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A Multi-Modality Image Data Collection Protocol for Full Body Finite Element Model Development

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ABSTRACT

This study outlines a protocol for image data collection acquired from human volunteers. The data set will serve as the foundation of a consolidated effort to develop the next generation full-body Finite Element Analysis (FEA) models for injury prediction and prevention.

The geometry of these models will be based off the anatomy of four individuals meeting extensive prescreening requirements and representing the 5th and 50th percentile female, and the 50th and 95th percentile male. Target values for anthropometry are determined by literature sources. Because of the relative strengths of various modalities commonly in use today in the clinical and engineering worlds, a multi-modality approach is outlined. This approach involves the use of Computed Tomography (CT), upright and closed-bore Magnetic Resonance Imaging (MRI), and external anthropometric measurements. CT data provide sub-millimeter resolution and slice thickness of the subjects in the supine and an approximately seated position. Closed-bore MRI complements CT data by providing high-resolution images with improved contrast between soft tissues. MRI pulse sequences that image fat-water interfaces out-of-phase are used to enhance contrast and facilitate segmenting organ and muscle boundaries. Upright MRI data complement closed-bore data by enabling quantification of morphological changes that occur when a subject is oriented upright with respect to gravity. The final component in this suite of image data is a set of external anthropometry (EA) measurements. EA measurements include three-dimensional point cloud acquisition of external bony landmarks as well as surface contours. These data serve as a valuable geometric validation tool for the assembled full-body FEA models.

Protocol development results, including preliminary image data sets, in-plane resolution and slice thickness achieved for each modality, pulse sequence designs for MRI acquisition protocols, and custom positioning systems used in image acquisition are presented. The approach outlined in this study is expected to provide sufficient data to develop models in both the seated and standing posture. This suite of imaging and anthropometry data will serve as a strong foundation for the collaborative development of a group of full-body FEA models for injury prediction in the coming years.

INTRODUCTION

Motor vehicle crash and its associated injuries remain a major public health problem world wide. In 2005 alone there were 6 million police-reported crashes in the United States, resulting in 2.5 million injuries and 43,000 fatalities (NHTSA, 2006). Given the recent advances in medical imaging technology, computer aided design (CAD), and finite element analysis (FEA), researchers have increasingly turned their attention to computational modeling of the human body for prediction, prevention, and mitigation of crash-induced injuries. This paper presents an imaging protocol that will ultimately yield several full-body CAD data sets. This data will serve as the foundation of a consolidated effort to develop the next generation full-body FEA models for injury prediction and prevention.

A number of medical image data sets have been referenced in the open literature for full-body FEA model development. Perhaps the most widely known of these is the visible human (VH) project (Spitzer et al., 1996; Spitzer and Whitlock, 1998). Anatomy based on the male cadaver used in this study has been an integral part of the development of numerous FEA models for injury biomechanics studies (Ruan et al., 2003, 2005). The individual used for VH male was aged 38 years and his stature and weight were 180 cm and 90.3 kg, respectively. Two-dimensional X-ray, Magnetic Resonance Imagining (MRI), Computed Tomography (CT), and serial sections of this individual were acquired. CT slice thickness ranged from 3 to 5 mm for fresh scans and 1 mm frozen scans. Axial MRI images were obtained at 4 mm intervals. The VH female dataset is similarly constructed, but that individual's stature and weight were 165 cm and approximately 128 kg (Bajka et al., 2004).

FEA model development has not been limited to anatomical data derived from medical images. A dataset for full-body FEA model development was generated as part of the HUMOS (Human Model for Safety) project (Robin, 2001). This data set is based on a male cadaver frozen in the driving position as specified by Robbins et al. (Robbins, 1983). The cadaver was serially sectioned in 5 mm-thick slices acquired with a 2.5 mm gap between each slice. The cadaver used in this study approximated the 50th percentile male, with stature and weight of 173 cm and 80 kg, respectively. Medical images of this individual were not acquired prior to sectioning.

A commercially-available data set of the anatomy of an average male (ViewPoint Datalabs / Digimation, St. Rose, LA, USA) has been employed in the development of numerous models (Iwamoto et al., 2000, 2002). Skeletal anatomy in this data set was digitally recorded from actual bone specimens using reverse engineering techniques. Descriptive values of the stature and weight of the individuals used in the development of this data set are not available in the literature. This geometry has been scaled to match populations of interest, such as the 5th percentile female occupant (Kimpara et al., 2005).

