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The Development of CAD Data for Full Body Finite Element Models: A Multi-Modality Approach

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ABSTRACT

This study describes progress in developing full body CAD data of the 50th percentile male. The data will ultimately be used as the foundation of a new full body FEA model currently in development throughout the injury biomechanics community. Current development efforts are focused on the seated occupant model. A range of imaging and data collection tools were used to compile a large dataset for this modeling effort. A male volunteer (26 y, 78.6 kg, 174.9 cm) was selected to be enrolled in the study after careful screening. The volunteer met strict inclusion criteria based on height, weight, body length segments, and medical history. The volunteer was prospectively scanned and image data was collected in both supine and seated postures.

Progress in the CAD development of the model is presented. We have adopted a number of unique approaches in the development of this geometrical data. These approaches were made possible by the data collection protocol. The data collected include: MRI in the supine and upright postures, CT in the supine and approximately seated postures, landmark data at externally palpable locations, and external body contours collected via a 7-axis digitizer. Upright MRI image data, in conjunction with the digitized external bony landmark locations allowed for accurate reconstruction of the skeletal geometry. For modeling internal organs of the thorax and abdomen, a compartmentalization approach was adopted. In this approach, body regions such as the mediastinum and abdominal cavity (including peritoneal and retroperitoneal spaces) were separately segmented in the upright MRI scan data. These spaces provided a framework in which organ segmentations from higher-resolution supine scans could be placed, thereby utilizing the strengths of both imaging modalities. While the individual enrolled in the study will be used as the foundation of the model, some deviations from the segmented scan data were necessary to achieve agreement with published literature where larger samples sizes were studied.

The most recent developments in applying the above approach to CAD development are presented. The model currently shows good agreement with the published literature where comparisons have been conducted.

INTRODUCTION

The use of computational human body models continues to grow in the study of injury biomechanics. (Yang, Hu et al. 2006). Models are also a cost-effective means of evaluating safety system designs in numerous areas, including vehicular and military environments. These models extend the tools investigators have to study the mechanisms of traumatic injury. Developers have relied on a variety of sources to describe human anatomy for such models over the years. One such means is external anthropometry measurements, which has been studied for the development of human surrogates, both physical and virtual. (Robbins 1983; Schneider, Robbins et al. 1983; Gordon, Churchill et al. 1989; Cheng, Obergefell et al. 1994) More recently, datasets for model development are commonly based on modern medical imaging data, as they contain high-accuracy three-dimensional representations of the human anatomy.

In the current work, we present a novel approach to CAD model development based on a single living subject, scanned in multiple modalities and postures. Given the amount of data that is required for model reconstruction, it is clear that there is not one single imaging modality that will provide all the necessary data to develop Full Body Models (FBMs). It is also clear that literature data, much of which is based on cadaveric specimens, plays a critical role in validating and supplementing data derived from imaging techniques.

We describe protocols for a multi-modality approach that employs imaging techniques such as MRI and CT, as well as methods for external anthropometry data collection. We also aimed to improve upon previous model development efforts by acquiring and using scans wherein the participant is seated upright, in the correct orientation with gravity. In validating our findings, it was noted that data on the morphology of many internal organs (volume, diameters, etc.) is available but is scattered across the open literature. Therefore the work will also serve to consolidate much of this information relative to the 50th male FBM (M50) model development.

The objectives of this work are twofold. The first is to present the methods used in the development of a full body CAD model that represents the average male vehicle occupant. We review the methods for recruitment, image acquisition, and scanning protocols that form the basis of the model development. We also provide detail on the methods used in segmentation and CAD development. The second objective is to present information on the resulting CAD data, including the physical dimensions of the model (i.e., volumes). For selected components, we examine how these compare to the published literature.

METHODS

Subject Recruitment

A single subject was recruited for this study, further details can be found in a previous work. (Gayzik, Hamilton et al. 2009) The subject selection and imaging protocol was approved by the Wake Forest University School of Medicine Institutional Review Board (IRB, #5705). A targeted weight and height requirement was used to narrow the applicant pool. We sought a single participant 175 cm tall, weighing 77 kg. These height and weight targets were selected from previous anthropometric studies of U.S. males. (Schneider, Robbins et al. 1983) These values were also used in the design of commonly used crash test dummies. (Mertz 1993) A tolerance of ± 2.5 cm on height and 5% on weight was permitted. A more focused review of applicants followed for the preliminary applicants. Exclusion criteria included claustrophobia, physical or orthopedic impediments, diagnosis of osteopenia, prior surgery, abnormal gross anatomy, and MRI risk factors. Fifteen anthropometric measurements were acquired from prospective participants. (Gordon, Churchill et al. 1989; Gayzik, Hamilton et al. 2009)

