THE INTRODUCTION OF A NEW ELDERLY ANTHROPOMORPHIC TEST DEVICE (EATD)

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ABSTRACT

This technical paper will discuss the development of the new Elderly ATD. This ATD was developed to represent a population with increased vulnerability to injury. The Elderly ATD will provide vehicle manufactures with new tools to evaluate future designs and provide insight on ways to enhance safety measures for their products.

INTRODUCTION

The Center for Disease Control and Prevention (CDC) stated that in 2012, there were approximately 36 million drivers 65 or older in the United States. They reported an average of 586 older adults are injured every day in crashes. [1] Drivers 65 and older are expected to be one fifth of all drivers by 2030. The prevalence of medical impairments, including cognitive deficits, rises with age, along with decreased strength of bones and internal organs, which may increase both susceptibility to injury in crashes and driving errors that lead to crashes. [2] Anthropomorphic Test Devices (ATD) are designed to simulate the weight, proportion and kinematics of the human body. Equipped with instrumentation, an ATD provides real time feedback used to assess the design of vehicle safety measures and evaluate injury occurrences in the occupant(s). The question that will be addressed in this study is what type of ATD should represent elderly people and what type of additional injury measures are needed as compared to current ATD's.

Humanetics enlisted the International Center of Automotive Medicine (ICAM), Injury Biomechanics Research Center of the Ohio State University (IBRC), University of Michigan Transportation Research Institute (UMTRI) and the SENIORS (Safety ENhancing Innovations for Older Road userS) project in Europe (http://www.seniors-project.eu/) to determine the answer to the question. The anthropometry requirements for the Elderly ATD was determined by ICAM's database to be 70 years old, female, and weighing approximately 73 kg with a stature of 1.61 meters. This represents individuals who are most likely to be injured. The UMTRI statistical body model was used in establishing the external shape of the ATD, while the inside organ shapes and positions from the ICAM's magnetic resonance imaging (MRI) scans provided guidance with the design of the internal organ shapes and positions. The experience designing and testing the Obese ATD [3] was also used to review kinematic and flesh stiffness requirements for this new ATD.

The prototype ATD was developed with advanced 3D modeling and cutting edge 3D printing techniques and materials. Utilizing the latest methods of manufacture and materials available permitted new freedoms of design for flesh, organs, ribs, etc. This greatly reduced the amount of time required to manufacture and develop parts; giving flexibility for updates while reducing the need to make and change standard manufacturing tooling.

PMHS match pair testing, sled testing, and certification type testing will be conducted to determine the performance of the ATD, while also investigating durability, repeatability and reproducibility of this new process of ATD development. The technology utilized in the Elderly ATD can be applied to further prototyping as well as providing insights for future ATD development.

Design Overview

The Elderly ATD was designed using the anthropometric data developed by International Center of Automotive Medicine (ICAM) and University of Michigan Transportation Research Institute (UMTRI). Figure 1 shows the first Elderly ATD prototype.

Figure 1. Elderly ATD

The current prototype utilizes the head and neck from the WorldSID Small Female, and lower arms, hands, knee and feet from the Hybrid III Small Female. The remainder of the ATD, including the flesh, are newly designed to meet the requirements for the Elderly ATD anthropometry. This paper will examine the design of the new Elderly ATD, the Anthropometry used, segment detail, preliminary components, and sled testing.

Anthropometry Targets

Overall Size and Weight Targets

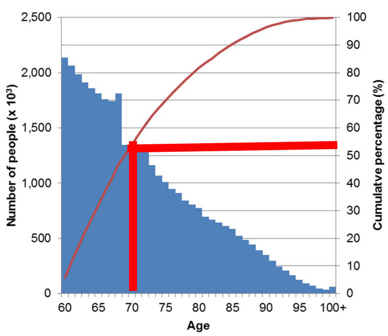
The anthropometry for the elderly was developed by two sources, ICAM and UMTRI. The first step was to develop the size required for an Elderly ATD based on the ICAM motor vehicle database as well as the University of Michigan Adult Trauma Registry. ICAM personnel statistically analyzed data for clarifying the target of an elderly model. They found 80 females whose ages are from 67 to 73 with a mean height of 1.61 meters and with a mean weight of 72.8 kg. From the ICAM/CIREN population the numbers turn out to be (see Table 1):

Table 1. ICAM/CIREN Population Summary

N	Avg. age	Avg. Ht (cm)	Avg. Wt (kg)	Avg. BMI
30	69.8	159.6	75.9	29.5

From the Annual Estimates of the Resident Population by Single Year of Age and Sex for the United States: 2015 Population Estimates from the U.S. Census Bureau, the 50 percentage female was around 70 years old (see Table 2).

Table 2. Annual Estimates of the Resident Population by Single Year of Age and Sex for the United States: 2015 Population Estimates (U.S. Census Bureau)



Based on the results of these reviews of the databases it was decided that the target values for the new ATD would be a 70 year old Female with a 1.61 meter stature, 73 kg total weight, and a Body Mass Index (BMI) of aproximately 28.

External Shape

Once the overall size and weight was established, the next step was to determine the shape of the ATD by using the UMTRI Statistical Body Shape Models (SBSMs) (see Figure 2). The ATD was segmented in a way to depict the ATD, to determine the segment masses and overal center of gravity of the ATD required. The table shown in Figure 2 shows the target segment weights, including the overall target center of gravity for the ATD.

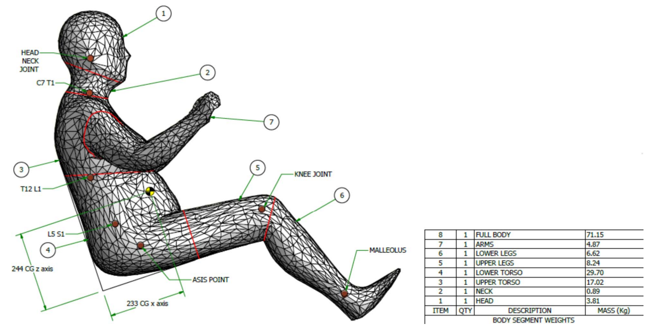


Figure 2 Results from the UMTRI SBSM

Combining MRI Scans and UMTRI Shape

From ICAM, the MRI scans were provided for this size of person to determine rib cage shape, organ size and placement, and flesh thickness. The scan was overlaid with the body shape to determine how to combine both sets of data into one ATD (Figure 3).

