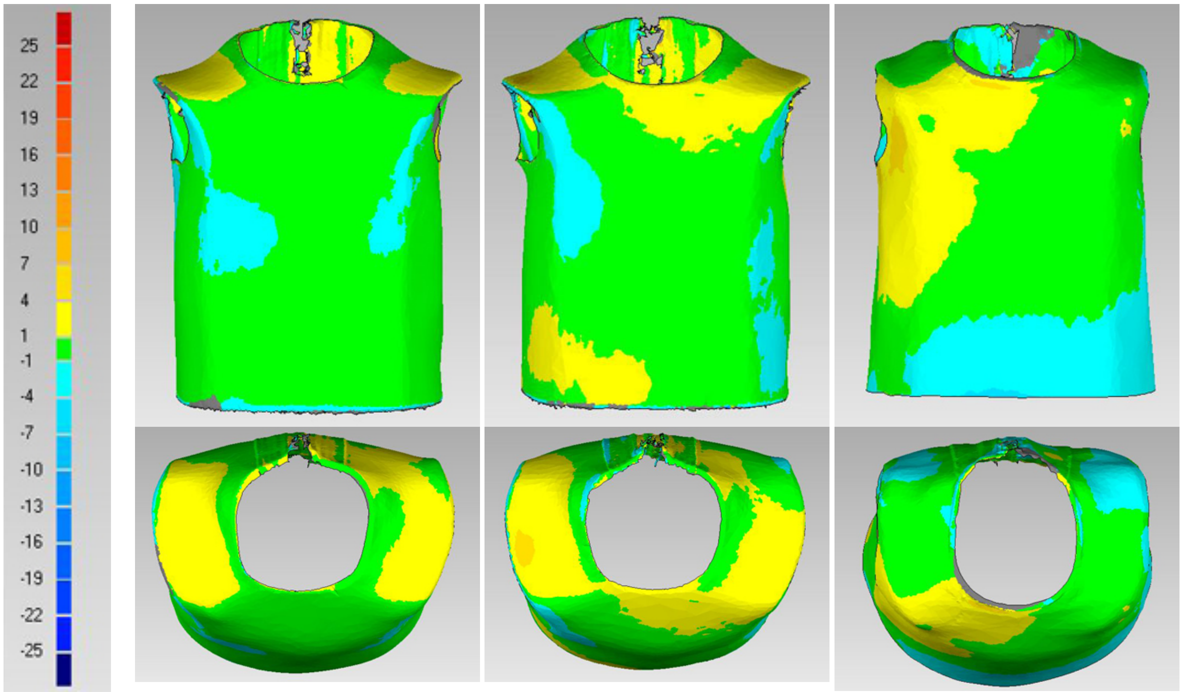


Figure 7. Shoulder-down/jacket max-down condition, **within jacket repetitions**: FTSS 1 (left), FTSS 2 (middle), Denton (right). Scale dimensions in mm.

FTSS Jacket Differences – Figure 8 shows a comparison of the two FTSS jackets in the shoulder-down/jacket max-down condition. In both trials, differences between the jackets were typically less than 4 mm. The differences between the two pairs of tests (repeats) show that the variability in repeated installations is of similar magnitude to the differences between the FTSS jackets.

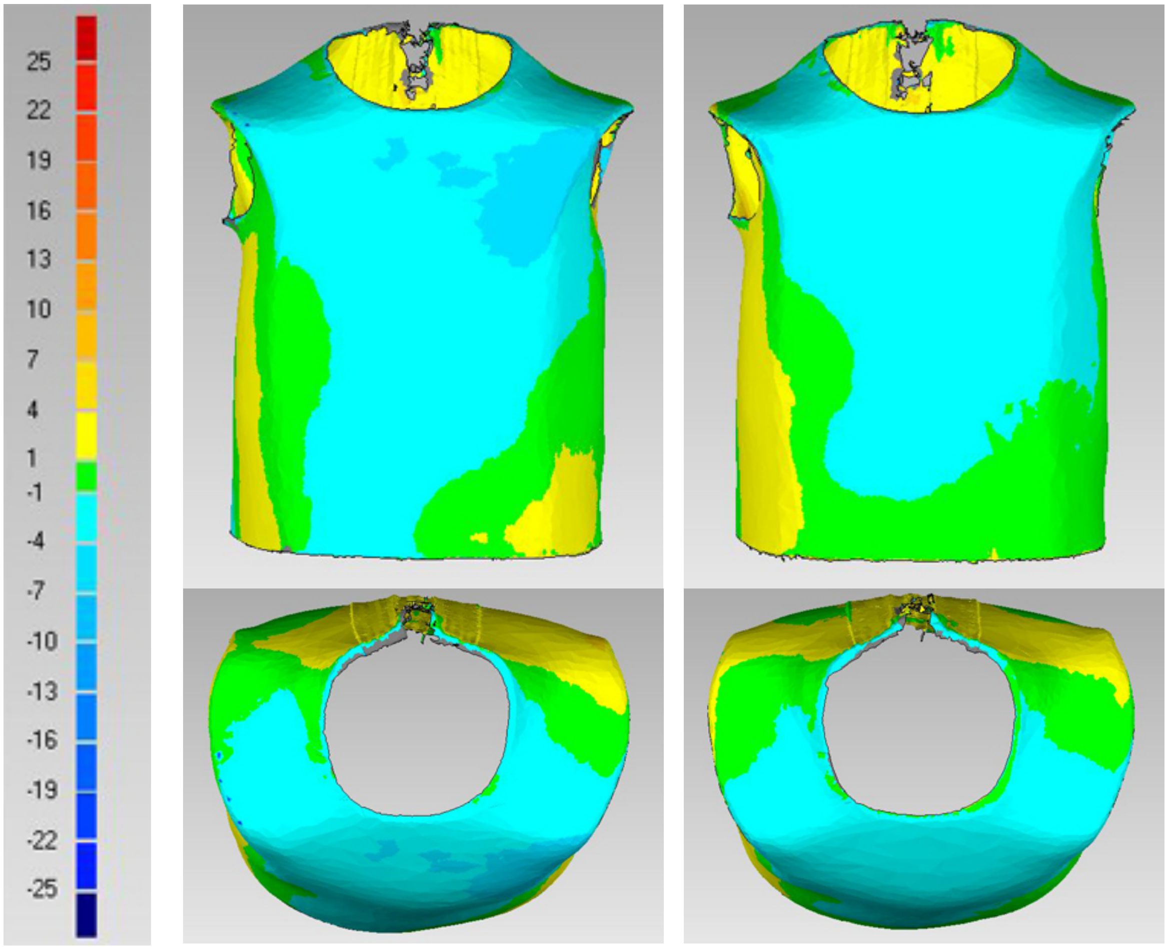


Figure 8. Shoulder-down/jacket max-down condition, FTSS 1 compared to FTSS 2, reps 1 and 2 (left and right) paired. Scale dimensions in mm.

Figure 9 compares the FTSS and Denton jackets. The differences are largest in the shoulder area, where the FTSS jacket is wider above the shoulder and has a more angular contour. The differences are fairly consistent across two repetitions, indicating that the differences between the jackets are not swamped by the variance in repeated installation. Other than at the lateral margin of the shoulder, the largest differences were observed on the left side of the jacket in an area that does not generally interact with the belt during testing.