Review of Imaging Modalities

A review of the strengths of each imaging modality used can be found in Table 1. The individual underwent the entire imaging protocol described here (Figure 1A-D). (Gayzik, Hamilton et al. 2009) MRI image data with the participant in the supine position was collected on a 1.5 Tesla Twin Speed MRI scanner (GE, Milwaukee, WI). A three dimensional Fast Spoiled Gradient Recalled pulse sequence was used. TE and TR were selected such that the fat and water signals were out of phase. This resulted in a darkened outline around viscera and muscles that aided segmentation of these structures. Breath-held scans were acquired in the chest and abdomen so acquisition time for these was short (~ 30 sec.). All other scans were non-breath held.

Table 1. Review of imaging modalities, showing advantages, and resolution of images taken for this study.

Modality	**Advantage**
Closed Bore Magnetic Resonance Imaging (MRI)	High resolution, pulse sequence specialization, 0.5 – 1 mm in plane resolution, 1 – 2 mm slice thickness
Upright MRI	Standing and seated postures, pulse sequence specialization, 1.4 – 2 mm, in plane 1.5 – 2 mm slice thickness
Computed Tomography (CT)	Highest resolution, fast image acquisition time, 0.5 – 1 mm in plane resolution, 0.63 slice thickness
External Anthropometry	Direct measurement of body landmarks, external contours of the seated occupant, 7 Axis digitizer, < 1 mm resolution

MRI. The field of view (FOV) varied between 200 and 480 mm depending on the anatomy being imaged. An 8 channel phased-array body coil was used to collect the majority of data. An 8 channel neurovascular coil was used to collect data from the head and neck. Images were predominantly acquired in the transverse plane, although coronal images of selected anatomy were acquired in the head and abdomen. All images were reformatted to a matrix size of 512 x 512 prior to segmentation. The slice thickness at acquisition varied between 2 to 4 mm, and was interpolated via the GE platform software.

Upright MRI. The upright MRI protocol utilized a Fonar Upright MRI (Fonar Inc., Melville, NY). Three dimensional gradient echo pulse sequences similar to supine MRI were used. Matrix size of a typical axial skeleton acquisition was 200 x 200 pixels. The field of view varied between 320 and 470 mm depending on the anatomy. A quadrature head coil and a set of spine and body coils provided by the manufacturer were used to acquire the images. The slice thickness at acquisition varied between 1.6 to 2 mm. Images were acquired in both the seated (head, neck, thorax, abdomen, flexed knee) and standing (shoulder, thorax, abdomen, load bearing knee) positions. The seat back angle was set to 23^{o} for the seated scans.

CT. CT scans were acquired using a GE LightSpeed, 16-slice scanner. Images were acquired in helical mode, with the subject in the supine and an approximately seated position. Scanning parameters were set to allow for the lowest practical dose. The approximately seated position was accomplished in two scans to accommodate the posture within the restrictive bore size of 72 cm. These scans were accomplished by essentially rotating the seated position so that head / torso, and lower extremity scans could be acquired that replicated the seated position as closely as possible. (Gayzik, Hamilton et al. 2009) Specialized inserts were developed that enabled the posture of the seated scan to be maintained during these scans. The field of view of the CT images ranged from 250 to 500 mm depending on the anatomy being scanned, and the matrix size was 512 x 512 pixels. Slice thickness of images used in segmentation efforts ranged from 0.65 mm to 1.25 mm.

