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Identifying characteristic back shapes from anatomical scans of wheelchair users to improve seating design

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ABSTRACT

Spinal deformities are common in people who require the use of a wheelchair for mobility as a result of spinal cord injuries and other disabilities. Sitting positions vary between individuals with disabilities who use wheelchairs and individuals without disabilities. In individuals with spinal cord injury, spinal deformities can result in the development of back contours that deviate from the shape of standard rigid back support shells. The purpose of this study was to distinguish and classify various back contours of wheelchair users by utilizing digital anatomic scanning technology in order to inform the future development of back supports that would enhance postural support for those with spinal deformities. The three dimensional (3D) locations of bony landmarks were digitized when participants were in position, using a mechanical wand linked to the FastScan^{tm} system commonly used to measure surface contours. Raw FastScan^{tm} data were transformed according to bony landmarks. A total of 129 individuals participated in this study. A wide range of back contours were identified and categorized. Although participant characteristics (e.g., gender, diagnosis) were similar amongst the contour groups; no one characteristic explained the contours. Participants who were seated in a forward lean position had a higher amount of pelvic obliquity compared to those seated in an upright position; however, participants' back contour was not correlated with pelvic obliquity. In conclusion, an array of different back shapes were classified in our cohort through 3D laser scanning technology. The methods and technology applied in this study could be replicated in future studies to categorize ranges of back shapes in larger populations of people with spinal cord injuries. Preliminary evidence indicates that customized postural support may be warranted to optimize positioning and posture when a standard rigid shell does not align with contours of a person's back. To optimize positioning, a range of contoured rigid backrests as well as height and angle adjustability are likely needed.

1. Background

Due to aging populations and the increased prevalence of disability, experts anticipate that the need for wheelchairs worldwide will surge [1,2]. Consumer demand for wheelchairs that fit the personal needs, physical abilities, and functional requirements of current and expected wheelchair occupants has led to the application of sitting biomechanics and ergonomic design to the development of wheelchair components [3]. Preserving health by preventing secondary medical conditions (e.g., repetitive strain injury, pressure wounds, scoliosis) while improving mobility is a primary consideration of healthcare professionals, rehabilitation engineers and assistive technology providers who prescribe and fit wheelchairs for clients with spinal cord injuries [4–6].

Studies have indicated that the design of back supports for office chairs, vehicle seats, and wheelchairs is a significant factor in reducing stresses on the spine and associated healthcare costs [7,8] and in improving seating comfort and function [8–13]. Moreover, in order to design clothing for function and comfort, anthropometric data (e.g., body size and composition, function and structure) are commonly analyzed to create meticulously fitted

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products such as shoes and clothes in a spectrum of sizes [14]. Anthropometrically-shaped back supports of vehicle seats and office chairs have similarly been proposed [15].

Wheelchair occupants require customized support for functional reach and efficient wheelchair propulsion, essential in cases where the muscles of the thorax are dennervated such as in thoracic level spinal cord injury (SCI), neuromuscular scoliosis, or spastic quadriparesis or hemiparesis [16–18]. However manual wheelchairs that are classified by Medicare as K0001–K0004 come standard with a sling upholstery back support. As the occupant's weight presses against the flexible sling upholstery the seat back partially conforms to the posterior torso; with time and use the upholstery becomes overstretched and can contribute to poor back support and poor posture. Adjustable tension straps on sling upholstery can compensate to a degree for anatomic and postural changes through adjusting the tension in areas of the back that require more or less support; however, the material can also become loose due to the flexibility of the material itself or slippage of the straps with wear [19]. Kyphosis, shoulder protraction and posterior pelvic tilt can occur without adequate postural support of the torso and pelvis. Propelling a wheelchair with poor torso, shoulder and pelvic alignment can limit the full range of shoulder motion and contribute to repetitive upper extremity strain, back pain and postural impairments [6,20]. Thus, wheelchair occupants require proper trunk support to maintain good posture and provide a firm base for propulsion [6,21].