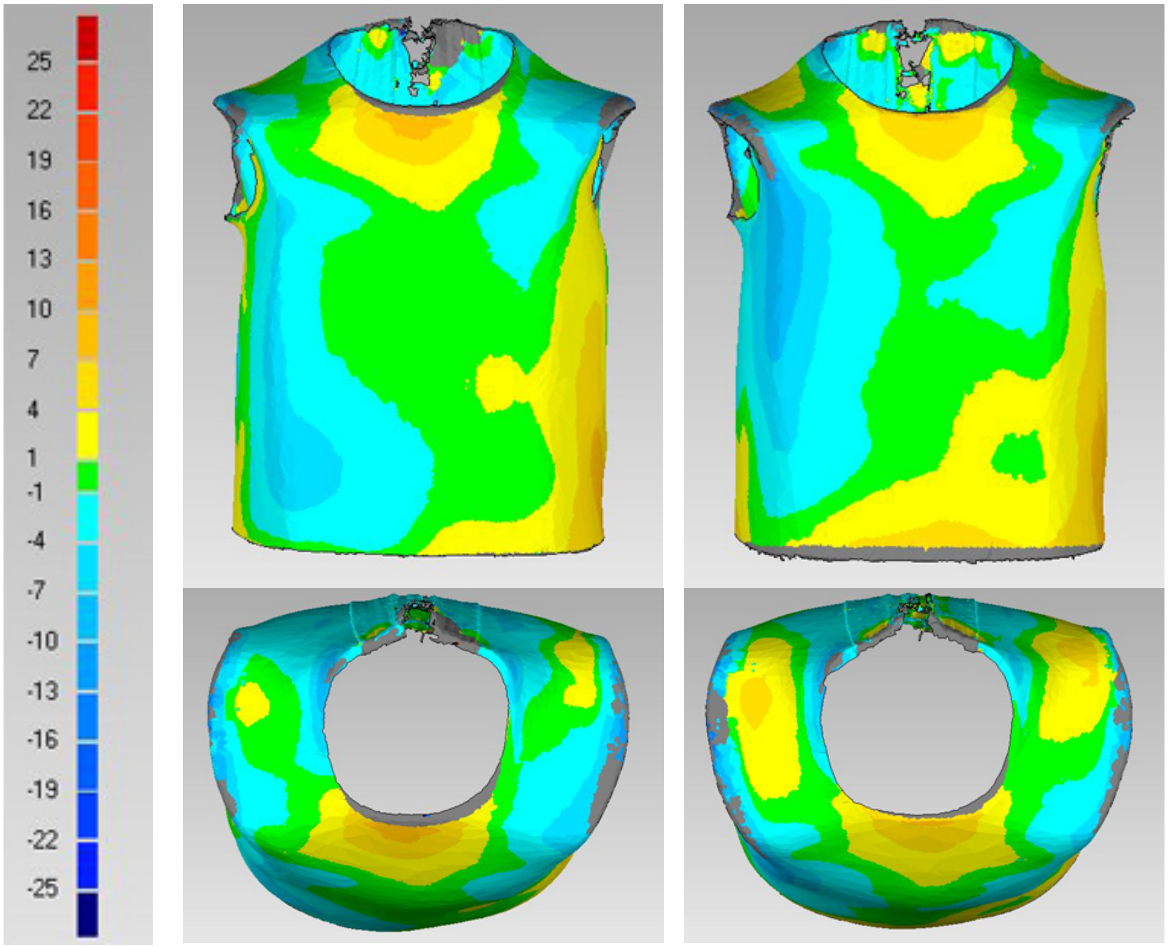
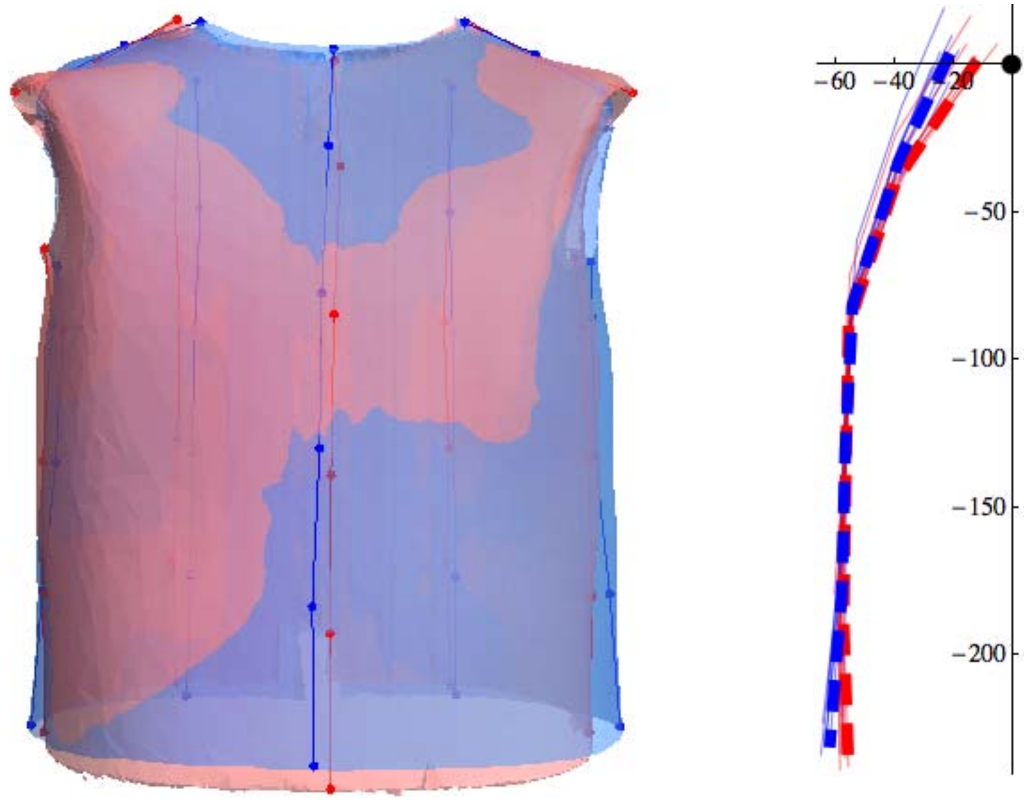


Figure 9. Shoulder-down/jacket max-down condition, Denton compared to FTSS 2, reps 1 and 2 (left and right) paired. Scale dimensions in mm.

Figure 10 compares the FTSS and Denton jackets using reference points in the sternum and shoulder areas. When the shoulder was placed in the down position and the jackets placed in the max-down position, the differences between Denton and FTSS jackets were small when compared using the chest and shoulder reference points. All shoulder jacket points fell within the 5 to 7 mm range (IIHS reference 10 +/5 mm). The range of the chest jacket points was greater, from -121 to -106 mm, with the Denton jacket being about a centimeter further out from the ATD chest than either FTSS jacket.



Front view

Front Centerline, Side View

Figure 10. Jacket contours on the left and dashed lines in the right plot are of the FTSS 2 (red) and Denton (blue) in shoulder-down/jacket-down condition. Lighter lines in the plot are from all other test conditions. The orientation is with the spine box vertical and the origin at the neck-bib assembly intersection point. Scale dimensions in mm.