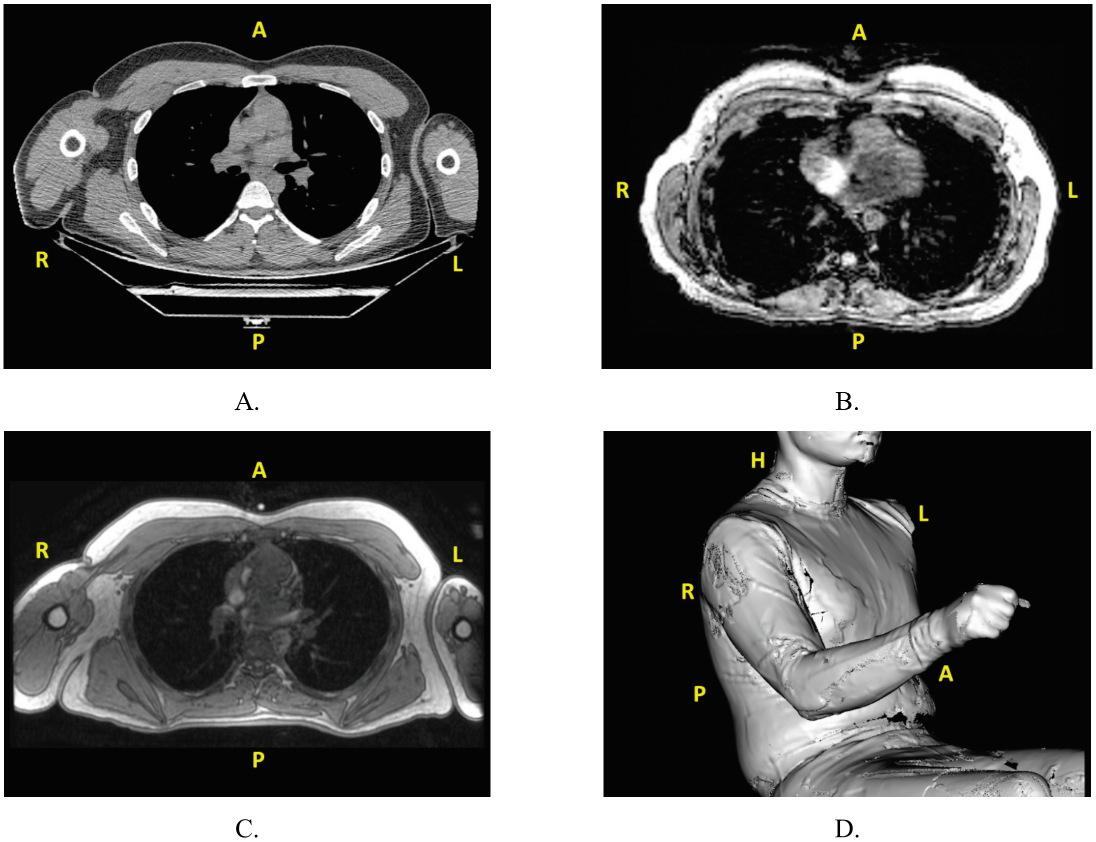

Figure 1. Overview of data collected for full body CAD development, showing examples of thorax data. A. CT, supine, arms at sides B. Upright MRI, C. MRI, supine, arms at sides, D. External body laser scan in seat buck (raw point data).

Combining Images Slabs. All images were reviewed by a faculty radiologist at Wake Forest University Baptist Medical Center prior to use. In many cases it was advantageous to merge and align two or more adjacent image slabs into a single continuous slab. This procedure facilitated subsequent segmentation as well as assembly efforts. Adjacent image slabs were combined using Amira image analysis software (v. 5.2, Visage Imaging, Andover, MA). Images were roughly aligned along the axis normal to the transverse slices. Fiducial landmarks and neighboring anatomy were adequate to align the datasets. A Lanczos interpolation algorithm was then used to merge the image sets using redundant image data at the ends of each. The result of this process was a single set of images representing the sum of two or more slabs.

Merged and aligned image sets were used in segmentation for all body regions. Of particular utility was a combination of slabs from the upright MRI scans, with the participant in the seated position. In this set, six slabs of transverse images depicting the neck, thorax, abdomen, and pelvis were combined and used as a framework for model development in the seated posture.

External Anthropometry. Model construction relied on external anthropometry data collected from the participant (Figure 2). Data were collected with a 7-axis 3D digitizer (Faro, Platinum Model arm, Lake Mary, FL). We collected data from the subject in the seated position using a custom seat buck. Seat buck parameters such as wheel to ball of foot distance, and steering wheel height, were adjusted to meet seating accommodation models from previous studies. (Flannagan, Manary et al. 1998) Seat back and pan angles were 23^{o} from vertical and 14.5^{o} from horizontal respectively (Manary, Flannagan et al. 1999). Fifty-six landmark locations (22 left, 22 right, 12 along the mid-sagittal plane) were identified through palpation. (Reed, Manary et al. 1999) These landmarks captured the posture of the subject in each body region. The SAE J1733 sign convention for vehicle crash testing coordinate system was determined relative to the seat buck and formed the basis of the model coordinate system. (SAE 1994) A laser attachment was used to record the complete body shape of the M50 subject in the seat buck (Figure 1D).

The buck features removable back panels and seat pans that could be dropped away from their docked positions. Design of the seat buck was developed through collaborations with the University of Michigan Transportation Research Institute (UMTRI). Removing one panel at a time, we used the laser scanning attachment of the 3D digitizer to record un-deformed body contour data of the back, buttocks, and posterior thigh.