Finally, the work by Schneider et al. (1983) focused on the anthropometry of motor vehicle occupants has been frequently used in development of FEA models, mainly focused on validating model posture, stature, weight, and external anthropometry. These data were determined from external measurements acquired from volunteers.

This is not meant to be an exhaustive review of FEA models in the current literature and their corresponding data sources, as such reviews are available. (Yang et al., 2006) Instead, the brief history above is presented to highlight the need for more complete anatomical data sets for FEA model development. For instance, neither of the visible human male or female closely approximate any definition of the 5th, 50th, or 95th percentile individuals by height and weight. These data sets are further limited by the fact that they depict frozen, cadaveric data in the supine position only. While the HUMOS project data does capture the seated occupant position, imaging data was not taken, and again the subject was a cadaver. The protocol presented in this paper has been developed to provide a new set of imaging and anthropometric data from volunteers of both genders that have been matched to targeted percentiles. The data are being acquired with the specific goal of FEA model development for the injury biomechanics community in mind, and to provide solid foundation to advance full-body computational model development.

METHODS

The methods section provides an overview of subject selection, recruitment, and screening procedures, followed by descriptions of the protocols used for collection of the full body image data set. The protocol was developed to enable modeling of both the seated and standing posture. Because of this, and because there is no one single modality that meets all the requirements to develop biomechanical models, a multi modality approach for data collection has been adopted. The approach is summarized in Table 1 and employs conventional MRI, upright MRI (UMRI), CT, and external anthropometry (EA). The individual strengths of each approach are highlighted in Table 1, with more "+" signs denoting relative strength of one modality over the others for a given attribute of the data.

Table 1. Summary of modalities used in image data collection and the relative strengths of each.

Attribute	MRI	UMRI	CT	EA
Bone contrast			+	
Soft tissue contrast	+	+		
Resolution	++	+	+++	
Orientation to gravity		+		+
Direct landmark locations				+
Participant positioning		+	+	+

Subject recruitment

The imaging protocol was reviewed and approved by the Wake Forest School of Medicine Institutional Review Board (IRB, #5705). Target height and weight for the 5th and 50th percentile female and 50th and 95th percentile male are provided in Table 2. This data is also shown in Figure **1** along with the acceptable tolerance on height (± 2.54 cm) and weight (± 5% of the target weight). The percentiles and corresponding target values were based on the sizes of the Hybrid III family of anthropomorphic test devices (ATDs).

Table 2. Target weight and height values for recruited individuals.

Gender	Percentile	Height, cm	Weight, kg
Female	5th	150.9	49.0
Female	50th	161.8	62.1
Male	50th	175.3	77.1
Male	95th	186.9	102.1

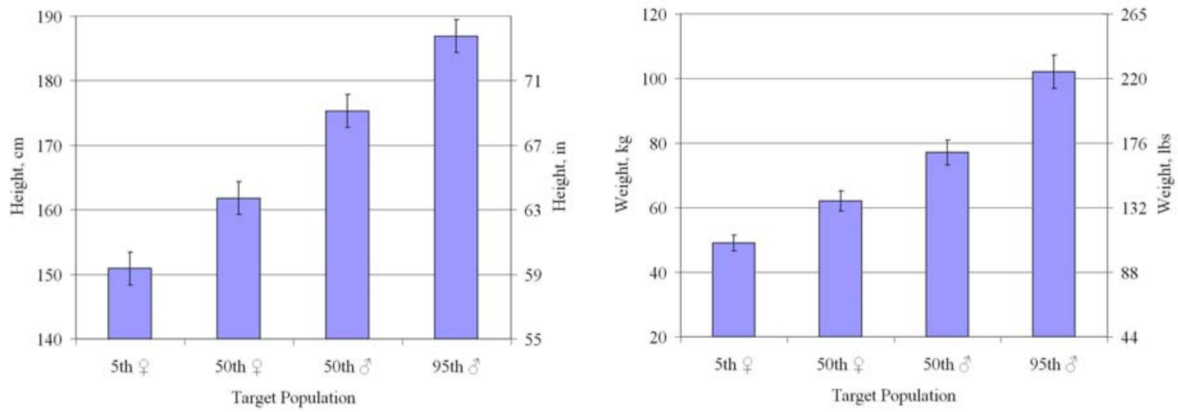


Figure 1: Target heights (Left) and weights (Right) with tolerances, in metric and English units.