As noted above, the width and shape of the anterior shoulder surfaces of the FTSS and Denton jackets are different. Figures 10 and 11 show that the FTSS jacket extends further laterally than the Denton jacket and that the lateral extent of the neck hole was wider for the FTSS jacket than the Denton jacket.

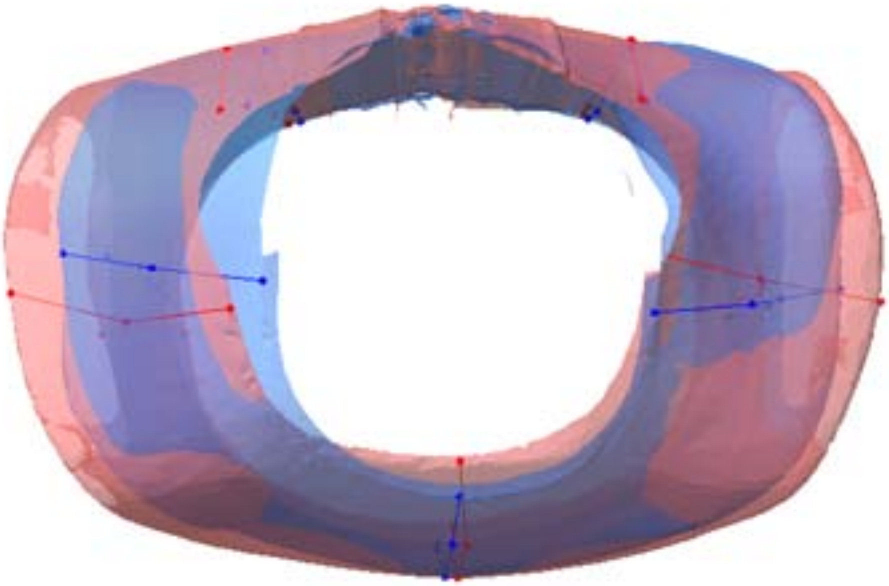


Figure 11. Top view of semi-transparent FTSS 2 (red) and Denton (blue) jacket contours from a shoulder-down/jacket max-down condition.

Other ATD and Jacket Positions

For conditions other than the down/max-down condition, deviations between jacket contours ranged in excess of 25 mm. Plots in Figures 12 and 13 compare starting shoulder position crossed with extremes in jacket positioning (up and down). Starting with the shoulders in the up position created a greater difference between jacket-up and jacket-down conditions. The lowest shoulder point and the most posterior chest point occurred when the shoulders started in the up position and the jacket was then forced down as much as possible.

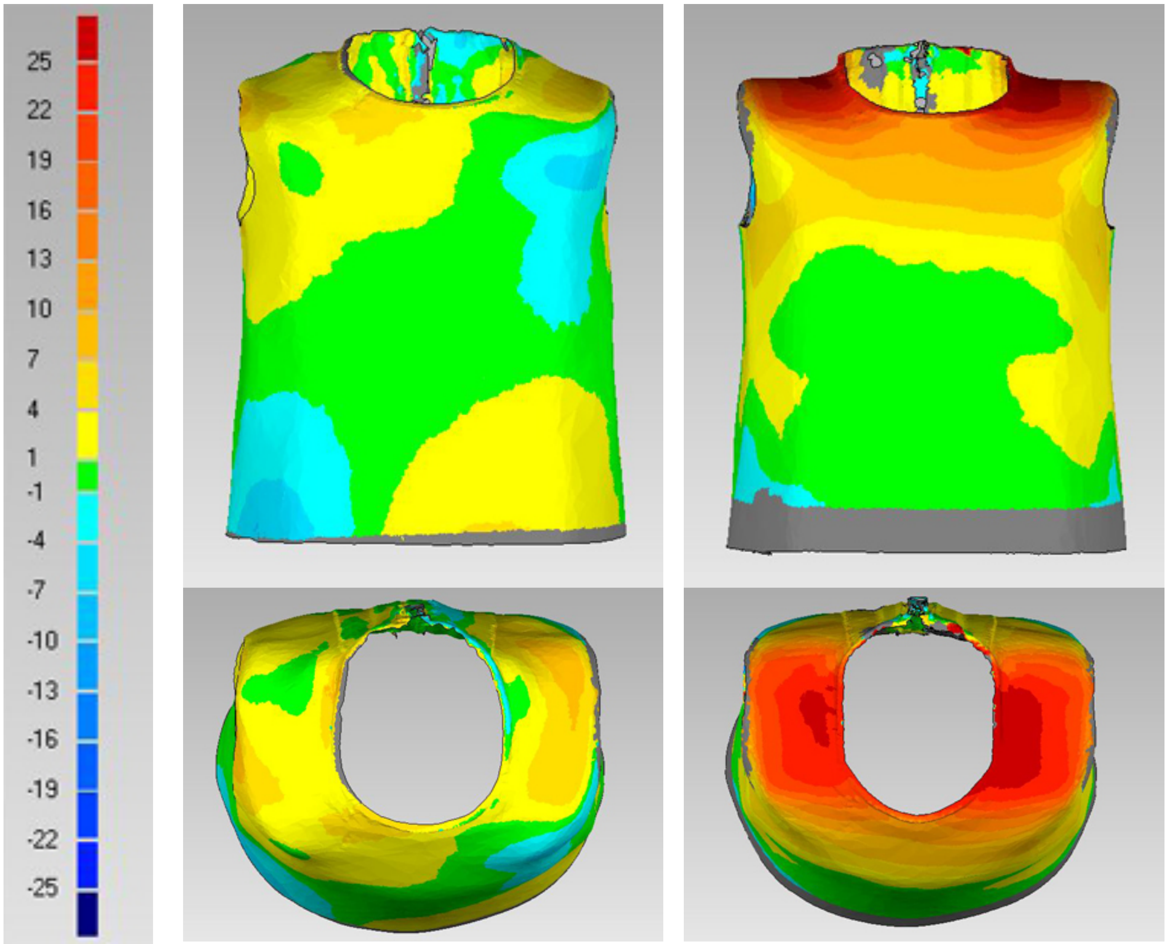


Figure 12. Comparison of *jacket max-up* with *jacket max-down* condition for *shoulder down* (left) and *shoulder up* (right) conditions using the Denton jacket. Scale dimensions in mm.