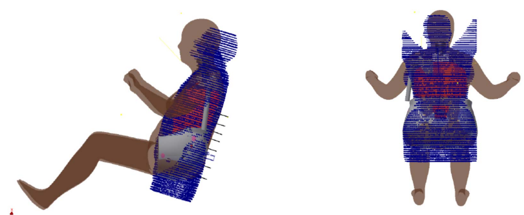


Figure 3. Overlay of ICAM Scans and UMTRI Body Shape

Since the body shape was in the seated position and the ICAM scans were from the supine position, it was necessary to determine how to use one with the other. As shown in Figure 4, scans were placed at different body landmarks provided with the UMTRI models. Using this method the locations of the ribs, organs, spine, and pelvis were determined.

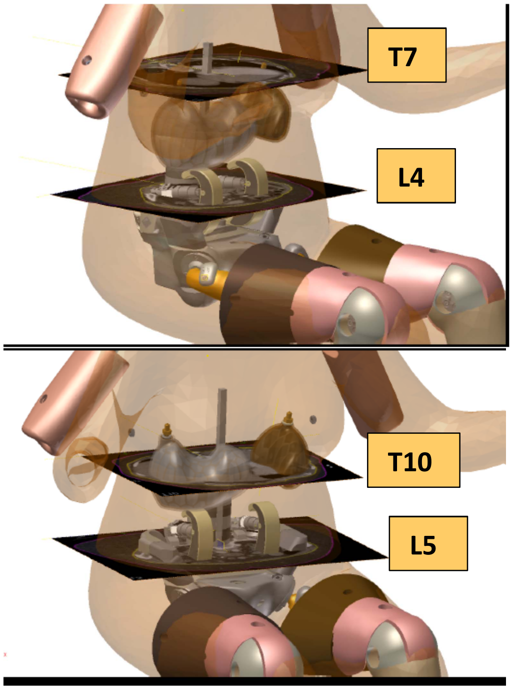


Figure 4. Overlay of ICAM MRI Scans into UMTRI Body Model

It was also seen that the flesh is different from the supine to the seated posture as shown in Figure 5. To determine if the organs moved as much as the flesh, a PMHS was dissected at The Ohio State University lab and repositioned from supine to the Automotive Seated posture (Figure 6).

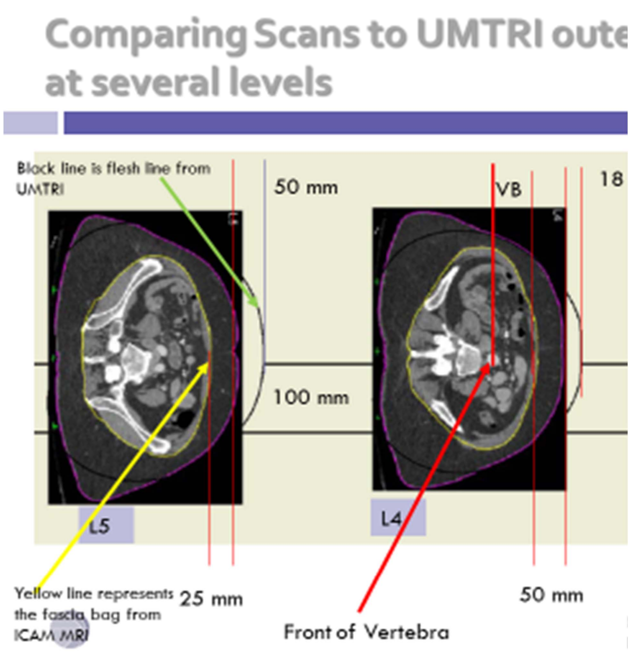


Figure 5. Comparing Scans to Outer Shape

It was determined that the liver and spleen movement was negligible and substantiated the use of MRI scan data for positioning. It was also determined that the flesh moved similarly to what was shown in Figure 5. Therefore, supporting the use of UMTRI's body model for the external body contour.

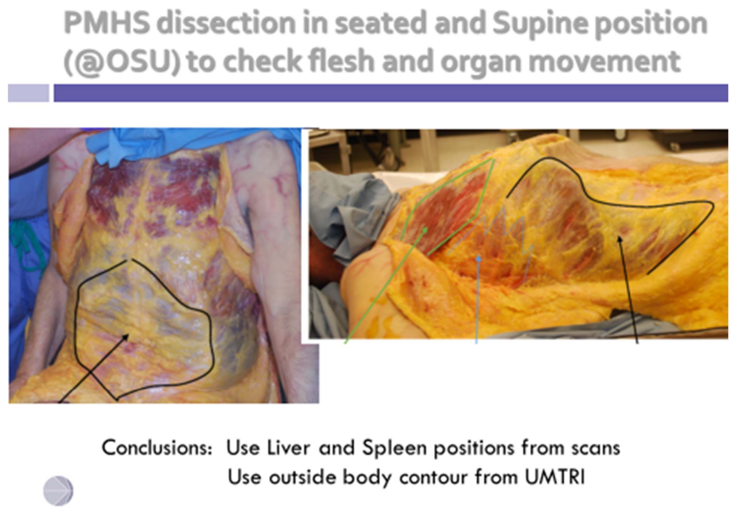


Figure 6. Comparison of Supine and Automotive Seated Posture using PMHS

ATD Design

The design was guided by the scans and shape to locate organs, spine, rib shape and size, and flesh thickness throughout the entire upper and lower torso and upper legs. As determined from the 2015 Humanetics Obese ATD project, it was important to provide the correct flesh thickness since this will determine where the seat belt would lie and how much the belt will need to travel through before coming in contact with hard skeletal structures. Figure 7 shows the overall design of the Elderly ATD. Each segment was chosen or designed to meet the Anthropometric requirements.

Figure 7. Overall Elderly ATD Design

The ATD was made up of standard parts for the head, neck, lower arms, pelvis bone and knee. New designs were created for the rest of the ATD. The following is a description of the design for each segment.