Volunteers between the ages of 22 to 44 were recruited through local advertising. Following informed consent, volunteers were screened for basic health data, including clear medical history. Exclusion criteria include MRI non-compliance (metal implanted in the body), history of osteopenia or osteoporosis, claustrophobia, prior surgery to remove major organs, internal electrical devices, physical or orthopedic impediment, or positive pregnancy test for females. Beyond height and weight checks, 10 additional external anthropometric measurements are acquired from the subject (Table 3). To be enrolled in the study, the prospective individual should be within 5% of the value for their particular percentile specified by Gordon et al. (1989) Should a participant be willing to participate in the study and meet the above criteria, they undergo the complete imaging protocol. Each of modality is described below and is presented in the order in which data is acquired. At the conclusion of this research, the following imaging protocol will have been completed for the four volunteers described in Table 2. Data collection is currently underway.

Table 3. Anthropological measures used in recruitment process.

Seated	Standing
Seated height	Shoulder elbow length
Hip breadth	Forearm hand length
Buttock knee length	Waist circumference
Knee height	Hip breadth
Bideltoid breadth	Foot length

Magnetic Resonance Imaging. MRI uses magnetic fields to create images of the body based on the hydrogen content and environment of structures in the field of view. The pulse sequences used in acquisition of this data are variations of the gradient echo pulse sequence, a sequence commonly used in the clinical setting. In this sequence, the TE (time to echo) and TR (time to repetition) of the pulse sequence are selected such that the fat and water signals are out-of-phase at the instant of signal acquisition. The timing is determined based on the respective precession frequencies of fat and water. The result is that in regions of the body where there are high concentrations of both fat and water in a voxel (for example at the borders of organs) the fat and water signals cancel one another out, creating a dark outline around these structures.

Closed Bore MRI. One strength of MRI is its ability to provide good contrast between soft tissues of the body. Examples of interest to biomechanists include white and gray matter in the brain and frequently-injured abdominal organs. Images are acquired with a dedicated research scanner (GE 1.5 Tesla TwinSpeed MRI) in Wake Forest University's Center for Biomolecular Imaging. Imaging experts from the manufacturer were consulted to develop pulse sequences that provide the best balance of signal to noise, voxel size, acquisition time, and image quality. A 3-dimensional FSPGR (Fast Spoiled Gradient Echo) pulse sequence is used to acquire the data. The receiver coil that used to acquire these images is an 8-channel phased-array surface coil. Parallel imaging techniques are used with this coil to reduce image acquisition time by a factor of two. The scanner can provide a maximum coverage of 48 cm for a given scan.

Table 4 summarizes the image acquisition plan for this modality. Scanning is conducted in three sessions; the subject is supine for all sessions. Resolution and thickness values below are target values after all image processing, (i.e., parameters describing the final images that will be used in segmentation). These values vary depending on the field of view used in the image acquisition, which is a function of the size of the individual being scanned. A set of fiduciary markers is applied prior to scanning to register image data from adjacent slabs (sets of individual images). Respiratory triggering and cardiac gating greatly increase the scan time given the pulse sequences used, and therefore are not employed. Instead, participants are asked to hold their breath during image acquisition in the thorax and abdomen. Acquisition time for breath held scans ranges from 20 to 30 seconds. The field of view varies depending on the participant and acquisition plane (axial vs. coronal) but is between 300 and 480 mm.

Table 4. Closed bore MRI summary.

Visit	Body Region	Number of Slabs	Target Resolution / Thickness (mm)	Matrix Size (pixels)
1	Abdomen & Lower Extremity	4 – 6	0.78 / 1.5 – 2	512 x 512
2	Thorax & Upper Extremity	4 – 6	0.78 / 2.5	512 x 512
3	Head	1 – 2	0.78 / 1.5	512 x 512

The 3D FSPGR sequence creates images with good structural clarity, clearly showing organ and muscle group boundaries. These qualities make this selection of pulse sequence a good choice for image segmentation. Figure 2 shows axial and coronal images acquired using the protocols developed for this study.