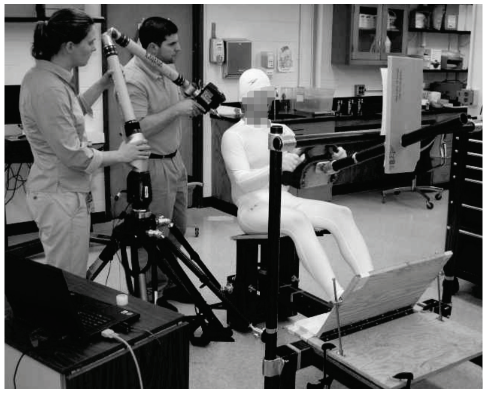

Figure 2. Custom seat buck external anthropometry data acquisition of the M50 subject. The rear right back panel has been removed.

General CAD Development Workflow

A schematic of the overall model development process is shown in Figure 3. Image segmentation was the beginning of the process. In the next phase, three dimensional polygon data extracted from image segmentations were conditioned to remove artifacts, and to verify against literature data. The assembly phase involved repositioning segmented and conditioned models to align with scans taken in an upright and seated posture. Finally, mathematical CAD surfaces composed of Non-Uniform Rational B-Splines (NURBS) were overlaid onto the polygon data. We returned to the polygon data as necessary to remove overlapping or penetrating structures noted in the assembly.

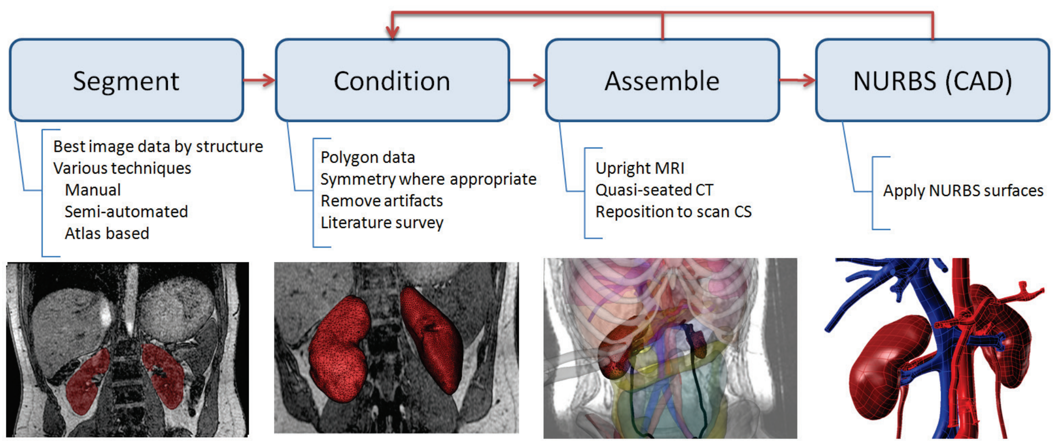

Figure 3. Model development phases for full body CAD.

Bone CAD Development and Assembly. Bone segmentation began by selecting pixels exceeding 226 HU. Bones with small articular spaces (such as cervical and thoracic vertebra) were manually separated. Standard segmentation operations such as region growing, morphological operations, and multi-slice linear interpolation were used. For the majority of bones only the periosteal surface was of interest to the modeling effort. For others, the endosteal bone surface was required. In these cases, one of two approaches was used. The first was used for bones with relatively uniform thickness, such as the sacrum. In these cases a uniform offset of the exterior surface inward with the specified thickness was applied. The second approach was used for bones that demonstrated large variation in cortical thickness. Many of these were long bones. For these, segmentation data was used for diaphyseal portions of the bone. Literature data was used to supplement the segmentation data at the epiphyseal ends of the bone. In these regions, the cortical segmentation was too thin to accurately reconstruct it from the scan data.

Bones were assembled by relocating each from the CT image set to the model coordinate system. As previously mentioned, the final model coordinate system was derived from the external anthropometry seat buck. Bone locations were validated against the landmark locations acquired from the external anthropometry portion of the study. Joint placement was also verified with image data where possible, such as the use of the flexed knee MRI scan.

Soft Tissue CAD Development and Assembly. Supine MRI data was used to segment all organs. The majority of organ segmentation was conducted manually using standard techniques, including dynamic region growing, multi-slice editing, and morphological operations. One notable exception to this was the white matter of the brain, which was segmented using statistical parametric mapping software (SPM5, Functional Imaging Laboratory, University College London). The mask was verified against the images and manually edited where needed.

After initial segmentation in supine MRI, 3D polygon models were transformed to align with seated upright MRI scan data. This type of positioned data was used throughout the body. Within the head, this data was used to match the distribution of Cerebrospinal Fluid (CSF) between the inner table of the skull and the cortex of the brain.

