Development of Three-Dimensional Anthropometry Methods for Patients with High Body Mass Index

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Patient handling equipment and related medical devices, such as hospital beds, slings, and patient transfer devices, must accommodate a diverse patient population while ensuring safety and comfort. Approximately 72 million U.S. adults, 34% of the adult population, are currently obese with a body mass index (BMI) greater than or equal to 30 kg/m^2. Detailed body size and shape data in functionally relevant postures are needed for this population to guide product design, but few individuals with high BMI have been measured in the postures of interest. This paper reports the development of methods to address the challenges of obtaining accurate and repeatable 3D anthropometry data for this population.

INTRODUCTION

Approximately 72 million adults, 34% of the US adult population, have a body mass index (BMI) greater than or equal to 30 kg/m^2 (Flegal et al. 2010), which the U.S. Centers for Disease Control and Prevention defines as the threshold for obesity. Additionally, the morbidly obese population, with a BMI greater than 40 kg/m^2, has increased from 3.9% to 6.6% of the US population from 2000-2010 (Sturm and Hattori, 2012). Increased patient size can complicate even the most basic medical interventions, as can the lack of proper equipment to lift and move the patient (Kumpar, 2014). Health care providers use assistive medical devices with these patients to ensure their own safety as well the patient's safety, comfort, and dignity. However, little data has been published on the physical attributes of people with high BMI or bariatric patients. This lack of knowledge is a constraint in the design of patient handling equipment (e.g. patient transfer devices, slings, lift assists), bariatric furniture (e.g. hospital beds, chairs, commode, wheelchairs), and emergency response equipment (e.g. stretchers).

Recent research has emphasized the consideration of ergonomics in the design of medical devices to improve safety and health for healthcare workers (Martin et al., 2008). A few studies have examined design factors of friction-reducing re-positioning devices and hospital beds (i.e., dimension, weight, wheel arrangement, and powered drives), and determined that such design factors can yield positive effects on physical demands (Petzäll and Petzäll, 2003; Kim et al., 2009; Mehta et al., 2011; Kotowski et al., 2013; Wiggermann et al., 2015a & 2015b). However, literature addressing the collection and application of anthropometric data for the design of healthcare equipment is sparse.

Characterizing body shape for design purposes is made more difficult by the limitations of the conventional set of measures available to estimate adiposity and fat distribution in large samples of obese adults. This cohort is highly variable in body structures, adiposity, and body fat distribution. Manual anthropometric measures such as waist circumference provide a surrogate measure of central fat distribution, though shape variability is important for product design.

This paper describes the development of laboratory methods to quantify 3D anthropometry of adults with high BMI in supine and supported reclined postures. A total of 6 adults with a range of sizes were measured. The current protocol is part of a larger research effort to develop a three-dimensional database of adult body shapes in functionally relevant postures for use in the product development and evaluation of medical devices and patient handling equipment.

METHODS

Laboratory Set-up

A table with transparent support surfaces enables supine whole-body body shape to be captured with hand-held 3D surface scanners (Figure 1). One end of the table articulates to a 30° inclination from horizontal to simulate a hospital bed. A 30° angle of inclination at the head of a bed is associated with achieving a torso angle necessary to mitigate patient migration and a torso elevation intended to reduce risk of ventilator associated pneumonia (Wiggerman, 2014).

A reconfigurable seating fixture, designed to simulate a range of supported seated postures representative of patient lift-assist equipment, was fabricated for this study. The fixture included various support structures and foot positioning aids to enable participants to achieve a range of supported torso recline, hip splay, and knee flexion angles. As shown in Figure 2, vertical poles supported the participant's hands so that the arms were abducted and flexed, to ensure that there was sufficient data collected on the torso contour.