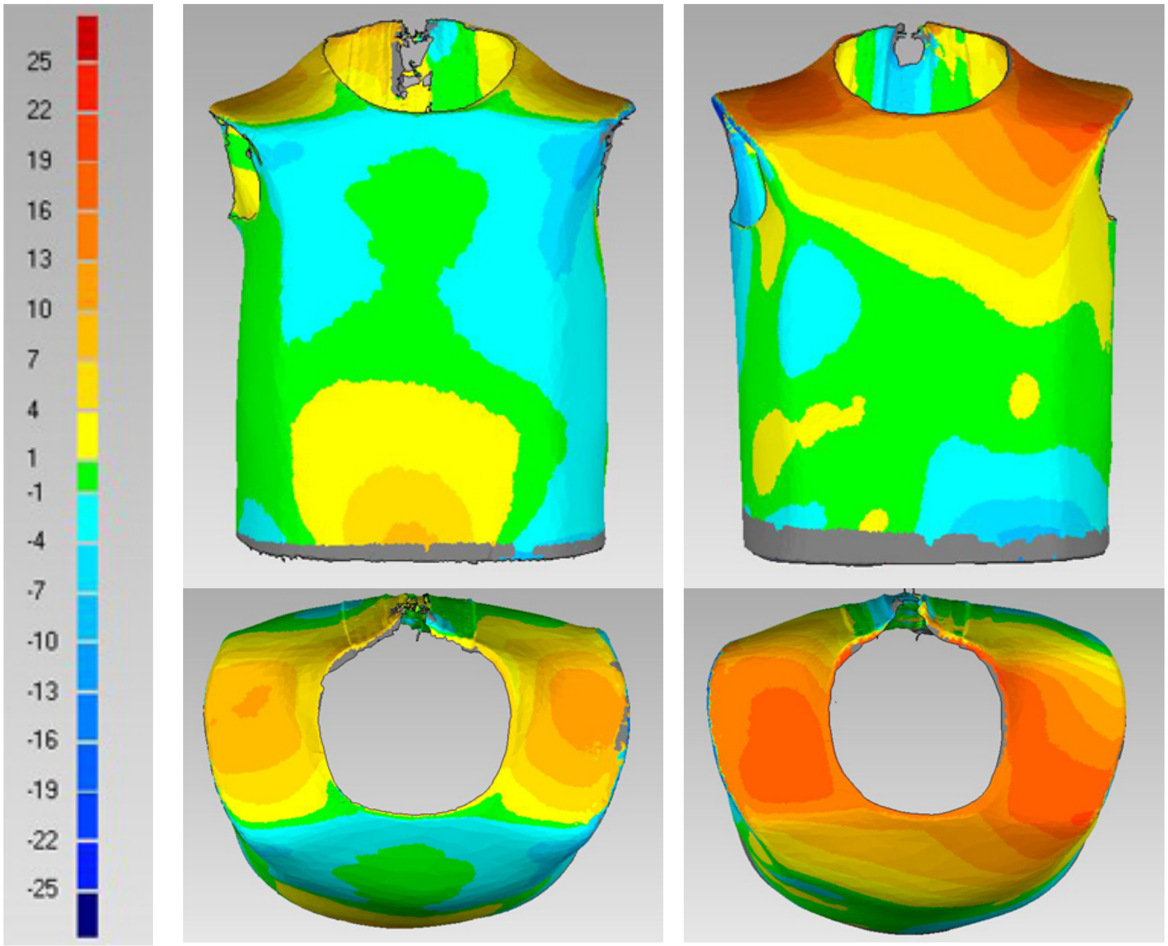


Figure 13. Comparison of *jacket max-up* with *jacket max-down* condition for *shoulder down* (left) and *shoulder up* (right) conditions using the FTSS jacket. Scale dimensions in mm.

The positioning of the shoulder components affected the fit of the jacket in part due to interference between the clavicles and the jacket neck opening. Figure 14 shows the scanned shoulder components in *shoulder up* and *shoulder down* conditions. Figure 15 shows that installing the jacket with the shoulders in the down position results in the jacket coming to rest without the inner ridges of the clavicle extending into the neck hole.

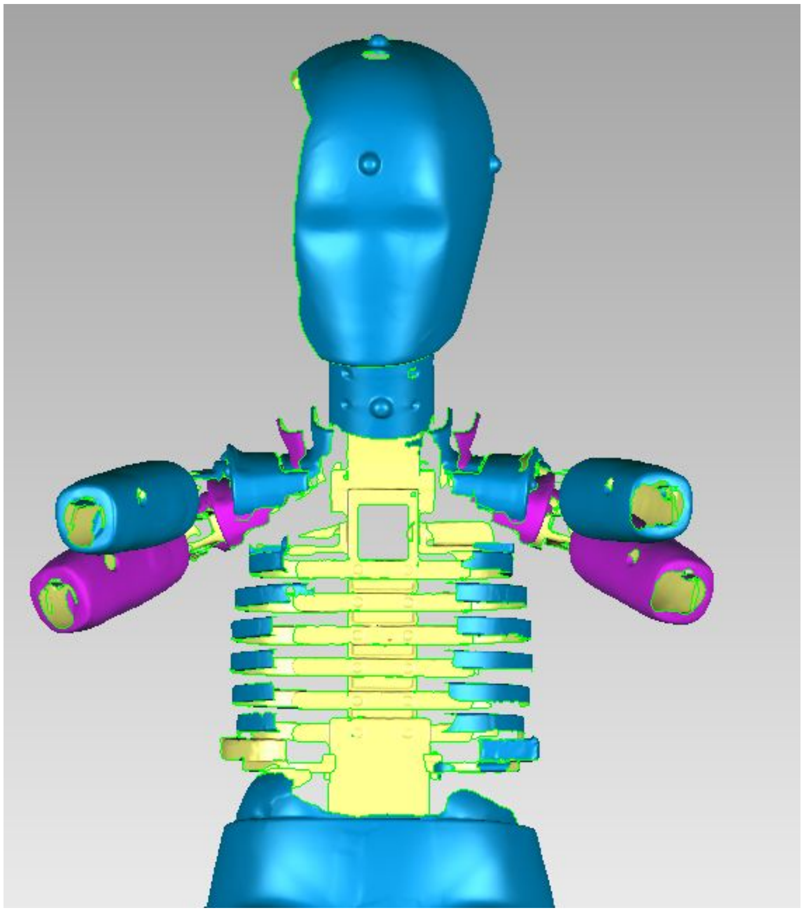


Figure 14. ATD shoulder position in clavicle up/jacket up (blue) and clavicle up/jacket down (purple).

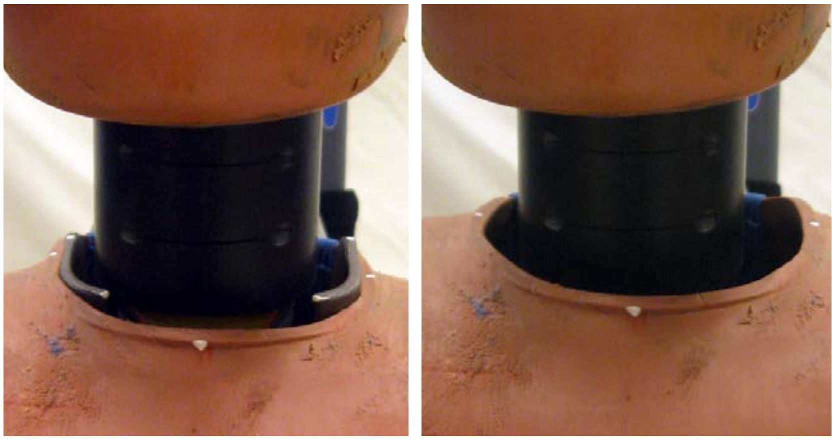


Figure 15. View of interaction between jacket and clavicle link for clavicle up/jacket up (left) and clavicle down/jacket down (right).