For the major organs in the thorax and abdomen, we adopted a compartmentalization approach for assembly. The mediastinum and abdominal cavity (peritoneum, retroperitoneum, and perineum) were segmented in the upright scan (Figure 4). In many cases, the resolution of the upright scan did not provide as accurate a segmentation of the structures of interest as the supine scan, so detailed segmentations from the latter were imported into the upright scan coordinate system and positioned to the location of the same organ in the upright scan. We refer to this scheme as a compartmentalization approach since the working envelope or compartment was defined by the upright scan data. The compartment was used as the framework to employ segmentations from the supine datasets.

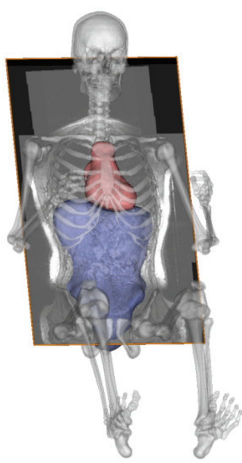

Figure 4. Compartmentalization approach showing skeleton and major cavities used in CAD assembly (mediastinum, red, abdominal, blue). Objects are overlaid on the coronal plane of the image stack.

Muscle Modeling. Muscles germane to the intended use of the model were segmented. In each body region, muscles were directly segmented from the supine MRI image data using techniques described above (dynamic region growing, multi-slice editing, and morphological operations). The selected pulse sequence which yielded images with fat and water out of phase proved well-suited for segmenting large muscle groups since a clear outline was visible in most cases (Figure 5).

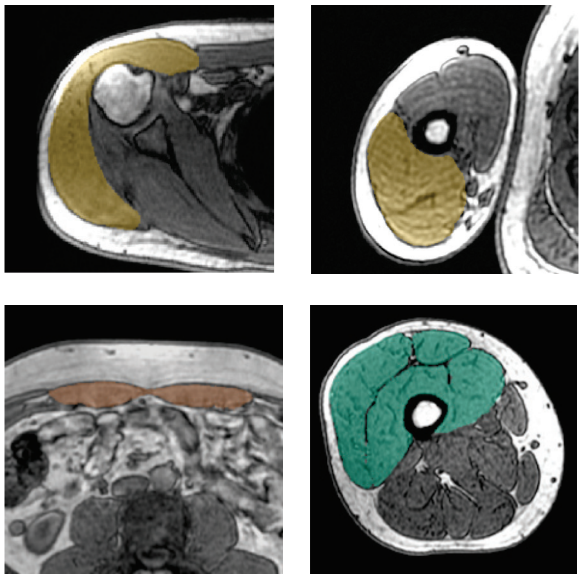

Figure 5. Examples of muscle segmentation, clockwise from top left; deltoid, triceps brachii, quadriceps femoris and rectus abdominis.

RESULTS

The selected individual was a 26 year old male. His height, weight, and BMI were 174.9 cm, 78.6 ± 0.77 kg, and 25.7 respectively. He showed an average deviation of 3% from the 15 external anthropomorphic measurements used as selection criteria. The subject passed all exclusion criteria, had a clean medical history, and was generally in excellent health. With regards to the external anthropometry measurements, left and mirrored right side landmarks showed good agreement with an average residual distance of 2.7 mm. The subject was deemed to have typical anatomy, exhibiting no major anatomical abnormality, or major pathologic condition by our collaborating radiologists.

While model development is still in progress, a limited set of results are presented in this work. Selected abdominal organ volumes from the M50 model vs. literature values, as well as images of the CAD assembly are shown in Figure 6. The final model comprises the necessary elements for biomechanical modeling efforts of the mid-sized male in the seated position. There are 410 individual components of the FBM. There are 179 individual bones, 46 organs and components thereof, 96 muscles, 37 vessels and 46 ligaments, tendons and other cartilaginous structures. The model is sagittally symmetric.

Selected Abdominal Organ Volume vs. Literature. The liver, kidney, pancreas and spleen volumes from the M50 model were compared against literature values. The results of this comparison are shown in Figure 6. In each case, horizontal lines represent values determined through segmentation. In these graphs, data sets that used only male participants are also noted.