A rigid back support is often recommended on an ultralight manual wheelchair (classified by Medicare as K0005) to provide back support for wheelchair occupants with spinal cord and other neurological injuries and disorders. The cushion forms a close fit to the shape of the occupant's back. The rigid frame provides a stable base of support for the spinal column. Rigid back supports are not user-adjustable and are selected based on measurements that a physical or occupational therapist and/or an assistive technology supplier collect during an evaluation for a wheelchair, including the seat to shoulder height, the seat to scapula height and width of the pelvis and torso. Consideration is also given to whether the user has significant lumbar lordosis, thoracic kyphosis, scoliosis and pelvic obliquity. Even though they can be curved or planar, not all differences in back contours are accounted for by standard rigid back supports. For example, a standard rigid back support may not accommodate those with fixed postural deformities such as neuromuscular scoliosis, bony deformity and/or scar tissue from scoliosis surgery or extreme lumbar lordosis or thoracic kyphosis [22,23]. People with SCI, spina bifida, spastic quadriparesis or hemiparesis and other disabilities have a high prevalence of scoliosis and pelvic asymmetries [22,24–27] with back shapes that may differ from the shape of the back support shell which could compromise posture [20,28]. Further, as a consequence of individual variations in back contours, improper contact to occupants backs may result in discomfort and high interface pressures which can lead to pressure ulcers [29–31].

The purpose of this study was to use digital anatomic scanning technology to distinguish and classify back shapes and the pelvic obliquity of wheelchair occupants in order to determine the seating needs of a wider range of wheelchair occupants by testing the following hypotheses: Hypothesis 1 was that individuals in two different postures (i.e., forward lean and upright) would have significantly different back contours and pelvic obliquity measurements. Hypothesis 2 was that, within the two different posture groups, the various back contour classifications identified would be significantly different with respect to the age, years of injury, and disability of the individuals within those groups. Hypothesis 3 was that the back contour measurements would be correlated with the pelvic obliquity measurements.

2. Methods

This study utilized the scanning technology known as the FastScan^{TM} System (Polhemus, Colchester VT, USA), which features rapid recording of three-dimensional surfaces obtained by sweeping a hand-held laser scanner several times over a surface to cover the entire range of the object's surface [32]. Similar to the process of spray painting, multiple swipes are needed to measure slices of an entire surface area. This system has been used previously in clinical settings to measure the skin surface of amputees in the process of fitting prostheses and orthoses [33]. Rather than applying the former technique of qualitatively comparing 3D scans of the surface contours, this study categorized back shapes through quantitative methods. Similar to geographic studies, surface contours were compared [34] and root mean square error (RMSE) was calculated and utilized to classify and compare back shapes.

2.1. Recruitment

This study was approved by the Veteran's Affairs Pittsburgh Healthcare System Institutional Review Board. Participants were recruited at the National Disabled Veterans Winter Sports Clinic and the National Veterans Wheelchair Games. The inclusion criteria of this study were that participants must (i) be between 18 and 80 years of age, (ii) be athletes or instructors with a disability necessitating use of adaptive ski equipment in order to ski, and (iii) be able to give informed consent. Those not eligible for this study were (i) participants with open wounds that precluded them from prolonged sitting, and (ii) participants with any injury or illness diagnosed by the on-site clinic medical team that precluded them from participating in adaptive skiing.

2.2. Protocol

Each participant was asked to wear a wrinkle-free tight white t-shirt. Two types of positions were used. A massage chair was used to simulate forward leaning position and a custom built postural support frame was used to simulate upright position (Fig. 1). Half of the participants were asked to transfer to a massage chair and lean forward against the chest support of the chair with knees supported on the chair. Half of the participants were asked to transfer to a postural support frame and sit upright without a back support with their back exposed and feet supported. Thus, both seating systems supported the hips on planar seat surfaces and each position supported either the knees or feet (Fig. 1).

Once participants were in position, the three dimensional (3D) locations of bony landmarks were digitized using the hand held wand linked to the FastSCAN^{tm}. The bony landmarks were cervical (C) 7, right scapular angle, left scapular angle, right inferior scapular angle, left inferior scapular, right medial edge of scapular spine, left medial edge of scapular spine, thoracic (T) 7, T12, right lowest rib, left lowest rib, right trochanter, left trochanter, right posterior superior iliac spine (PSIS), left PSIS, right iliac crest, left iliac crest and sacrum. The bony landmarks oriented the scan to the transverse, coronal, and sagittal planes. The process to digitize the bony landmarks and complete the surface mapping of each participant's back required approximately 20 min.

2.3. Data analysis

Surfaces were generated in the FastSCAN^{tm} program using Basic Surface Processing (smoothing: 2.50 mm; decimation: 2.00 mm, limit object to 1; surface simplification: 0.10). Each back model was oriented in the same direction relative to the others by alignment and rotation. A local coordinate system was fitted to each back surface contour, centered at the T12 bony landmark, with x, y,