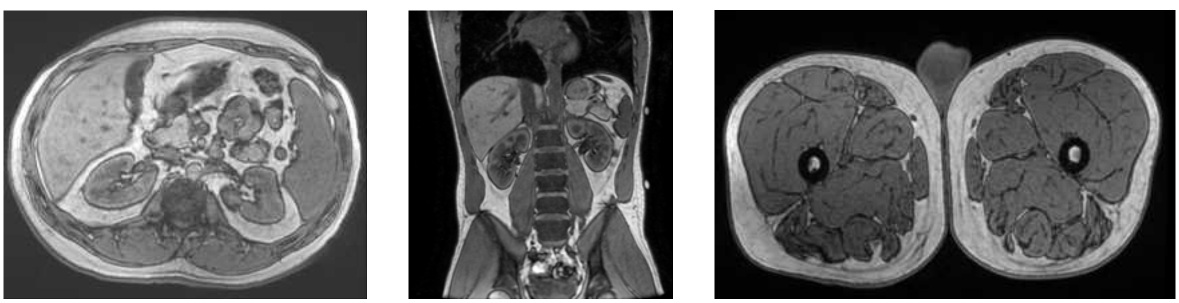


Figure 2: Closed-bore MRI results using 3D FSPGR (Fast Spoiled Gradient Echo). Left, axial slice of abdominal cavity; Middle, coronal slice of abdominal cavity; Right, axial slice of the lower extremities.

Upright MRI. Upright MRI data is acquired at Bristol Regional Medical Center, in Bristol, TN. The scanner (Fonar Inc., Melville, NY) has a 0.6 Tesla magnet. This modality is utilized since, unlike conventional MRI, quality images with the subject oriented with gravity can be acquired. Gradient echo pulse sequences similar to those developed for the close-bore MRI scanner are used so that the resulting images are acquired with the fat and water signal out of phase. Like the closed-bore machine, this provides maximum contrast between structures. Transmit and receive coils designed by the manufacturer of the scanner, are used in image acquisition. These include a head coil that mounts directly to the support table, cervical spine coil, and thorax/abdomen coil. Exemplar images of the upright MRI data can be found in Figure 3.

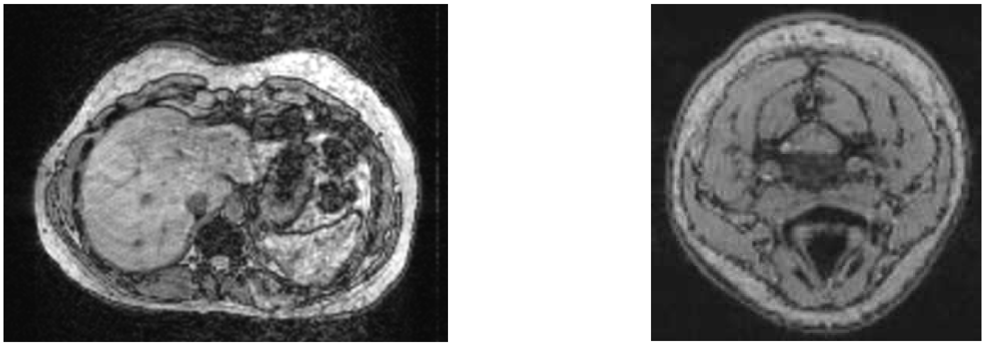
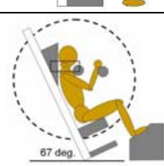
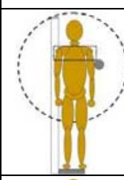
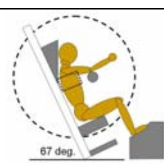
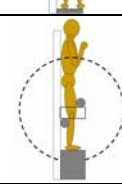
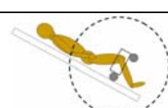


Figure 3: Exemplar images of the Fonar upright MRI scans. Left; seated abdomen axial slice, Right; seated neck axial slice.

Since postural changes are anticipated to affect the location of the abdominal organs relative to one another and surrounding structures, as well as the morphology of these organs, images are acquired in the seated and standing position. In addition, scans of the head, neck, and knees are acquired. Depictions of the subject posture per scan are summarized along with resolution, and slice thickness, in Table 5 . As with the closed-bore MRI, these values can vary depending on the field of view used in the image acquisition, which is a function of the size of the individual being scanned. The dashed circles in the schematics represent the profile of the magnets and therefore the location where images can be acquired. The thickness of the slabs ranges from 14 to 19 cm. Field of view ranges from 32 cm to 47 cm depending on the anatomy being scanned.

Table 5. Upright MRI data summary.