State of CAD Development. At the present time, we have applied the methods described herein to the development of much of the M50 seated model. Figure 7 shows the state of the current model development, in polygon phase (block 3 of 4 in Figure 3). The brain model is being developed with separately segmented gray matter. The model includes major thoracic and abdominal viscera (heart, lungs, great vessels, diaphragm, liver, stomach, pancreas, spleen, kidneys, colon, and bladder). Musculature currently includes neck muscles (26 total), deltoid, biceps, triceps, and pectoralis major in the thorax. In the abdomen we are currently developing the rectus abdominis, obliques, iliacus and psoas muscles. In the lower extremity we are targeting the gluteus maximus, quadriceps femoris, soleus, and gastrocnemius. Once complete, the model will contain 48 muscles on each side of the sagittal midplane.

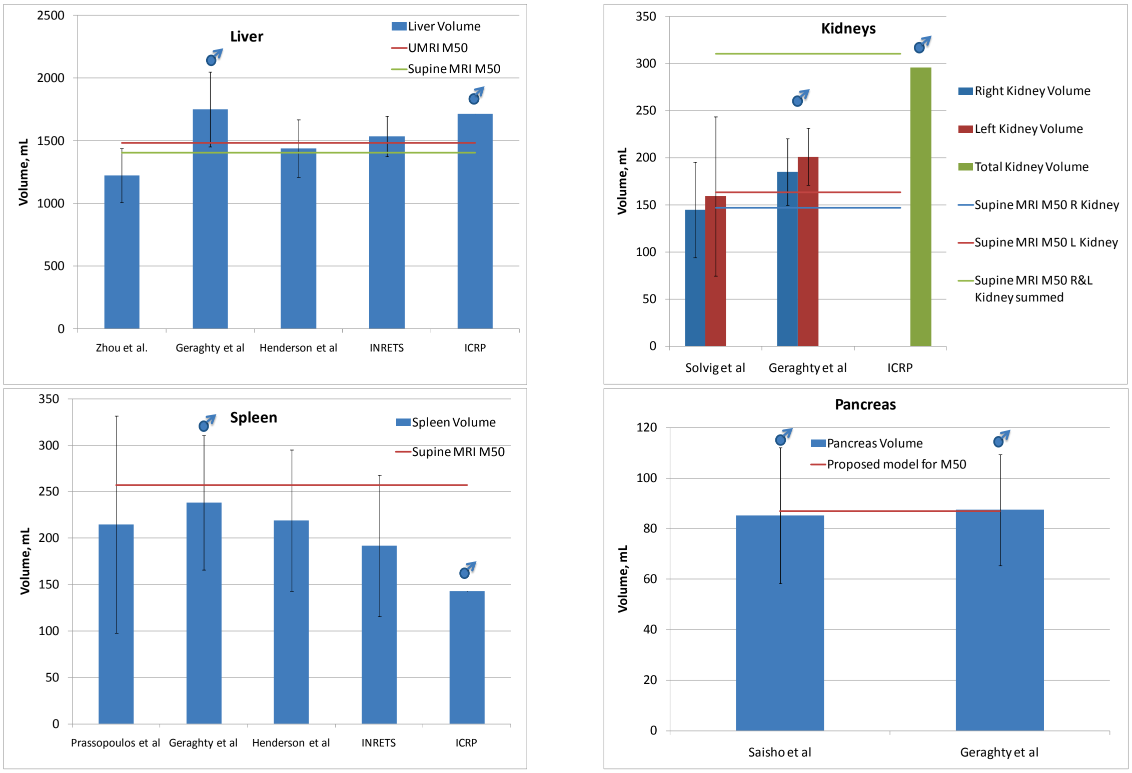

Figure 6. Selected abdominal organ volumes vs. literature.

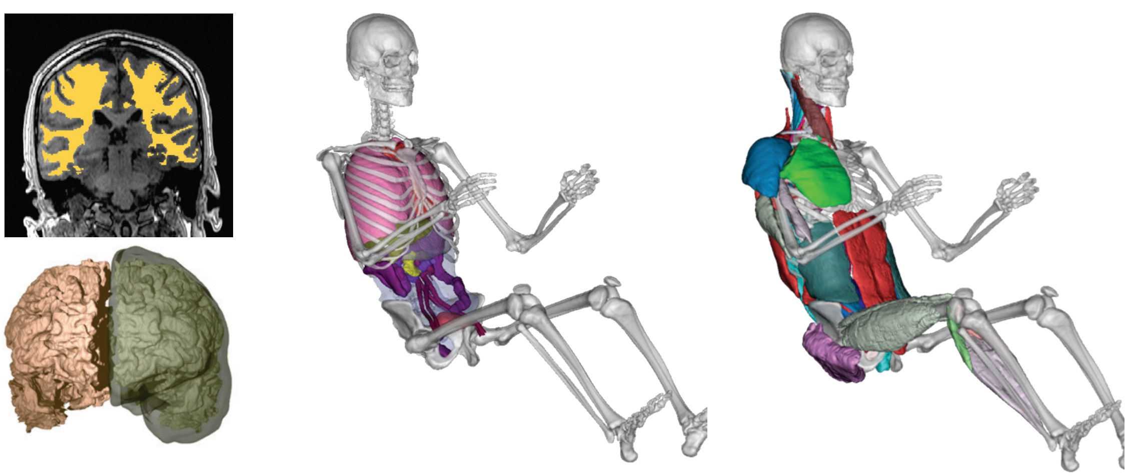

Figure 7. Current stages of model development. Left to right; brain polygon models, thoracic and abdominal viscera polygon models, and musculature polygon models.