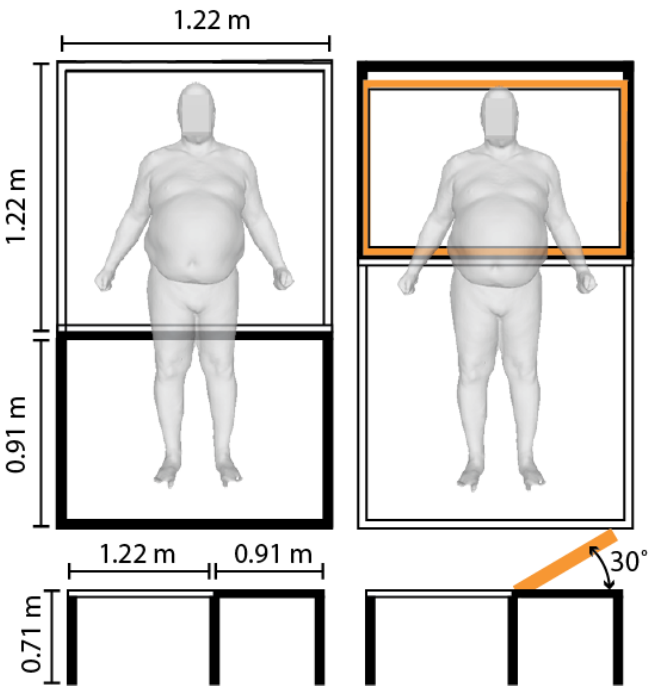

Figure 1. Transparent table to represent hospital beds. Adjustability includes: 30° inclination configuration at the head of the table.

Figure 2. Participant in full-body scanner reconfigurable seating fixture with investigator also using a hand-held scanner to record the shape of the lap area Adjustability includes: seat back angle, hand, and foot positing aids.

Anthropometry and Posture Measures

Standard anthropometric dimensions, including stature, body weight, and linear breadths and depths were gathered from each participant to characterize the overall body size and shape, following the procedures in Hotzman et al. (2009). All measurements were obtained from the participants in minimally clad test clothing. Subsets of the anthropometric measures were obtained at multiple measurement site(s) to provide preliminary data on points of maximal breadth, depth or girth. The intention of these maximal measures was to capture body shape variability, particularly the location and contour of the panniculus during standing, supine, and seated postures. Measurements were added to better quantify the range and the postural effects of obesity. Additions include measuring participants with a natural leg splay in addition to legs parallel and in supine postures.

A FARO Arm coordinate digitizer was used to record surface landmarks to document skeletal posture. The landmark set and measurement methods were derived from those used in previous studies of automotive posture for both adults and children (Reed et al. 1999, Reed et al. 2005). This procedure involved the participants sitting in a specially designed laboratory hardseat that provides access to posterior landmarks on the spine and pelvis.

The locations of landmarks on the participants were recorded via skin targets stamped on the skin. Body landmarks were marked on the skin using a pattern of water soluble, non-toxic, square ink stamp into which was placed a high contrast white paint dot. A grid pattern of landmarks was also stamped on the participant's torso during a standing posture (Figures 3 & 4). The centerline (S0-S4) was established at equally spaced distances between the sternum marker and a marker placed just below the omphalion. Two vertically oriented lines (A0-A4), located directly bilateral to the centerline (anterior), were defined by equally spaced distances between a marker at the sternum height, placed halfway between the centerline (anterior) and axilla, and a marker placed at the height just below the omphalion. Markers were located along the sagittal plane at the height of the 10th rib, iliocristale, and at the mid-point. Markers along the spine (posterior) were defined at T12, L3 and L5. The remaining markers were set at halfway points on the horizontally oriented lines connecting the bilateral to centerline (A0-A4) and spine (posterior) markers with the sagittal markers. If additional markers were required to capture the panniculus below the omphalion in the supine posture, the vertically oriented grid pattern was extended at same spacing as used when standing. The objective of the torso grid pattern was to track surface shape and deformation differences between scan postures.

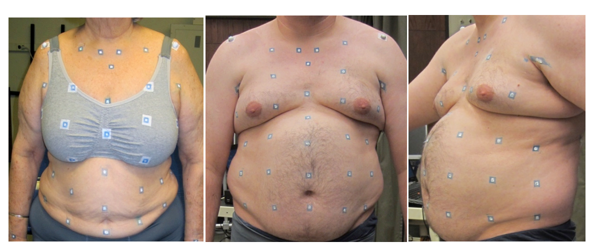

Figure 3. Torso grid markers stamped on participants' skin and taped to sports bra.