DISCUSSION

Jacket Differences

The testing reported here quantified differences in shape between the jackets manufactured by Denton and FTSS. Discussions with representatives of the two manufacturers in the early phases of this project did not reveal a strong empirical justification for either shape, suggesting a future opportunity for harmonization. Indeed, Humanetics (the new company formed by the merger of Denton and FTSS) has determined that it will discontinue manufacture of 6YO jackets based on Denton design.

The manufacturers also described changes that can occur to jackets over time. Jackets typically shrink over time, but also can be stretched or otherwise damaged during installation and testing. The current study documented that the interaction between the neck opening and the clavicle castings is particularly important for determining jacket position. Standardization of the location of the neck opening relative to the clavicles is needed.

Concerns and Study Limitations

Shoulder Stops — The positions of the ATD shoulder components, when pushed downward or rearward, are influenced by the condition of elastomeric stops. If these stops degrade over time, the positioning of the jacket obtained using the procedure suggested in this report will also change. The stops also influence the ease with which the shoulder components can be maintained in position during and after installation of the jacket. Stops that are dimensionally within tolerance may produce different shoulder postures.

Cables – The current testing was performed without instrumentation cables attached to the ATD. The jackets fit very closely to the posterior of the ATD torso even in the lower back/abdomen area where the cables would exit the ATD. The cables may affect the ability of the user to position the jacket and may cause the jacket to sit higher on the ATD. Routing the cables consistently using the technique cited in the dummy users' manual may reduce the influence of the cables on jacket fit.

Exemplar Jackets – Due to resource limitations, tests were conducted with only three jackets, with a focus on documenting the effects of installation procedure rather than differences among jackets. This approach was chosen because evidence from pilot testing in the current project showed that installation procedure had large effects on the jacket location relative to the ATD, potentially much larger than the effects of jacket shape. However, it is possible that jackets in use exhibit considerable variability. A subsequent study sampling a larger number of jackets could examine this variability, but the alternative suggested in this report is to verify jacket positioning prior to testing in the critical area near the shoulders.

Bib Design – With the clavicle link rotated down and the clavicle rotated rearward, the shape of the bib assembly does not match the shape of the ATD. The bib must be twisted to clear the clavicle links. The photo in Figure 16 shows the bib contour. This suggests that the design position for the bib may not match the target assembly posture for the shoulder components, leading to potential problems with installation. The bib also puts pressure on the shoulder components, and may affect their position statically or dynamically.

Figure 16. Bib assembly fit on ATD shoulder with clavicle link rotated down and clavicle rotated rearward.

CONCLUSIONS

The measurements and analyses conducted for this report show differences in shape between exemplar chest jackets manufactured by Denton and FTSS. However, jacket installation can have a much larger effect than jacket shape on the locations of the critical shoulder and chest regions of the jacket with respect to the ATD spine.

Based on the results of this preliminary testing, the follow procedures are suggested to improve the repeatability of jacket placement with the Hybrid-III 6YO:

1. Rotate the clavicle link firmly rearward, and push the clavicle link firmly downward, prior to installing the jacket.
2. Install the jacket using a specified procedure (see Appendix B) that includes pulling the jacket down firmly after it is zipped.

The consistency of jacket positioning would benefit from:

1. Documenting the locations of the jacket surface reference points described in this report after final ATD installation to ensure that the jacket is consistently positioned across tests.
2. Developing specifications for external contour relative to ATD skeleton components to ensure that the contour produced by the jacket is both realistic and consistent across tests,
3. Developing standards for jacket shape and position that can be used to assess wear, shrinkage, and other deterioration that may affect test results, and
4. Developing performance standards for shoulder joint stops so that the shoulder components can be positioned reliably.

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APPENDIX A
JACKET MEASUREMENT PROCEDURE

Overview

This appendix describes the procedure that was developed to obtain accurate and precise measurements of the jacket shape and position relative to the ATD. This process is made challenging in part by the flexible components of the ATD, including the lumbar and cervical spines. To ensure consistent positioning of the ATD, the head, spine box, and pelvis were bolted to a specially designed fixture. Securing the spine box was required an offset at the top of the thorax to avoid interfering with the jacket.

Quantitative comparisons of component shape requires careful consideration of registration procedures by which multiple measurements are aligned. Tracking targets were added to both the ATD hardware and the jackets to facilitate accurate alignment. Spherical and hemispherical targets were developed that could be probed with the FARO Arm coordinate measurement equipment and could also be aligned using sphere-fitting procedures in the scan processing software. Additionally, profile targets were applied to the jackets and other locations on the ATD to facilitate point-to-point comparisons across measurement conditions. Finally, detailed procedures for positioning the ATD components and installing the jackets were developed to ensure that the procedures would be repeatable and reproducible.

Positioning and Marking the ATD

The pelvis, spine box and head are rigidly attached to the mounting fixture shown in Figure A1. The fixture is designed to hold the ATD in its design posture. The Hybrid-III 6YO lacks the adjustable neck angle of other Hybrid-III ATDs, and lacks the lumbar spine adjustment of the Hybrid-III 10YO, so it was tested in only in the nominal (design) configuration.

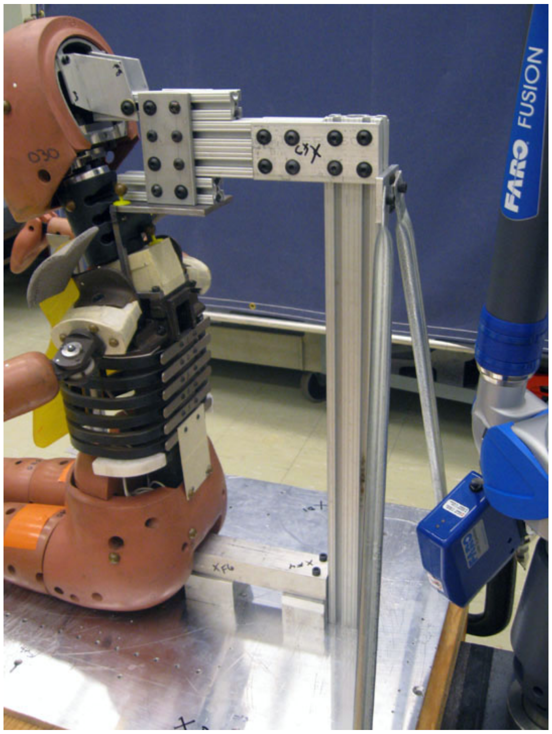


Figure A1. ATD attached to fixture on a measurement platform. The FARO Arm with laser scanner is mounted to the platform.

Attaching the ATD to the fixture:

1. The pelvis is attached to the fixture through the sacrum. The XY planes of pelvis and base of the lumbar spine are level.
2. The spine box is mounted to the fixture using the socket head cap screw at the base of the neck block. The bottoms of the lower rib stops are positioned so that their XY planes are level.
3. The skull cap is removed, and the head is attached to the fixture through the top two socket head cap screws on the back of the head. The head is positioned such that the neck is not bent in any direction.