DISCUSSION

This paper reviews the development of a full body CAD model of the 50th percentile male in the seated posture. We have presented our methods and the development procedures for this model, from subject selection, to image acquisition, to CAD development.

There are a number of datasets in the published literature that are frequently used in the development of FEA models (Figure 8). Many of these datasets are based on cadaveric data. Perhaps the most well-known of these datasets is the Visible Human Male (VHM). (Spitzer, Ackerman et al. 1996) While it is a landmark dataset, there are some drawbacks to using VHM in the development of mid-sized FBMs. The subject was quite large, (90 kg, 180 cm) which requires CAD data derived from this set to be scaled downward to the population of interest. VHM data is also derived from scans of a formalin-perfused cadaver. Finally, VHM images were collected solely in the supine position. Since occupant models are designed in the upright seated position, this provides an extra challenge for model developers in translating the data. Nonetheless, the VHM dataset is extremely valuable and has been used in countless ways, including the development of a number of well-known FEA models. (Lee and Yang 2001; Ruan, El-Jawahri et al. 2003; Ruan, El-Jawahri et al. 2005)

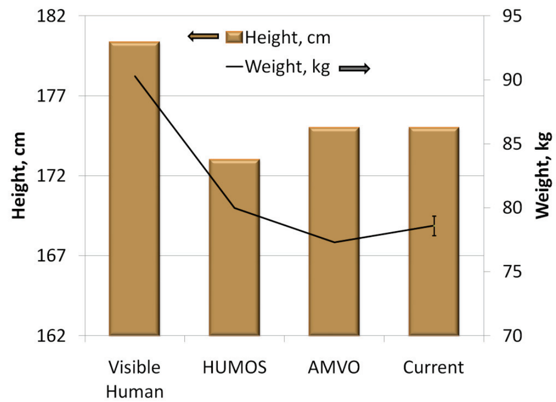

Figure 8. Height and weight for current model vs. other studies used in injury biomechanics research.

Recent FBMs demonstrate that imaging techniques are not the only method for development. The full body FEA model resulting from the Human Model for Safety (HUMOS) project was generated from a male cadaver frozen and sectioned in the driving position. (Robin 2001) 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. While the data was collected in the seated position, medical images of this individual were not acquired prior to sectioning, complicating the reconstruction task. Yet another set of data commonly used by the modeling community was generated by ViewPoint Datalabs / Digimation, (St. Rose, LA, USA). In the case of the bones, these models were digitally recorded from cadaveric specimens. This dataset also utilized the VHM dataset and has been used in past modeling efforts. (Seki and Iwamoto 1998)

We believe that there are a number of advantages to the approach we have chosen for this study. Nearly all bony data and soft tissue data in the M50 model was derived from scans of a living subject who was thoroughly screened prior to acceptance into the study. The subject met a large set of criteria ranging from his anthropometry to MRI compliance. With a height and weight of 78.6 kg and 175 cm, the subject was a close match of the 50th percentile male of the U.S. population. In addition, this individual closely matched existing standards for mid-sized male crash test dummies. This is important since the principal use of the CAD data presented in this work will be the development of FEA models for injury prediction in vehicle crash simulations. Proper selection of this individual also eliminated the need to scale the CAD data.

The image set used here is distinct from others that have been used in FBM development. Many of these sets contain data from individuals of an advanced age, or of a dramatically different size than the mid-sized male. None are in the upright position during the scanning process. While the study involved a single individual, we have made efforts to ensure that the components of the M50 model agree with broader studies within the literature.

Upright MRI data was critical for the assembly process. The data was acquired with the participant seated position, with the head in the Frankfort plane. While the scan quality did not match the closed-bore MRI due to the reduced field strength of this scanner (0.6 T vs. 1.5 T), the data proved valuable nonetheless in positioning. This was particularly true of soft tissues. These scans were used more closely represent the CSF layer within the skull when the subject is seated in the upright position. Furthermore, the image slabs of the upright MRI provided excellent guidance for the placement of abdominal contents (Figure 4).