Head and Neck

It was determined that the head and neck from the current WorldSID Small Female would be used on the Elderly ATD. The head size and weight are similar to the body shape model. The head coupled with the current neck, provides potential frontal and side responses which would be reviewed during the testing of the ATD in different configurations Figure 8).

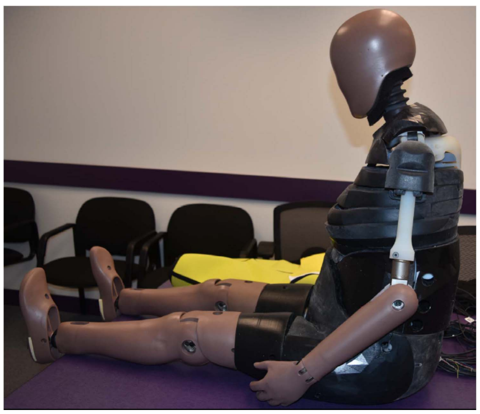


Figure 8. WorldSID Small Female Head and Neck on Elderly ATD

Shoulder Design

The shoulder design for the Elderly ATD consists of a clavicle, sliding scapula, and a ball joint for the arm attachment (Figure 9). The clavicle and sliding scapula design was chosen based on a Humanetics child ATD design completed in 2010. Humanetics impact testing showed that this design could be used for both frontal and side configurations. The scapula is mounted to the ATD by rubber blocks which permit the shoulder to move in all directions. The arm attachment is a ball joint to provide the range of motion and is compact in design. All the pieces of the shoulder are made using additive (3D printing) manufacturing techniques.

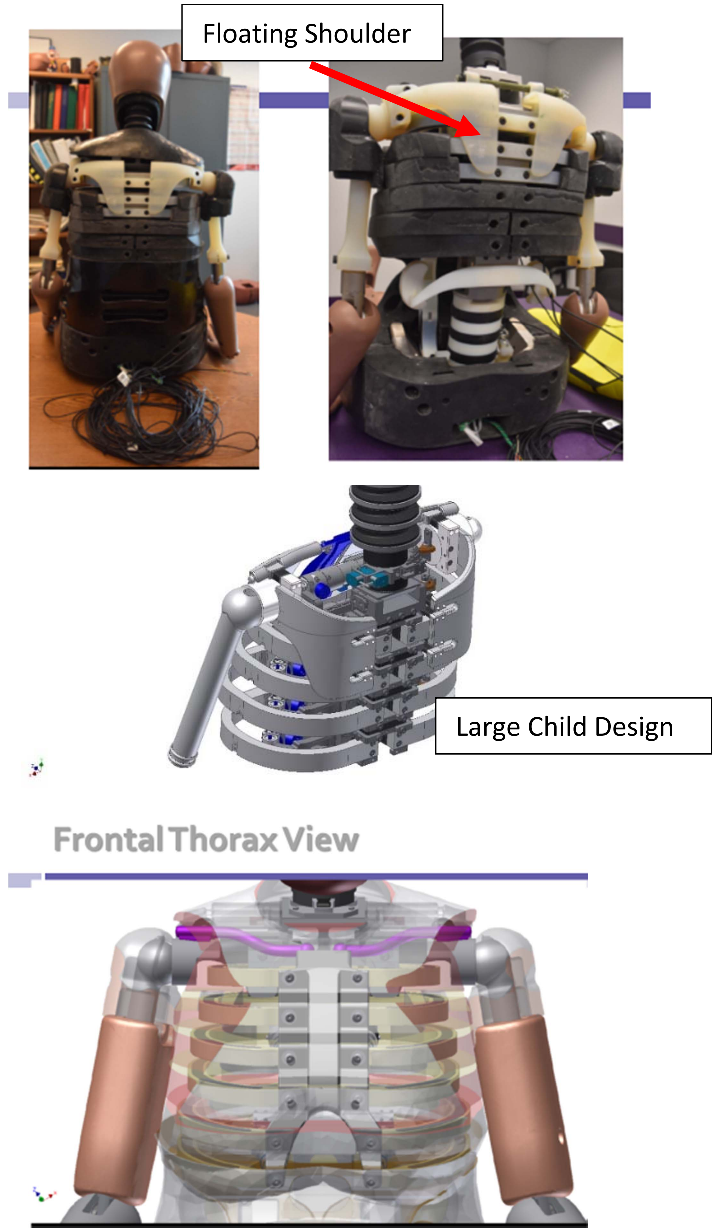


Figure 9. Upper Torso Shoulder and Rib Design

Spine Assembly

The spine consists of four major sections (see Figure 10). The neck and shoulder mount, the upper flexible joint, the main body, with the standard thorax load cell, and the segmented lumbar spine. The spine was made by using additive manufacturing techniques.

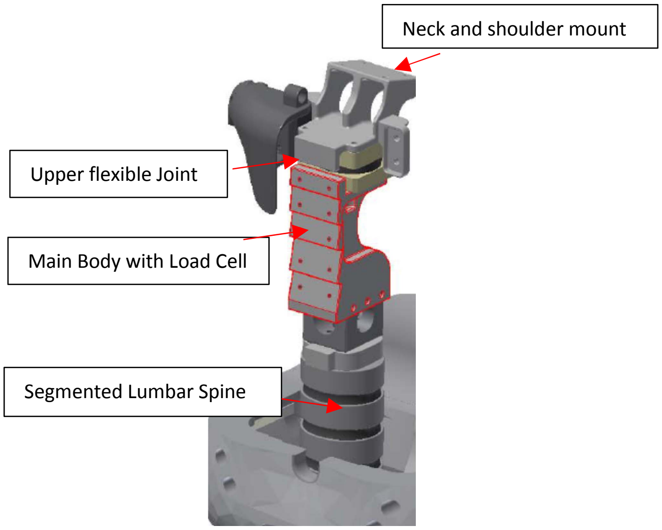


Figure 10. Spine Assembly

The neck and shoulder mount and main body are made from 3D printed aluminum. Integrating the shoulder mount and neck bracket was made easier and in one piece with the utilization of 3D printing techniques. Also the main body had sections designed to accommodate four IRTRACC's. The upper flexible joint and lumbar spine are fabricated from 3D printed rigid plastic plates with 3D printed rubber like discs in between. The load cell is a standard Hybrid III Small Female Thorax load cell. Tri axial accelerometers can be mounted at the front of the spine box and at T-12 locations.