Seated				**Standing**			
Body Region	Number of Slabs	Resolution / Slice Thickness	Posture Schematic	Body Region	Number of Slabs	Resolution / Slice Thickness	Posture Schematic
Head	2	1.5 / 1.6		Thorax and Abdomen	3 – 5	2.15 / 2	
Cervical Spine	1 - 2	1.5 / 1.6		Chest and Shoulder	1 – 2	2 / 2	
Thorax and Abdomen	3 – 5	2.15 / 2		Loaded knee	1 – 2	1.5 / 1.6	
Flexed Knee	1 – 2	1.5 / 1.6					

All upright MRI data are taken in a single session. Breath holding and cardiac gating are not used, as these features are not available on the scanner. Instead, the participants are coached to use shallow, rhythmic breathing during image collection. The total scan time per slab varies from 3 to 6 minutes depending on the number of averages used to acquire the image data. Multiple averages (typically 2) are used to reduce artifact from breathing. Fiduciary markers are used to facilitate registration of adjacent image slabs. For seated scans, the seat back angle is placed at 23 degrees from vertical and the angle of the thigh from horizontal is recorded for consistency between image acquisitions. Seated posture is based on data available in the literature.

Computed Tomography. Computed tomography (CT) scans are acquired from the study subjects using a dedicated research scanner (GE LightSpeed, 16-slice) at Wake Forest University. The minimum slice thickness of this scanner is 0.625 mm. Institutional Review Board approval has been obtained for this portion of the protocol. Efforts have been made with collaborating radiologists to lower the dose resulting from this scanning to the lowest practical level.

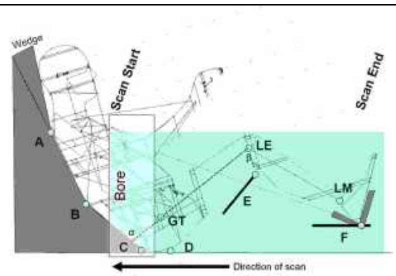
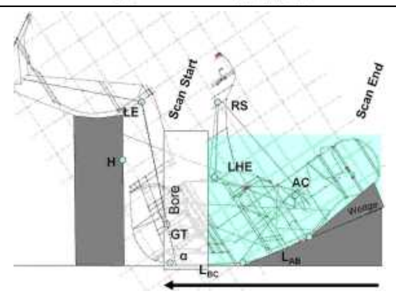
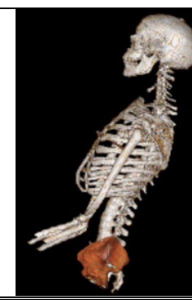
Scans are acquired in two positions, supine and approximately seated. All CT scans are acquired in helical mode. The scanning occurs in three sections; head, thorax through abdomen, and lower extremity. Table 6 summarizes the technical aspects of the supine CT scans. Image acquisition time is less than 40 seconds for all scans. Participants are asked to breath-hold during a portion of thorax and abdominal scanning. The in-plane resolution values provided in the table are based on field of view data that may need to be adjusted based on subject size. Foam supports have been designed and sized for the range of individuals in the study for the supine scans. These foam supports have two functions: (1) to align the participant along the central axis of the scanner, parallel to the bed, which facilitate image slab registration and (2) to keep the subject from moving during scanning.

Table 6. Specifications for supine CT scans.

Body Region Slab	Resolution / Thickness (mm)	Voltage (kV) / Current (mA)	Sketch of Scan Region	Reconstruction from test
Supine, Head / Neck	0.35 / 0.65	120 / 205		
Supine, Chest / Abdomen	0.97 / 1.25	120 / 300		
Supine, Lower Extremity	0.78 / 0.63	120 / 350		

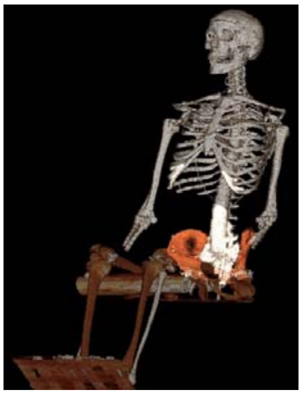
Two additional scans in an approximate seated position are acquired. These scans are outlined in Table 7. These scans use a specially-designed, lexan and wood apparatus to be mounted to the scanning bed. The apparatus positions the participant according to the seated anthropometry guide published by Schneider et al. (1983) The full upper extremity is not captured in these approximately seated scans. Anatomical structures distal to the elbow may be excluded. However, any excluded anatomy is certainly captured in the supine position. Voltage and current is maintained at lower levels to reduce dosage for the seated scans. The fused images sets in the supine position, seated position, and the adjustable seating apparatus are shown in Figure 4.

Table 7. Specifications for seated CT scans.