Portions of the head, neck, spine box, pelvis, clavicles, clavicle links, and upper arms are scanned during each trial and their positions are tracked via scanned targets and digitized points that are also visible in the scans. The scanned targets are spheres and hemispheres, both of which have divots that are digitized with the hard probe. To document the orientation of the thorax with the jacket on, an extension plate is bolted to the lowest rib so it extends below the jacket and is visible. A list of these tracking features is in Table A1 with photos in Figures A3, A4, and A5.

Figure A2. Sphere and hemisphere targets with divot for probe digitizing.

Table A1
List of Scanning Features

Part	Sphere Targets (With divot for digitizing)	Probe Points (Visible in scan)
Head	3 hemispheres	3
Neck	2 hemispheres high on neck 1 hemisphere low on neck	
Spine Box	2 small hemispheres placed low 2 spheres placed near neck block	
Pelvis	3 hemispheres	
Clavicle, Right	3 hemispheres	
Clavicle, Left	3 hemispheres	
Clavicular Link, Right		3
Clavicular Link, Left		3
Shoulder Joint, Right		3
Shoulder Joint, Left		3
Upper Arm, Right		3
Upper Arm, Left		3
Jacket		34

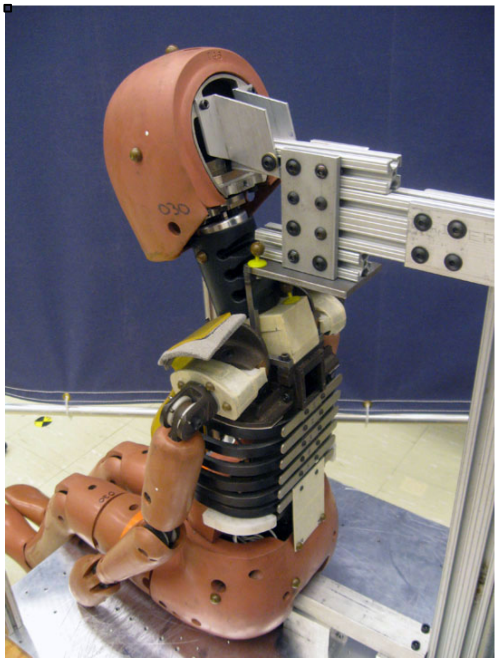


Figure A3. 6YO ATD position on fixture with sphere targets attached.

Figure A4. Pelvis in fixed position and sphere targets on pelvis and spine box

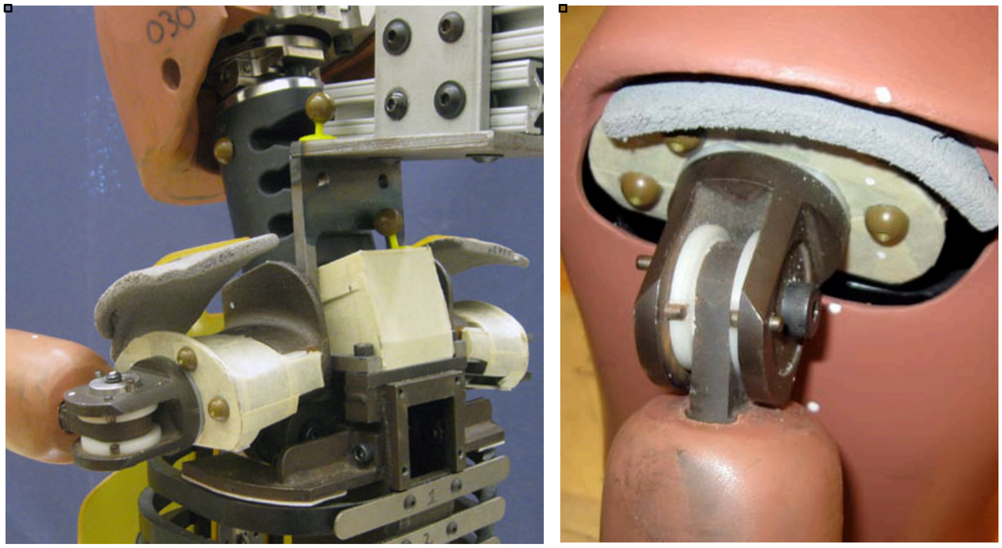


Figure A5. Sphere targets on upper spine box (left) and clavicle (right)

The entire jacket is scanned for each trial. The jacket has a set of points that are visible in the scan. A subset of these points are also digitized with the probe. Figures A6 and A7 show the locations of the points.

Creating Jacket Points

1. Zip jacket and measure circumference at bottom margin of jacket.
2. Starting at the bottom margin of the jacket at the front midline, make marks every 50 mm up to the top of the jacket, plus one mark at the top of the jacket at the neck hole.
3. Measure out a quarter of the circumference from the front midline, and repeat process with marks every 50 mm plus one mark at the bottom of the armhole and one at the top of the armhole.
4. Measure 55 mm out from either side of the zipper and repeat process of marking every 50 mm up the back of the jacket.
5. Measure the circumference of the neck hole and make a mark one quarter of the distance from the front midline on either side of the jacket.
6. On either side of the jacket, mark the midpoint between this neck hole mark and the mark at the top of the armhole.