Thorax and Abdominal

The thorax is a major injury location in motor vehicle crash occupants. Thoracic trauma is the principal cause of 30% of road traffic deaths[3]. The thorax contains a variety of critical physiological processes. For example, housing the primary elements of the respiratory and circulatory systems. The rib cage protects the inner organs, including the liver, spleen, kidneys, and stomach. It is evident that the chest, more than any other body region, is particularly vulnerable to crash injury as the subject ages. The total injury rates are higher in elderly motor vehicle crash occupants than in younger occupants and there are significant differences in their respective injury patterns, particularly thoracic, in incidence and severity. [4]

The thorax and abdominal sections of the ATD are developed together as a system approach and not two independent assemblies connected together. The goal was to develop the rib cage, liver and spleen system which met the location and size requirements based on the MRI scans provided from ICAM. The rib shape, organ size, and placement is patterned after the MRI scan from ICAM. The overlay aligning body landmarks from the UMTRI shape with the MRI scan provided the information needed to develop the rib cage and organ design (see Figure 11).

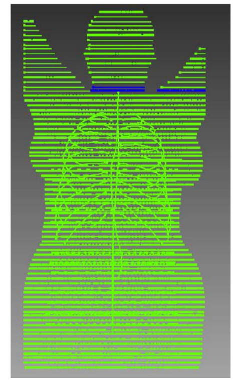


Figure 11. Rib Cage Scan Used to develop Rib Cage Design

The ribs are designed to use constrained layer damping in place of the standard free layer damping conventional crash dummies have used for years. The design consists of a rib with two bands of a spring like plastic material connected on the ends and rubber like damping material placed in the middle between the bands (Figure 12).

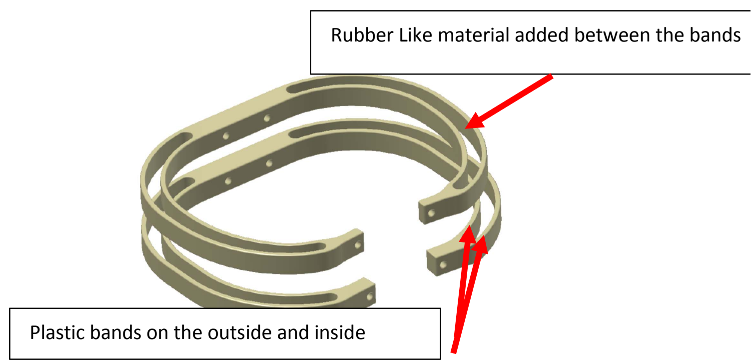


Figure 12. Sample of Elderly Rib Design

To eliminate the conventional jacket and foam pieces used in existing dummies, each rib was provided with a slip on soft plastic layer covering the rib while providing the outside contour shape required. This permits the ribs to move more independently from each other from side to side and top to bottom. A tailor fitted neoprene jacket with a durable Cordura chest cover is then added over the ribs to smooth the contour (Figure 13).

Figure 13. Thorax Rib Coverings

The organs chosen to be represented in the Elderly ATD are the liver and spleen. Research has shown in the AIS ≥ 3 category, the liver was the most frequently injured organ in frontal, right side and far side crashes; this was followed by spleen trauma. In contrast, the spleen sustained the maximum number of injuries in left and near side impacts. [5] More biofidelity in this region provides greater insight on potential injury criteria.

The abdominal cavity is the largest cavity of the human body. The liver is largest internal organ through which about 1.5 liters of blood flows each minute. This makes any injury or laceration to the organ a potential for large amounts of blood to leak into the abdominal cavity. The spleen also has a rich blood supply and bleeds extensively when injured. [6]

To determine deflection of these organs, the lower IRTRACC's of the ATD went through the liver area and just above the spleen. Additional deflection bands (connecting IRTRACCs) were added in front of each organ to also capture deflection directly in the liver and spleen areas (Figure 14).