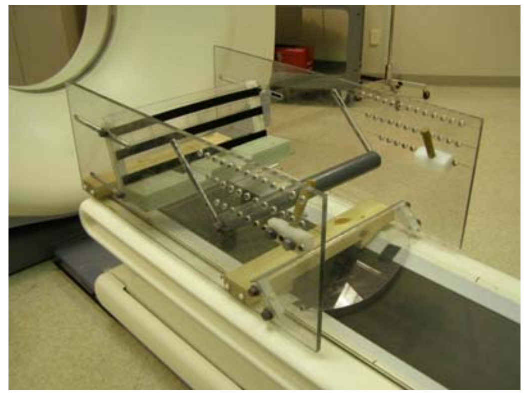
Body Region	Resolution / Thickness (mm)	Voltage (kV) / Current (mA)	Sketch of Scan Region	Reconstruction from test
Lower Extremity and Pelvis	0.98 / 1.25	100 / 250		
Upper Body	0.98 / 1.25	100 / 250		

A.

B.



C.



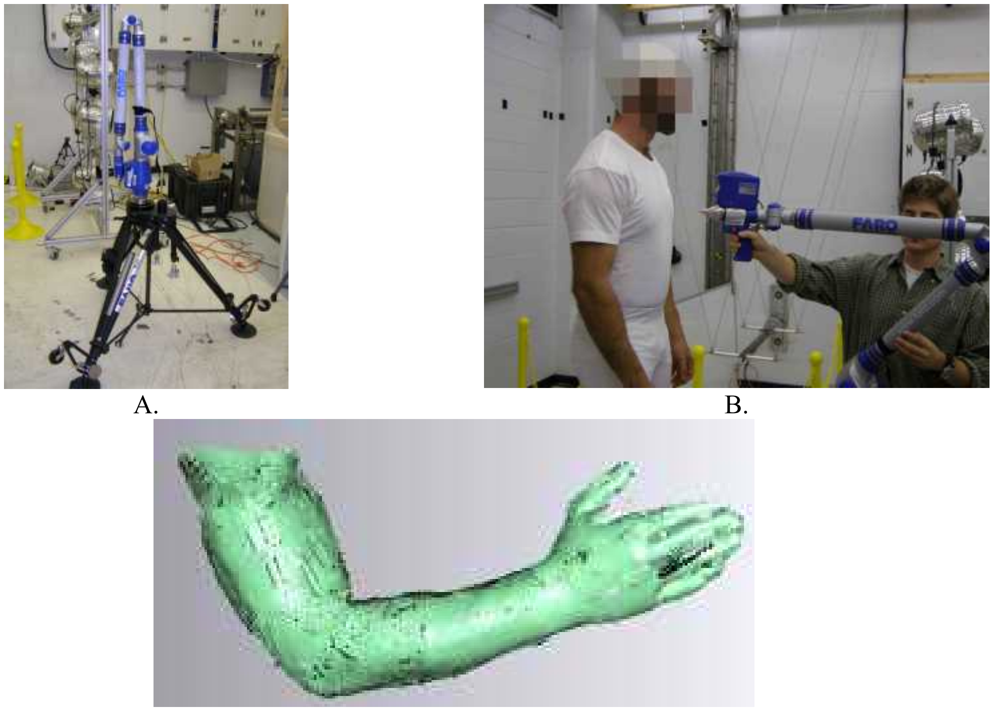
D.

Figure 4: Review of CT results using test phantom. A. co-registered head/neck and thorax slabs, supine; B. co-registered thorax and lower extremity slabs, supine; C. co-registered seated slabs; D. Seating apparatus for lower extremity scan, back support not shown.

External Anthropometry. External anthropometry of the participants is acquired using a Faro Arm, Platinum model, 8 ft. arm (2.4 m). The arm has an accuracy rating of ± 25.4 μ (0.001 in). A laser scanning attachment is used to scan the body surface contours. The attachment has a beam width of 60 mm (2.36”) and an accuracy of 50 μ (0.002”). Landmark data is acquired in 3 dimensional spaces in a standing and seated posture. Standing and seated surface contour data are also acquired.

The external anthropometry protocol was developed in conjunction with collaborators at the University of Michigan Transportation Research Institute (UMTRI). Thirty-four specific external bony landmarks are acquired in each position. Landmarks cover the full body, from the top of the head to the malleolus (ankle). A seat buck design optimized for external anthropometry data collection is used. The seat buck has a split back support so that spinal landmarks can be selected in the seated position, and removable panels to facilitate surface contour scanning. The seat back angle is 23 degrees from vertical and seat pan angle is 14.5 degrees from horizontal.