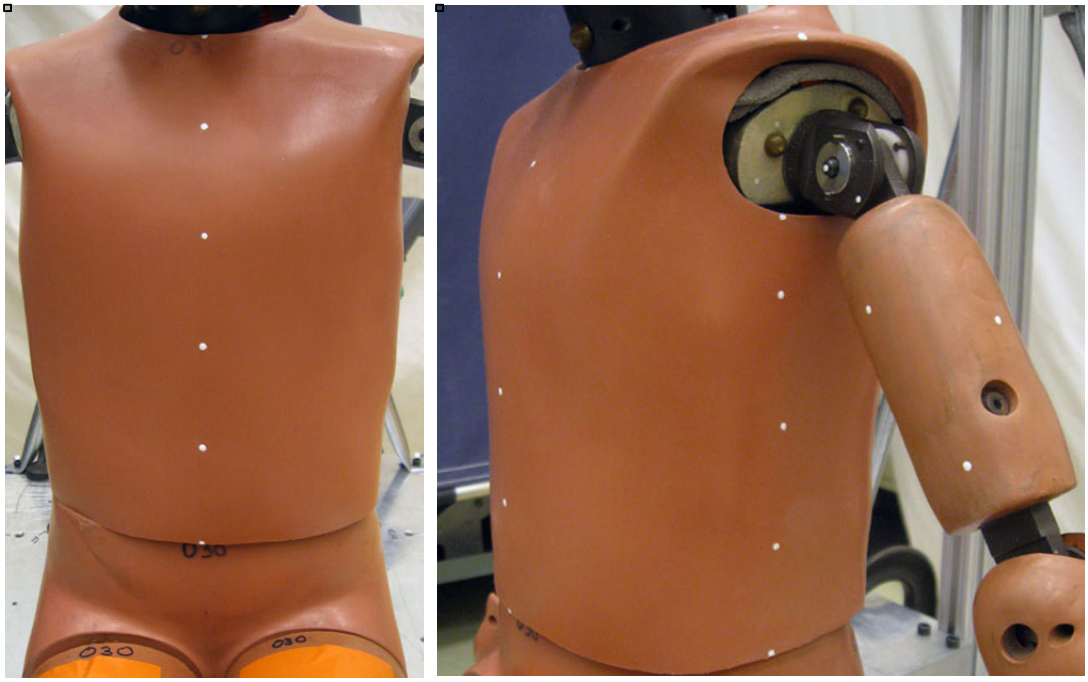


Figure A6. Points on jacket and upper arm

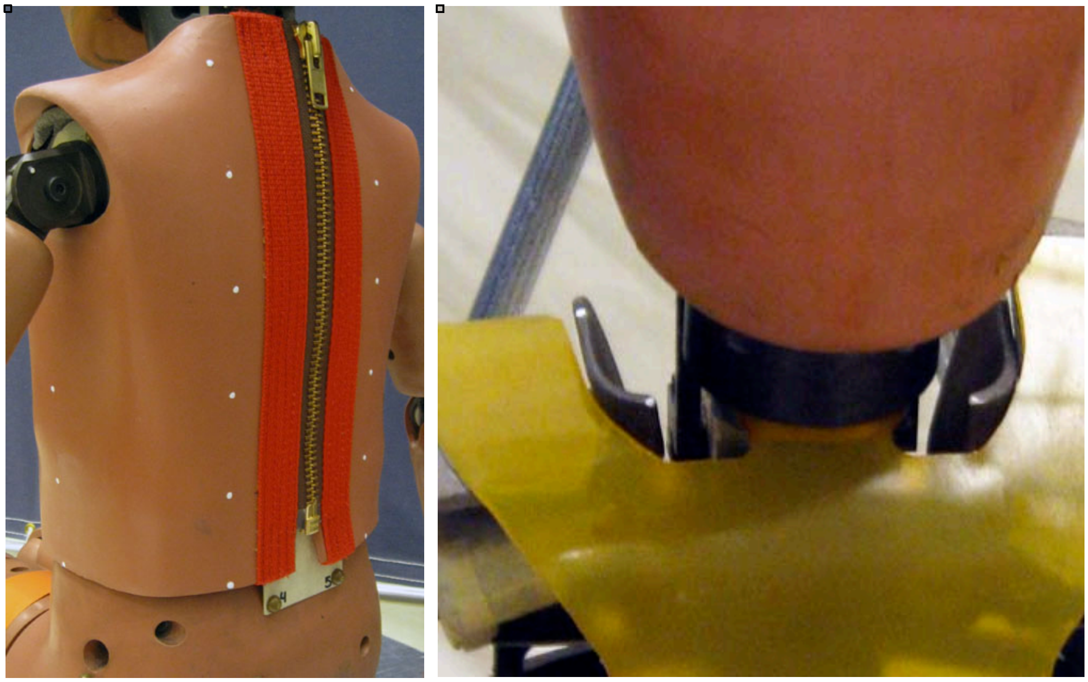


Figure A7. Points on back of jacket and clavicle links.

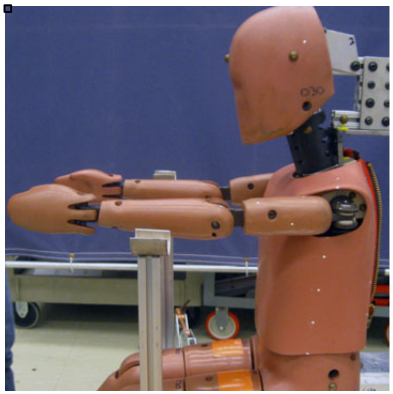
Position Shoulder Components

Prior to installing the jacket, the shoulder components are positioned according to the desired test condition. Table A2 lists the combination of ATD and jacket conditions in the test matrix. A total of six conditions were created by combining two clavicle positions with three jacket installation procedures. Table A3 describes the steps for installing the jacket according to the test conditions.

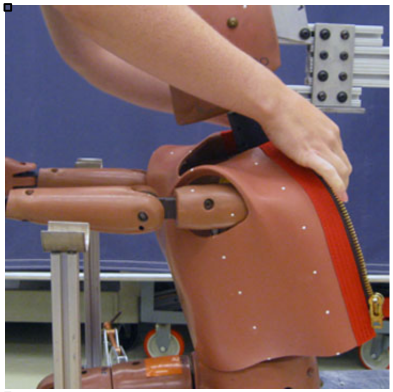
Measurement

The entire jacket is scanned for each trial using the laser scanning head on the FARO Arm coordinate digitizer. The jacket has a set of points that are visible in the scan. A subset of these points are also digitized with the probe. Figures A6 and A7 show the locations of the points.

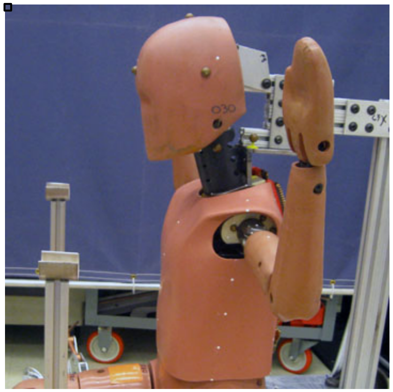
Table A4
Putting Jacket on ATD



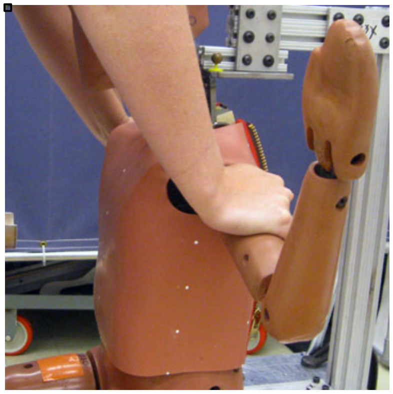
Step 1. Extend arms (rotate shoulder to 90 degrees flexion, zero abduction)



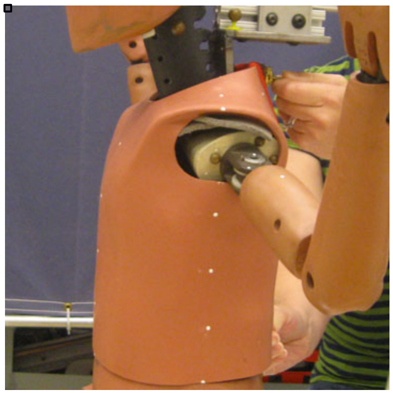
Step 2. Put jacket on until jacket shoulders clear shoulder bolts on either side



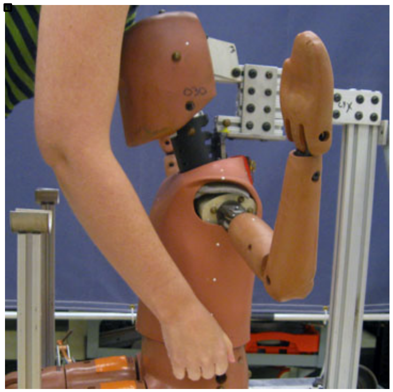
Step 3. Move upper arms outward (abduct shoulder)



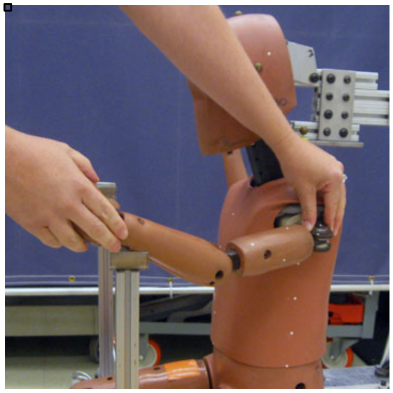
Step 4. Position clavicle link and clavicle according to test condition.