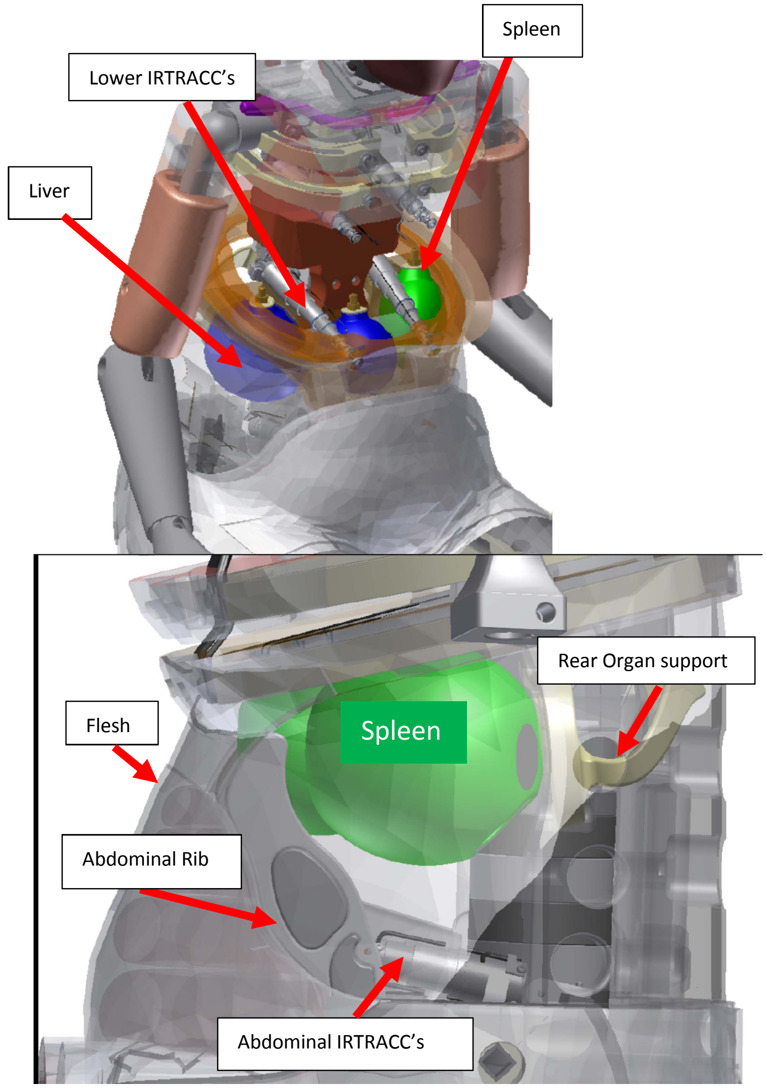


Figure 14. Organ Layout in the Elderly ATD

The liver and spleen are designed to be adjusted as more testing and biomechanical data becomes available. They are designed to represent the overall shape and size of each organ, but are made with an internal hex pattern so that stiffness can be adjusted. The parts are 3D printed from a rubber like material (Figure 15).

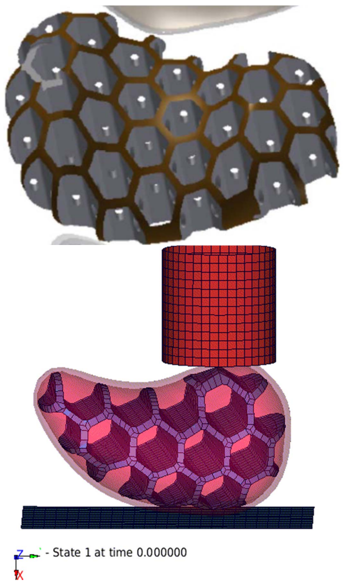


Figure 15. Design Concept of Liver and Spleen Structures

Preliminary modeling has also been done to experiment with different sizes and shapes of the structure to adjust the stiffness as required. The flesh to locate the organs is based on the UMTRI outer shape and is 3D printed from a soft rubber like material with additional structural holes under the skin to adjust stiffness as necessary (Figure 16). The liver was divided into two parts to permit the IRTRACC to go through the center of the liver area.

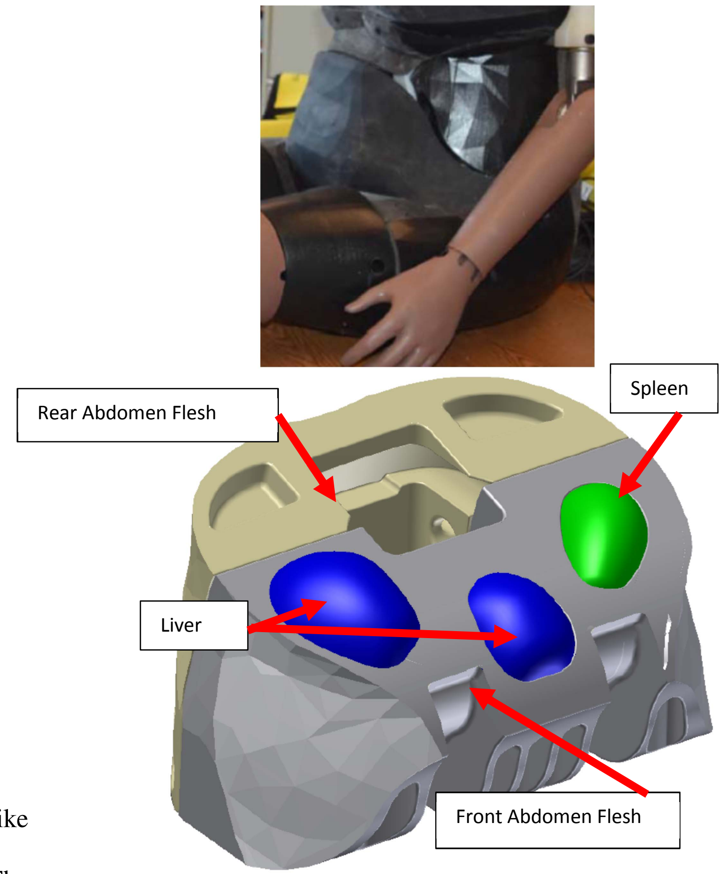


Figure 16. Abdominal Flesh with Organs

Pelvis

The pelvis consists of a standard Hybrid III Small Female bone, upper femurs, ASIS load cells, and 3D printed soft rubber like flesh (Figure 17).

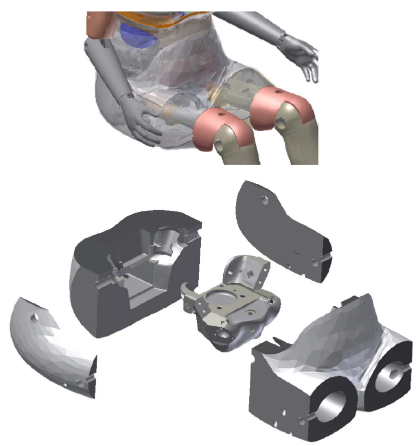


Figure 17. Pelvis Assembly

The stiffness of the flesh is controlled by the material and internal coring to vary the stiffness from side to side, bottom, and front areas of the pelvis. The small female bone was used due to the fact that the ASIS lateral spacing was similar to the spacing provided in the body land marks from ICAM and UMTRI.

Upper Legs

The upper leg structure consists of a standard Hybrid III Small Female leg bone slightly extended to match the 1.6 m stature. The knee assembly is the Hybrid III Small Female knee assembly. The external shape of the thigh flesh is designed to match the shape of the UMTRI shape model in the pelvis area and then match the standard knee flesh on the other end (Figure 18).