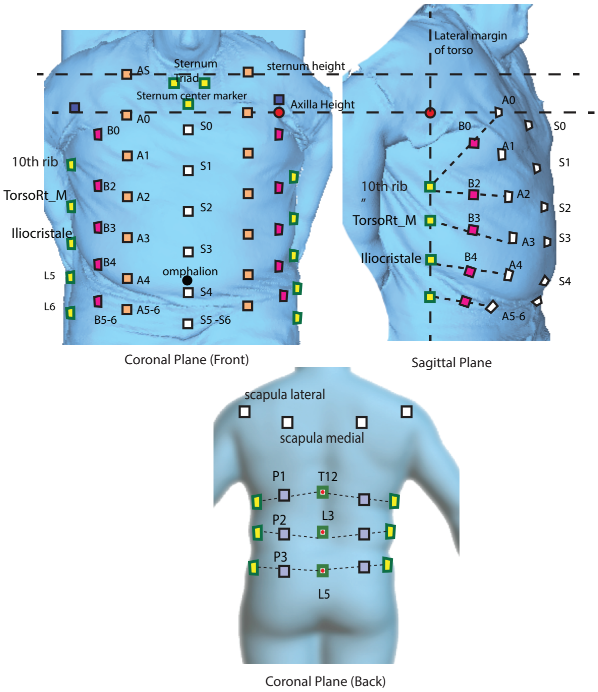

Figure 4. Illustration of markers stamped onto the participants' torsos.

A Vitronic VITUS XXL full-body laser scanner and ScanWorX software by Human Solutions was used to record whole-body 3D surface geometry in standing and supported seated postures. In some postures, body regions of interest that were shadowed from the whole-body scanner were recorded using a handheld scanner. Handheld Artec 3D and Cubify Sense scanners were used to capture the supine scan posture on the transparent table (Figure 5).

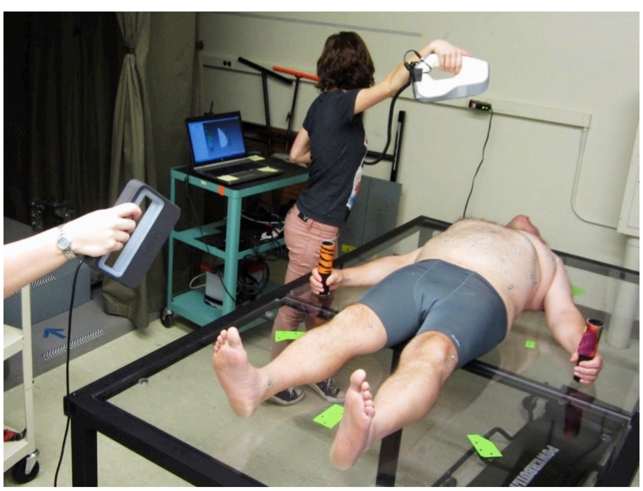

Figure 5. Recording scanning supine posture with Artec and Sense scanners on participant's anterior (left) and posterior (right)

Scan Postures

Scan postures included standing, sitting and supine (Figures 6 & 7). Postures were chosen to capture a range of body shapes expected in upright slings and lift assist devices (Figure 8) and representative of patients lying supine in hospital beds (Figure 7). The medical sling postures involved two postures in which the participant's posture went from an erect to a 20° reclined torso inclination angles while maintaining both parallel thighs and a natural splay about the hips. Feet were also positioned to achieve both 60° and 90° included knee flexion angles. To set each scan posture the seating fixture was reconfigured to position the participant and joint angles were confirmed with a goniometer.

Figure 6. Unsupported seated posture.

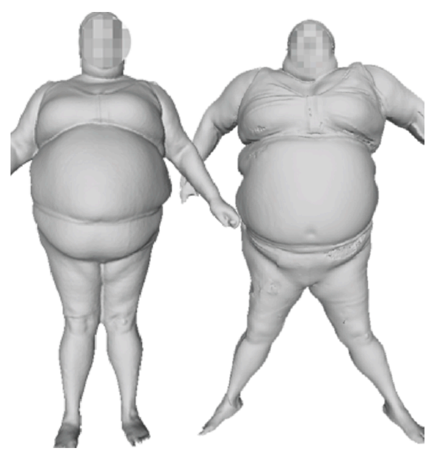

Figure 7. Standing (left) and supine (right) postures.