White, tight fitting clothing is provided to the study participants as our preliminary data has indicated that this type of surface greatly facilitates surface data collection. Based on our preliminary data, it is anticipated that the full set of data from an individual can be acquired in a single coordinate system (i.e. without having to reposition the Faro Arm mount or the participant during data collection). This depends on the size of the subject. If this is not possible, the data sets will be merged using Studio v. 10x software, (Geomagic, Research Triangle Park, NC, USA).



A. B.

C.

Figure 5: External anthropometry protocol. A. Faro Arm with tripod base, B. Scanning test subject, C. Test scan result, raw point cloud data, upper extremity, prior to surface fitting and noise reduction.

DISCUSSION

This paper presents a method for generating a complete image data set for constructing a full-body FEA model for injury prediction and prevention. While data sets for constructing full body FEA models for biomechanical studies of injury currently exist in the literature, this endeavor represents a more complete approach to answering the need for anatomical data. This is accomplished by: (1) recognizing that acquiring data from a single modality is insufficient to accurately develop full body models, (2) acquiring a large amount of anatomical data from both males and females that meet screening criteria for weight, height, anthropometry, and general health prior to scanning, and (3) choosing acquisition protocols that maximize the ability of the corresponding images to be segmented for CAD geometry and FEA meshing.

Each modality used in this protocol provides a unique strength and adds to the overall utility of this data set. As evidenced by Figure 2 and Figure 3, the gradient echo pulse sequence provides scans that are well suited for segmenting soft tissue structures that are involved in frequently-observed crash induced injuries. The detail of these scans is sufficient to segment abdominal organs such as the liver, kidneys, and spleen, including substructures of these such as the medulla of the kidney. The supine scans taken with the closed bore MRI provide a good compliment to the UMRI data of the same region acquired in the subsequent sessions. By using the 8-channel surface coil to acquire images, scan time has been dramatically reduced, allowing for ample image redundancy, assuring that the data set is adequate to reconstruct the desired anatomy, and allowing for images to be acquired in multiple planes (i.e., axial vs. coronal).

The UMRI scanning is a useful addition to the tools available for model construction. To the authors knowledge there is currently no UMRI dataset available in the literature that covers both males and females in a seated and standing posture. This data will enable those involved with the model development to quantify the morphological changes and location changes of the abdominal organs due to changes in posture. In addition, scan data of the knee at 65^{o} of flexion and under load are acquired. These types of scans are not possible to acquire using a closed-bore MRI scanner.

CT provides the highest resolution and the data will be used primarily to segment the bony structures of the body. In addition to the supine scanning, a novel, approximately seated posture scan is part of this protocol. This scan is the result of a fusion of two image acquisitions, one of the lower extremity and one of the upper body. This later image set is unique in its ability to capture joint articulations and locations in the seated posture. While there is a limitation in the orientation of the upper body for the seated scan, since it is not truly opposed to the direction of gravity, the preliminary data indicate that the scans are of value nonetheless. The diameter of the bore on this CT model (72 cm; 28 in) prevents imaging in a true seated posture.

The external anthropometry is the final component of the study. This data will serve as an important check for when the models are assembled and positioned for either the seated or pedestrian posture. The assembled computational models can be validated against direct 3D measurements of the participants taken during this session.

CONCLUSIONS

A method to scan participants in multiple modalities has been presented and is currently underway in the Center for Injury Biomechanics at Wake Forest University. Four volunteers, extensively pre-screened to match target populations of the 5^{th} and 50^{th} female, and 50^{th} and 95^{th} male have been selected. The data collection process described in this paper will yield an extensive image data set for use in a consolidated effort to develop the next generation of FEA models for the biomechanics community.

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DISCUSSION

PAPER: **A Multi-Modality Image Data Collection Protocol for Full Body Finite Element Model Development**

PRESENTER: ***Scott Gayzik, Virginia Tech – Wake Forest University Center for Injury Biomechanics, Wake Forest University School of Medicine***

QUESTION: *Costin Untaroiu, University of Virginia*
Nice presentation. I saw it also yesterday, but I forgot to ask you something from yesterday. For a pedestrian, you will take CTs in an upright position or in mid-stance?

ANSWER: Upright position. We looked a little bit with our collaborators at the University about how to best position for the upright scans, but ultimately what we decided was to just take it in a relaxed position with feet side-by-side.

Q: Because all validation is in mid-stance position.

A: Yes.

Q: So we'll have this problem again.

Q: *Erik Takhounts, NHTSA*
I just want to make sure you don't ask questions from yesterday or from a year ago because not everyone knows what happened yesterday. You can ask this question in private. I'm sorry, Costin. That's kind of not fair to everyone else.