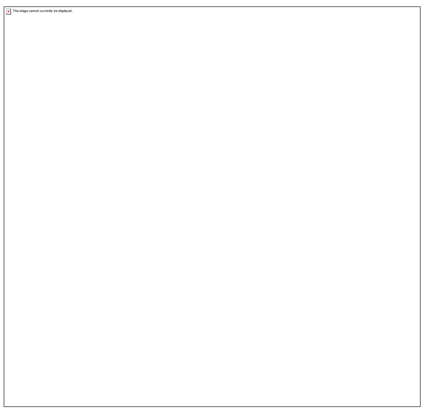


Figure 18. Elderly ATD Leg Assemblies

Lower Legs

The lower legs are standard Hybrid III Small Female design but extended 24 mm to match the UMTRI 1.6 m profile. Therefore a new flesh is 3D printed. The design allows for the fitting of upper and lower tibia load cells. The foot is standard HIII.

Arms

The arms consist of a standard lower arm and hand assemblies from the Hybrid III Small Female and upper arm has a new upper arm bone, which is longer than the standard Small Female arm to meet the length of the UMTRI arm and is made from a 3D printed rigid plastic. The flesh of the upper arm contains a standard upper arm flesh from the Hybrid III Small Female with a 3D printed soft rubber like material at the top to cover the area that was lengthened (Figure 19).

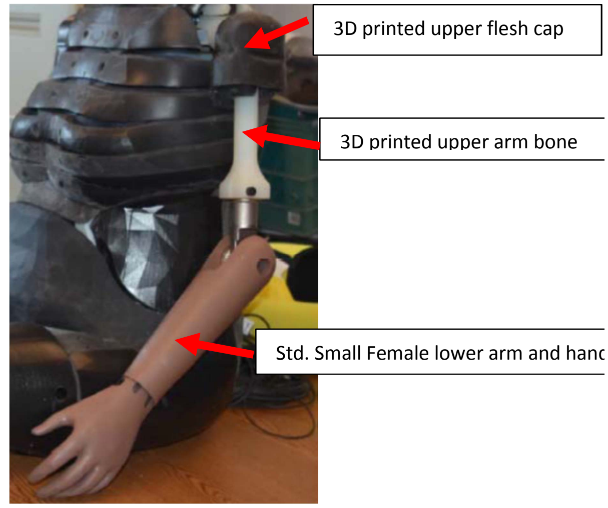


Figure 19. Arm Assembly for Elderly ATD

Instrumentation Available for Elderly ATD

Table 2 contains a list of possible instrumentation available for the current version of the Elderly ATD.

Table 2
Current Instrumentation for Elderly ATD

Transducer Type	Dummy Location	No of Channels
Accelerometer	Head (World SID SF mount)	3
Upper Neck Load Cell	Head (World SID SF)	6
Accelerometer	Thorax	3
Mid Spine load cell	Std. THOR spine load cell	6
Accelerometer	T12	3
IRTRACC	Thorax	(4) 3 channel type
Tilt sensors	Thorax T4	1
IRTRACC	Abdomen/Organ/Pelvis	(2) 1 channel type
Accelerometers	Pelvis Cavity	3
Iliac Wing Load Cells	Pelvis	3 each
Femur Load cell	Upper Leg	3 or 6 channel type
Knee slider Potentiometer	Knee	1 channel each side
Lower leg load cells	Lower Leg	Up to 6 channels each side

Completed ATD Verifications

ATD Anthropometry

The ATD weight compared to the targets, after adding ballast, is shown in Table 3.

Table 3.
Weight Summary vs Targets

Segment	Current Weight of ATD	UMTRI Date Segmented like ATD (targets)
Head	3.75	3.8
Neck	0.263	0.9
Upper torso	21.09	19.1
Pelvis & Abdomen	29	29.7
Upper legs	8.3	8.2
Lower legs & Feet	8.14	6.6
Arms	3.1	4.9
TOTAL	73.643	73.2

Current Component Testing to date

Thorax Impacts

Thorax impact testing (Figure 20) was performed to review the initial response of an ATD of this shape and size. Additionally, the impact results will create a picture of what to expect from 3D printed parts, and serve as a baseline for expectations moving forward.

It was decided to impact the EATD with the standard 23.4 kg pendulum used to impact the Hybrid III 50th Male ATD, since these two ATDs are the closest in weight. This size pendulum exposed the EATD to higher levels to review the durability of the system.

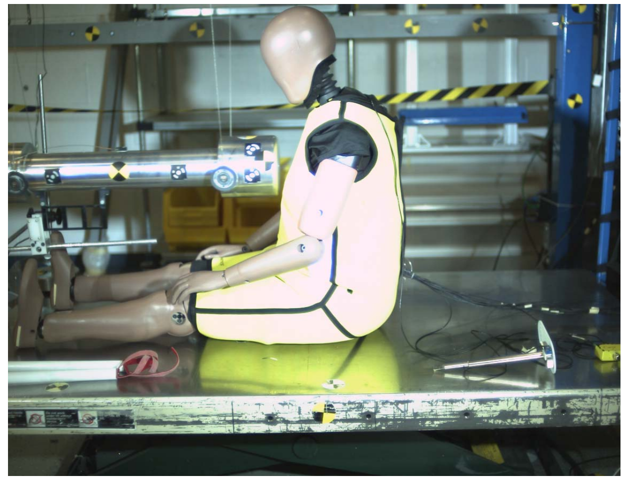


Figure 20. Thorax Impact Testing

The results of impacting the thorax at 4.3 m/s is shown in Figure 21. Peak deflections are 30 mm with peak forces at 3400 N. The hysteresis is 76%.

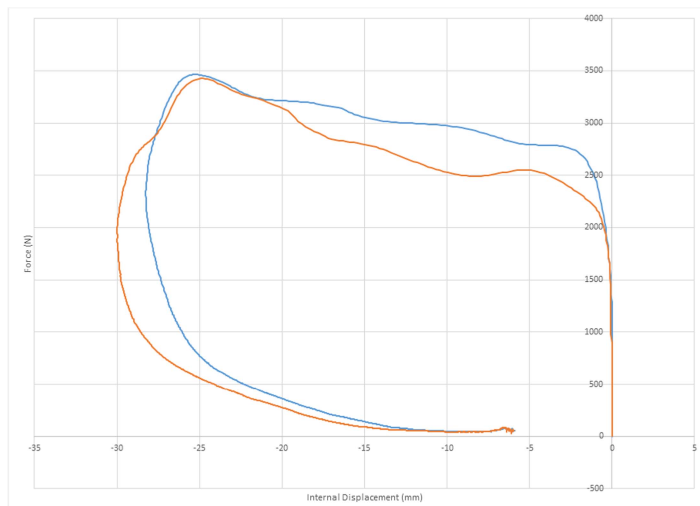


Figure 21. 4.3 m/s thorax impact results

Next, lower oblique impact tests were conducted to develop a baseline result for this area of the ATD as well. These tests were also conducted with the 23.4 kg pendulum at 4.3 m/s (see Figure 22). The peak deflection was just over 30 mm and the peak force almost 4500 N.