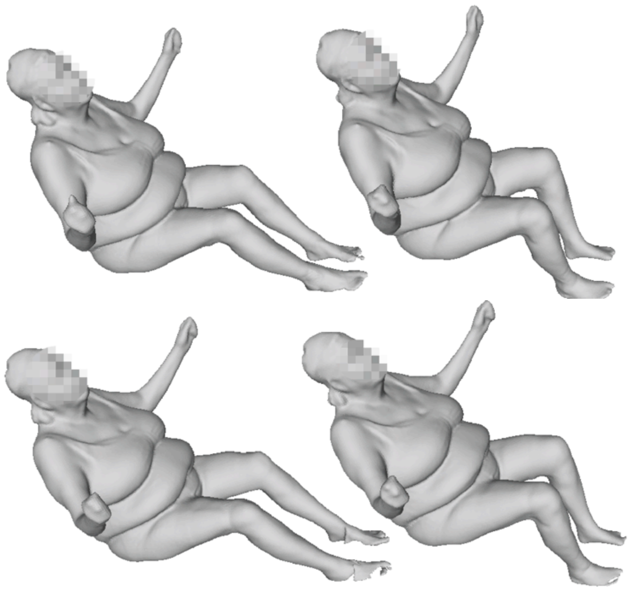

Figure 8. Medical sling postures with 0˚ back recline angle and knee angles at 60˚ and 90˚ (two on left) and with 20˚ back recline angle and knee angles at 60˚ and 90˚ (two on right).

Protocol

The study protocol was approved by the University of Michigan Institutional Review Board (IRB) for Health Behavior and Health Sciences (IRB #HUM00102426). Participants were recruited through online postings and through healthcare providers at the University of Michigan Adult Bariatric Surgery program. Each participant was briefed on the purposes and methods of the study and written consent was obtained. Participants first changed into test clothing and standard anthropometric measures were taken. Body landmark locations were recorded in the laboratory hardseat. The body shape of each participant was measured in a supine posture on transparent table using handheld scanners, and in supported seated scans using a whole-body scanner. All testing was completed in a single session of about two hours.

Scan Data Processing and Landmark Extraction

Surface data obtained from the laser scanners were pre-processed in the ScanWorX software (Human Solutions, GmbH). First, the structure of the transparent table, reconfigurable seat and artifacts (for example, handholds and foot-positioning aids) were removed manually. Hand-scan data were then aligned and merged with the whole-body scan data where needed using Geomagic Studio software (Geomagic.com). Lastly, anatomically derived landmarks were manually extracted using a custom script in the Meshlab software (meshlab.org).

RESULTS

Study Participants

Four women and four men were tested in this pilot study. Participants were stratified based on BMI classification (Obesity Class I, II, and III). Table 1 lists the standard dimensions for the participants measured during the development of this protocol.

Table 1. Standard Anthropometry: Selected Dimensions

Gender	Subject	Weight (kg)	Stature (mm)	Age (years)	Obesity Classification
Female	S01	81.8	1628	28	I
	S02	78.4	1564	35	I
	S03	110.2	1656	67	II
	S04	147.6	1633	50	III
Male	S05	92.5	1706	54	I
	S06	91.5	1558	73	II
	S07	163.1	1870	44	III
	S08	198	1840	48	III

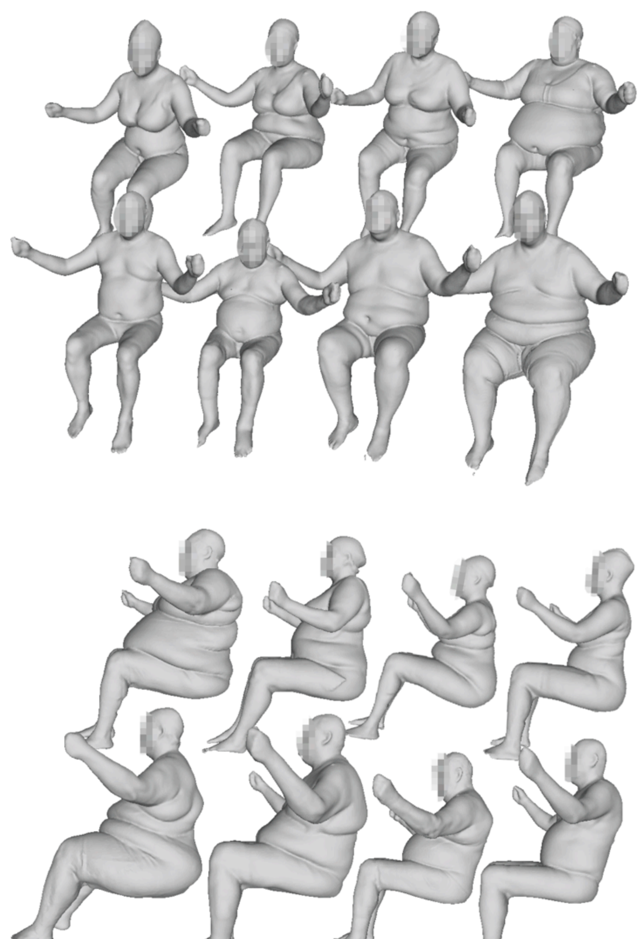

Figure 9. Body scan variability of four female and male participants in a supported, seated posture, defined at 0-deg torso inclination with 90-deg knee angle, representative of patient lift assist designs.