CONCLUSIONS

We have presented work in progress on a novel set of CAD data that describes the mid-sized male occupant in the seated position. The model is being developed for subsequent use in computational models aimed at predicting commonly encountered traumatic injuries in vehicle crash environments. The CAD model was developed from an individual that was scanned in multiple image modalities and postures. The M50 CAD data was derived from a carefully selected average male subject, and with verification from the literature, the morphologic data contained in this work can be used as an average male reference. The approach is generalized and can be applied to individuals of various anthropometries of interest to the injury biomechanics community.

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REFERENCES

CHENG, H., OBERGEFELL, L., RIZER, A. (1994). *Generator of Body Data (GEBOD), Manual*. DOD Air Force Material Command, Systems Research Labs Inc. 74 pages.

FLANNAGAN, C., MANARY, M., SCHNEIDER, L.W., REED, M.P. (1998). An Improved Seating Accommodation Model with Application to Different User Populations. SAE International Conference and Exposition. Detroit, MI.

GAYZIK, F., HAMILTON, C., TAN, J.C., McNALLY, C., DUMA, S.M., KLINICH, K.D., STITZEL, J.D. (2009). Multi-Modality Image Data Collection Protocol for Full Body Finite Element Model Development. SAE Digital Human Modeling. Gothenburg, Sweden, SAE.

GORDON, C., CHURCHILL, T., CLAUSER, C.E., BRADTMILLER, B, MCCONVILLE, J.T., TEBBETS, I.L., and WALKER, R.A. (1989). 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics. Prepared for United States Army Natick Research, Development and Engineering Center. Natick/TR-89/044.

LEE, J. B. and YANG, K.H. (2001). Development of a finite element model of the human abdomen. Stapp Car Crash J 45: 79-100.

MANARY, M., FLANNAGAN, C., REED, M.P., SCHNEIDER, L.W. (1999). Human Subject Testing in Support of ASPECT. SAE International Congress and Exposition. March 1 – 4, Detroit, MI.

MERTZ, H. (1993). *Anthropomorphic Test Devices. Accidental Injury, Biomechanics and Prevention*. A. Nahum and J. Melvin. New York, Springer-Verlag.

REED, M. P., MANARY, M.A., SCHNEIDER, L.W. (1999). Methods for Measuring and Representing Automobile Occupant Posture. SAE International Congress and Exposition. March 1 – 4, Detroit, MI. SAE Paper 1999-01-0959.

ROBBINS, D. H. (1983). *Anthropometric specifications for mid-sized male dummy*. University of Michigan Transportation Research Institute. United States Dept. of Transportation, NHTSA, Vol 2: 134 pages.

ROBIN, S. (2001). Human Model for Safety – A joint effort towards the development of redefined human-like car-occupant models. 17th International Conference for the Enhanced Safety of Vehicles. Amsterdam.

RUAN, J., EL-JAWAHRI, R., CHAI, L., BARBAT, S., PRASAD, P. (2003). Prediction and analysis of human thoracic impact responses and injuries in cadaver impacts using a full human body finite element model. Stapp Car Crash J 47: 299-321.

RUAN, J. S., EL-JAWAHRI, R., BARBAT, S., PRASAD, P. (2005). Biomechanical Analysis of Human Abdominal Impact Responses and Injuries through Finite Element Simulations of a Full Human Body Model. Stapp Car Crash J 49: 343-66.

SAE (1994) *Sign Convention for Vehicle Crash Testing – SAE J1733*. Report of the Dummy Testing Equipment Subcommittee of the Biomechanics and Simulation Standards Committee Volume 34, pp. 551-575.

SCHNEIDER, L.W., ROBBINS, D.H., PFLUG, M.A., SNYDER, R.G. (1983). *Development of anthropometrically based design specifications for an advanced adult anthropometric dummy family*. University of Michigan Transportation Research Institute. United States Dept. of Transportation, NHTSA, Vol 1.

SEKI, S. and IWAMOTO. H. (1998). Disruptive forces for swine heart, liver, and spleen: their breaking stresses. J Trauma 45(6): 1079-83.

SPITZER, V., ACKERMAN, M., SCHERZINGER, A.L., WHITLOCK, D. (1996). The Visible Human Male: A Technical Report. JAMIA 3: 118-130.

YANG, K. H., HU, J., WHITE, N.A., KING, A.I., CHOU, C.C., PRASAD, P. (2006). Development of numerical models for injury biomechanics research: a review of 50 years of publications in the Stapp Car Crash Conference. Stapp Car Crash J 50: 429-90.