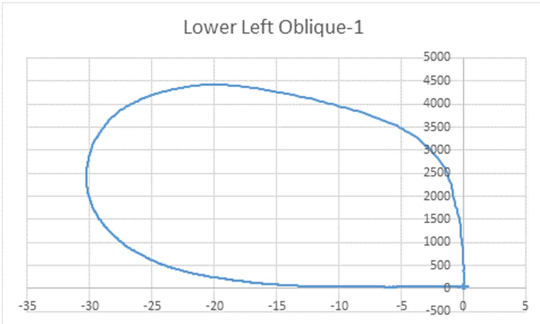


Figure 22. 4.3 m/s Oblique Thorax Impact Test

Side Impact Sled Testing Results

The Elderly ATD was taken to Honda in Ohio to be tested in a side impact sled test. The test was at 50 kph with a side air bag, seat and door panel (Figure 23). One test was conducted to provide a baseline of side impact performance for durability and to compare with PMHS later this year.

Figure 23. Set up of Elderly ATD in Side Impact Test Fixture at Honda

The Ohio State University provided a 59 channel chest band to provide shapes during the sled test, see Figure 24 of chest band on the ATD. The ATD contained 4, 3 channel IRTRACC's positioned on the right and left side of rib 3 and 6. Two other single axis IRTRACC's were placed in the pelvis to measure abdominal intrusion.

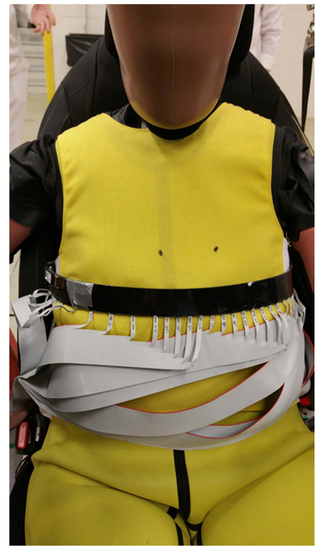


Figure 24. Chest band installed on Elderly ATD

Test Results

Baseline Data from the data channels

Figure 25 provides the sled pulse which was used in the sled testing.

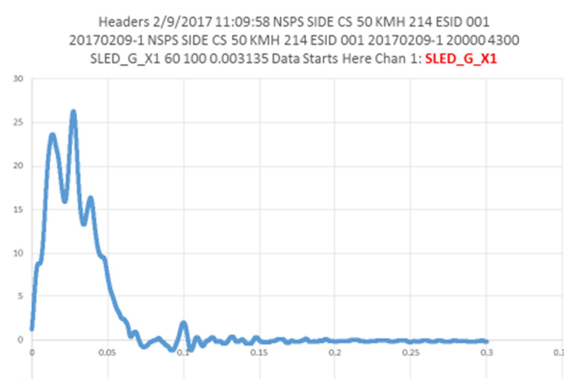


Figure 25. Sled Pulse (G's)

Figure 26 provides the ATD X direction of the ITRRACC's for right and left rib 3 and 6. The left Rib 3 X axis had the most deflection of 20 mm with lowest being the right rib 6 data. The belt moved to the left during the test. The rotations about the Z axis on the IRTRACC's are shown in Figure 27. The largest motion in the Z-axis was the IRTRACC on the left side on rib number 3. Right Z on rib number 6 failed.

The experimental abdomen/pelvis deflection measurements, shown in Figure 28, did respond as planned to provide deflection data across the pelvis and abdomen areas of the ATD.

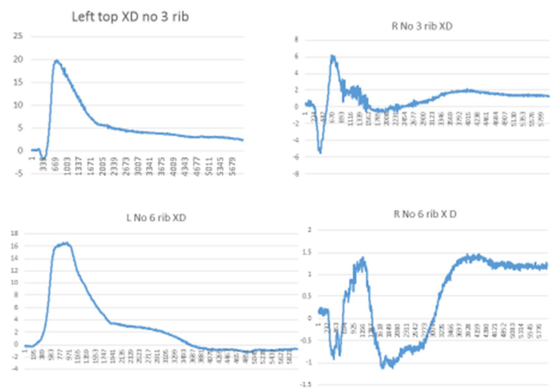


Figure 26. Left and Right X direction Results from IRTRACC's (mm vs msec)

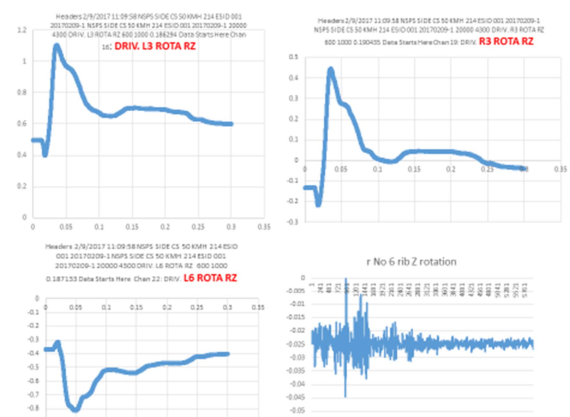


Figure 27 Left and Right Z direction results from the IRTRACC's (Degree vs msec)

The right side shows more deflection then the left side, 5 vs 1.5 mm. This result matched the direction of the ATD sliding toward the right side into the buckle as shown in the films.