DISCUSSION

This protocol developed methods for obtaining high-resolution data on posture and body shape for adults with high BMI that has not previously been addressed in a 3D anthropometry survey. These data also capture a range of functionally relevant postures for medial equipment design.

Some methodological challenges arose due to the large variance in obese and morbidly obese participants, in comparison non-obese participants. Palpating bony landmarks needed for standard measures is difficult, and appropriate measurement sites were often hard to determine as a result of increased skinfolds and deformation. Comorbidities related to mobility and joint range of motion are common in this cohort, challenging their ability to achieve standardized scan postures. For example, the widely used "A-scan" standing posture cannot be easily achieved by some individuals with high BMI.

This research is revealing information concerning the variability of obese body shapes, providing useful guidance for developing improved medical devices. Data on body shape from a larger sample will enable statistical analysis of the body shape to be conducted. Results will be used to create virtual fit avatars representing obese patients that will provide guidance on user requirements to medical device manufacturers for product design and evaluation.

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REFERENCES

Flegal, KM, Carroll MD, Ogden CL, Curtin LR. (2010). Prevalence and trends in obesity among US adults, 1999–2008. *JAMA*. 303:235–241.

Hotzman, J., Gordon, C.C., Bradtmiller, B., Corner, B.D., Mucher, M., Kristensen, S., Paquette, S., and Blackwell, C.L. (2011). Measurer's Handbook: U.S. Army and Marine Corps Anthropometric Surveys. Technical Report NATICK/TR-11/017. U.S. Army Natick Soldier RD&E Center.

Kim, S., Barker, L. M., Jia, B., Agnew, M. J., & Nussbaum, M. A. (2009). Effects of two hospital bed design features on physical demands and usability during brake engagement and patient transportation: A repeated measures experimental study. *International Journal of Nursing Studies*, 46(3), 317-325.

Kotowski, S.E., Davis, K.G., Wiggermann, N., and Williamson, R. (2013). Quantification of Patient Migration in Bed: Catalyst to Improve Hospital Bed Design to Reduce Shear and Friction Forces and Nurses' Injuries. *Human Factors*, 55(1) 36-47.

Kumpar, D. (2014). Prepare to care for patients of size. *American Nurse Today*, 9(9), 20-22.

Martin, J.L., Norris, B.J., Murphy, E., Crowe, J.A., 2008. Medical device development: the challenge for ergonomics. *Applied Ergonomics*. 39 (3), 271–283.

Mehta, R. K., Horton, L. M., Agnew, M. J., & Nussbaum, M. A. (2011). Ergonomic evaluation of hospital bed design features during patient handling tasks. *International Journal of Industrial Ergonomics*, 41(6), 647-652.

Petzäll,K., and Petzäll J., 2003.Transportation with hospital beds. *Applied Ergonomics*, 34 (4), 383–392.

Reed, M.P., Ebert-Hamilton, S.M., Manary, M.A., Klinich, K.D., and Schneider, L.W. (2005). A new database of child anthropometry and seated posture for automotive safety applications. *SAE Transactions: Journal of Passenger Cars - Mechanical Systems*, 114: 2222-2235.

Reed, M.P., Manary, M.A., and Schneider, L.W. (1999). Methods for measuring and representing automobile occupant posture. Technical Paper 990959. Society of Automotive Engineers, Warrendale, PA.

Sturm, R. and Hattori, A. (2013). Morbid obesity rates continue to rise rapidly in the United States. *International Journal of Obesity*, 37: 889-891.

Wiggermann, N. (2014). The sliding patient: How to respond to and prevent migration in bed. *American Nurse Today*, 9(9), 17-19.

Wiggermann, N. (2015a). Biomechanical Evaluation of a Bed Feature to Assist in Turning and Laterally Repositioning Patients. *Human Factors*. doi: 10.1177/0018720815612625.

Wiggermann, N. (2015b). The Effect of a Powered Drive on Pushing and Pulling Forces When Maneuvering Bariatric Hospital Beds. Proceedings of the 59th Meeting of the Human Factors and Ergonomics Society.