Q: *Guy Nusholtz, Chrysler*
I'll ask a question from today. [laughter] How are you going to average the data for the different anatomical structures? We had a presentation earlier today with regard to the difficulties of averaging values in just one dimension. You're going to try and average them in three dimensions.

A: I don't know that we'll be actually averaging any of this data. The purpose of this study, given the constraints and given what our goal is for this particular research, [is that] we are trying, at the outset, [to] identify individuals who will be seen as the percentile and the individual that we are after. And so, that host of data that we're going to collect we're taking as representative of, say, the 50th percentile male. His data would be basically contained within that scope. And in terms of averaging, there will be no average of sort of scaling these organs to a particular size or shape. That's sort of beyond the scope of our study at this point.

Q: Are you going to try and end up with one anatomical value for the whole human body or are you--?

A: Well, the process here—I guess this sort of alludes to what's going on with this data set after we're done collecting it. The next step is to segment, which is to basically identify key anatomy that will be included in the model from these medical images. And so, once, for example, we segment the liver, for example, that would be the size, the shape, the morphology that the liver of the actual FEA model that is ultimately created—that would be the basis for that structure.

Q: But in order to do that, you have to somehow take your images and map those into the anatomical FEA model that you're doing and you're going to have to make, then, some sort of either subjective or objective estimate of what the actual shape is.

A: To some extent I agree with you, but I think that the resolution of these images that we're acquiring is adequate to actually capture that shape. Now, there are considerations, of course, with element size, for example. We are going to discortize these objects, and certainly each element will be much larger than a single pixel. And so, we'll give up some of the external contours of those. The design of the project is to develop CAD geometry that can be directly meshed. Now, I agree that there will be some morphological changes to that structure simply but virtue of meshing it, but that process is fairly well developed in terms of going from something that's been segmented from a medical image to then something that's been meshed.

Q: That's if you have only one image, but the assumption you're making is, say, all livers are exactly the same shape and size.

A: This gets to some very interesting points about the research and I'd like to talk with you after, but I don't know that we'll be able to come to a consensus at this point. There are some limitations involved with how we're going about doing this model in Phase 1 of the research.

Q: Okay, then I'll turn it over to the next dude.

Q: *Rolf Eppinger, NHTSA Retired*
I thought I heard you say you're going to do 50th and 95th sizes.

A: Well, 5th female, 50th female, 50th male, 95th male.

Q: Now that says you're only having four individual sizes. I was wondering why that is the best strategy if you have to make four surrogates to represent the entire population, why if you had done some research to pick out which combination of size and weight would be most optimal and lowest number of different designs. I could imagine if I wanted to have—Right now, we have 5th, 50th, and 95th; but if I would limit myself to only two sized dummies, it might be 35% and 65%. Or if I want to allow myself a few more samples of the population, I could have three samples or four samples height and weight and a combination of that. And, I was wondering what strategy you have to pick out what size and weight of each of these subjects that you will want to have the dummy represent.

A: Well, the strategy for developing the size and weight was based on the height and weight data that went into the design of the Hybrid III dummy. The idea is that these models that we create would correlate to those in terms of size. Now I agree with you that it would be an excellent idea, especially within the computational world, to develop a model that is scalable. We certainly have that freedom when we're talking about computational model development. But in Phase I of the project, because the idea here is to develop models that can be correlated to the results of current dummies, this strategy was chosen as the strategy to move forward with the development of these models.

Q: So you want to build on somebody else's potential mistakes while you're developing this new data set. [laughter] I was wondering if you'd step back one time and just reflect on that. If you had—If you wanted to build four representative test dummies that best fit the entire population, would you come to the same answer as if you had two or three?

A: I think it's an excellent point. When developing these models, we consulted Enhanes data and tried to use existing as was appropriate to fit our target population. Certainly, [it's] something to consider, but this is the way that the project has been sort of started out at this point. And given the timeframe that we have in terms of recruiting and selecting, it's really not feasible to expand our target population at this point. But, I do agree with you that it is an interesting take on how to solve the problem; but it sort of—Ultimately when you're looking at developing one of these data sets, there are so many considerations, in terms of how many will we recruit, that with the help of our research sponsors, this was determined to be the best way to proceed.

Q: Alright. Thank you.

Q: *Erik Takhounts, NHTSA*
Glad to see your brain is still working, Rolf [laughter] Picked up on one of the most probably controversial questions. I think Guy was saying the same thing, but thanks, Scott.