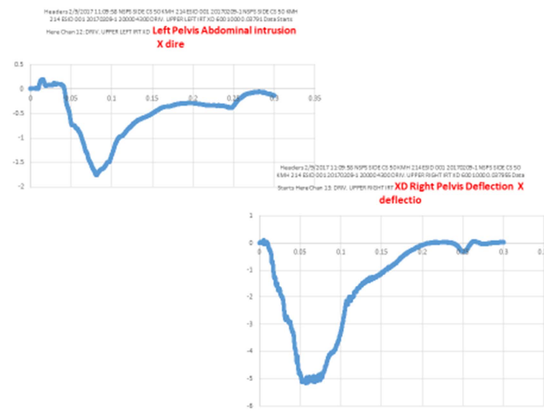


Figure 28. Right and Left Side Abdomen/Pelvis X axis IRTRACC's (mm vs msec)

Chest Band Results

The 59 channel chest band provided baseline information of how this ATD performed in a pure side impact test. These results will assist in the development process to make a better omni-directional ATD. Figure 29 provides a sequence of shapes during the test.

Durability Results

Two items were seen during the testing, one is that the right arm broke off at the ball joint when the arm was free to flail (Figure 30) coming across the thorax and striking the inner door. The second item was the left scapula which fractured during the test due an inadequate amount of clearance between the scapula and the neck bracket.

Figure 30. Post Test

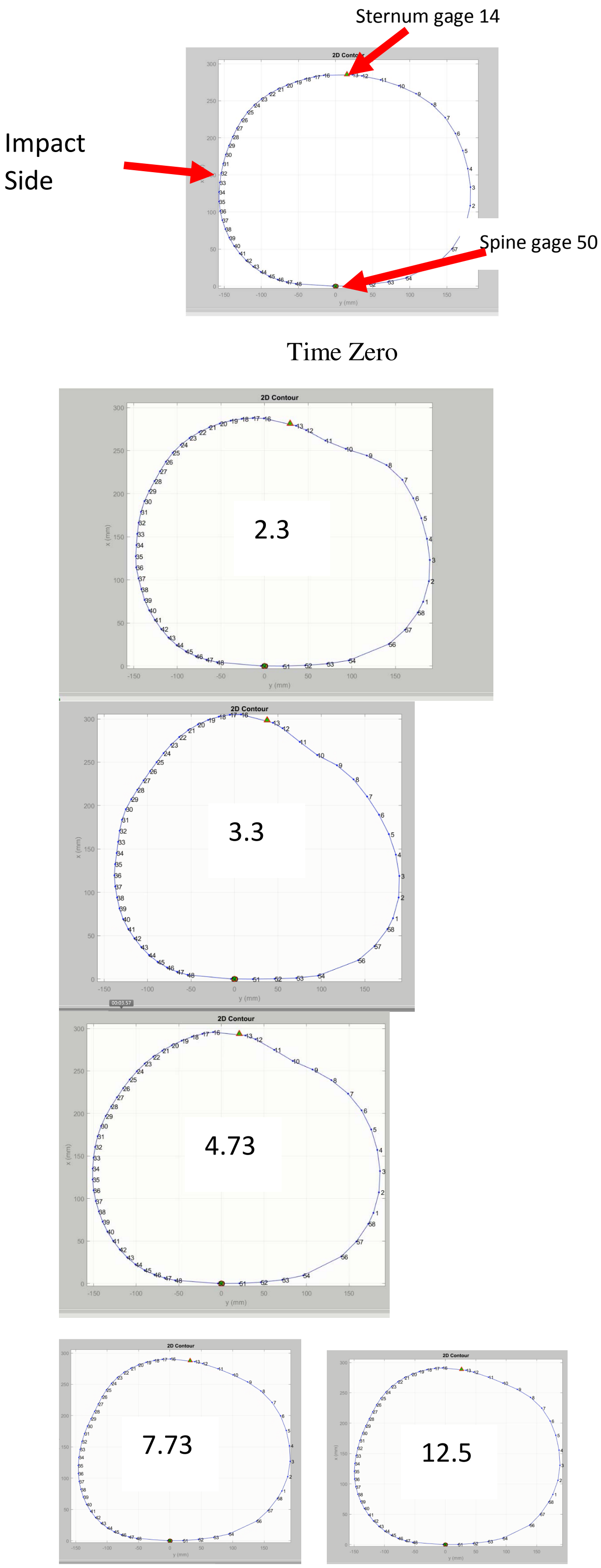


Figure 29. Chestband Data (mm)

CONCLUSIONS

The 3D printing process has been shown to be an invaluable tool to design and develop crash dummies without the need to develop molds. Durability has been shown to be good in some areas but some areas need improvement, so different materials, such as printed materials with Kevlar or Carbon Fibers, will be used. The many materials available today and more tomorrow will continue to advance the process of making better crash dummies.

The design target weight for mass and size was achieved using this manufacturing process. To better understand about belt interaction with overweight occupants, exploration into pressure measuring organs with new types of abdominal deflection measurement systems showed promise.

Elderly ATD Updates

The next steps of the Elderly ATD development is to continue component testing and update the design based on what has been learned to date. The following is our plans for the update of the current ATD and upcoming testing (see Table 4).

Table 4.
Summary of Updates and Testing

Part	Design Update	Material Update	OSU PMHS Match Pair Testing (April)	Component Lab Testing (March – June)	Honda Side impact sled testing (June)	Senior Sled Testing (Sept – Feb)
Neck bracket	Increased clearance for scapula movement	Steel to meet weight traget without ballast		X	X	
Spine		Steel to meet weight traget	X	X	X	X
Lumbar spine	Increase area of rubber for durability + 2 cables	Improved rubber like material	X	X	X	X
Scapula		Plastic w/kevlar	X	X	X	X
Clavicle		Plastic w/kelvar	X	X	X	X
Sterum		Plastic w/kevlar	X	X	X	X
Ribs		Plastic w/kevlar	X	X	X	X
Chest jacket	Improve fit		X	X	X	X
Upper arm and socket	Improve ball attachment	Plastic w/kevlar	X	X	X	X
Rib covers	Improve fit to prevent cracks	Improved rubber like material	X	X	X	X
Organs	Make less stiff by revising structures	Improved rubber like material	X	X	X	X
Pelvis flesh	Redesign for better fit and durability	Improved rubber like material	X	X	X	X
Legs	Redesigned to match UMTRI legs and shapes	Improved rubber like material	X	X	X	X

REFERENCES

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