Step 5. Pre-position jacket without pulling down; zip jacket. Check clavicle and clavicle link positions and reposition if necessary.



Step 6. Position jacket per test condition, one of Maximum up, Maximum down, or Resting.



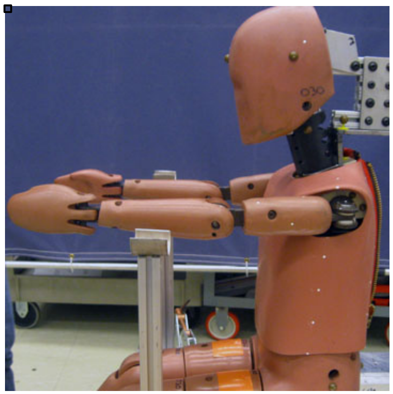
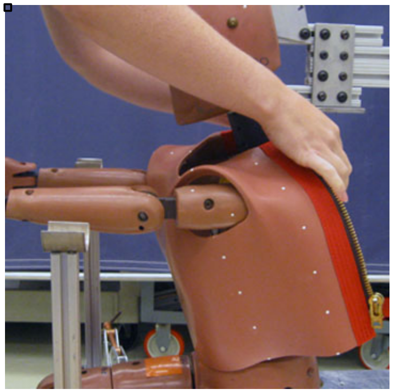
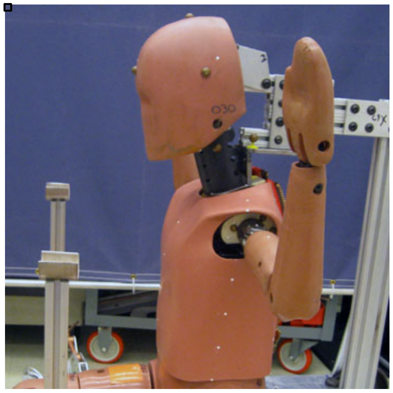
Step 7. Without moving clavicle link or clavicle, move arms to supports so that vest is visible for laser scanning.

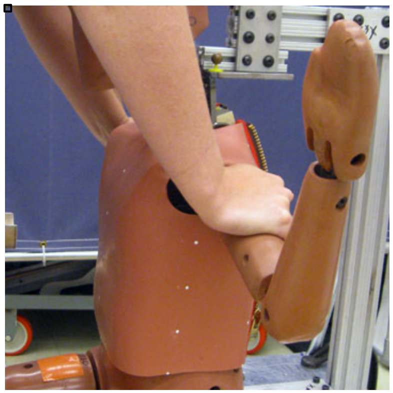
APPENDIX B
JACKET APPLICATION PROCEDURE

Overview

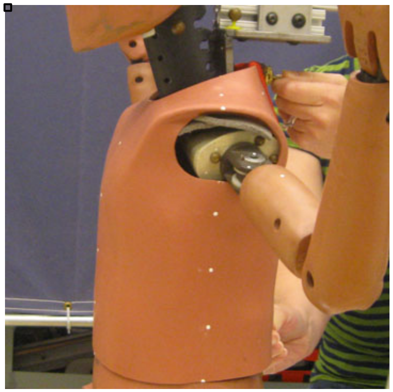
This appendix describes a procedure for applying the 6YO Hybrid III chest jacket and measuring its location with respect to the ATD spine. Table B1 is an expanded version of Table A4 that focuses on use of the ATD for measuring belt fit, but is also applicable to other ATD applications. The procedure is illustrated with the ATD attached to a test fixture, but the procedure would normally be performed with the ATD seated on a table or other surface that provides good access to the ATD torso.

Table B1
Procedure for Putting Jacket on ATD

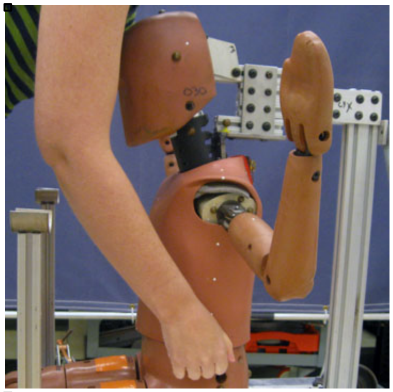
	Step 1. Extend arms (rotate shoulder to 90 degrees flexion, zero abduction)
	Step 2. Put jacket on until jacket shoulders clear shoulder bolts on either side
	Step 3. Move upper arms outward (abduct shoulder)



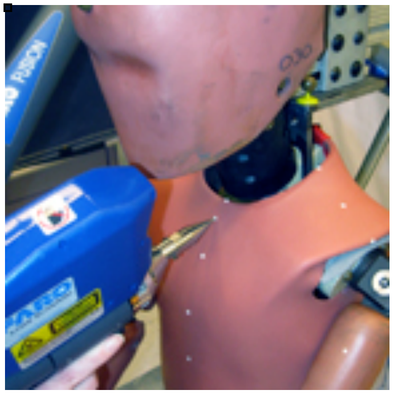
Step 4. Position clavicle link full down (push down firmly on shoulder/arm joint) and clavicle full rear (push rearward firmly on shoulder/arm joint.



Step 5. Zip jacket. Confirm full-down/full-rear position of shoulder/arm joint.



Step 6. Pull jacket firmly downward. Verify that the jacket is in contact with the clavicle link and not hung up on other ATD components. The clavicle link should not protrude through the neck hole. If the jacket cannot be pulled down, unzip jacket, move the jacket downward, and rezip. Verify clavicle and clavicle link positions.



Step 7. Measure reference points on the jacket.

APPENDIX C
PROCEDURE FOR PROCESSING SCAN DATA

Overview

This appendix describes the steps used to process the jacket laser-scan data. The point-cloud data obtained with the FARO Arm laser scanner was processed using Geomagic Studio 12 and Geomagic Qualify 12 software (see www.geomagic.com).

Processing Steps and Software Settings

1. The scans were aligned to a common coordinate system using "Feature" objects on (or attached to) the neck block and spine box of the ATD. These points digitized with the hard probe or were spheres scanned with the laser.

2. All non-jacket points were manually deleted.

3. The scan were ordered, removing outliers of 2 mm, with the noise reduction set to medium, maximum view deviation set to 45 degrees, and the filter angle set to 85 degrees.

4. Noise was reduced using the "Free-form" option, smoothness level set to one.

5. Multiple scan patches from the same trial were combined with the "remove overlap" and "retain normals" options selected.

6. A mesh was created by "wrapping" the points with the noise reduction option set to "automatic".

7. The locations of the paint points on the jacket surface were digitized by creating parameter points in "Features" menu.

8. The scan was decimated to 20,000 polygons.

Comparison of Two Jackets After Alignment to ATD Points:

1. Two of the decimated jacket scans to be compared were imported into Qualify.

2. One scan was designated as the "Reference" object onto which the other scan "Test" scan was projected. The comparison was conducted with the maximum deviation set to100 mm and the critical angle set to 45 deg.