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Feasibility of freehand ultrasound to measure anatomical features associated with deep tissue injury risk

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ABSTRACT

Deep tissue injuries (DTI) are severe forms of pressure ulcers that start internally and are difficult to diagnose. Magnetic resonance imaging (MRI) is the currently preferred imaging modality to measure anatomical features associated with DTI, but is not a clinically feasible risk assessment tool. B-mode ultrasound (US) is proposed as a practical, alternative technology suitable for bedside or outpatient clinic use. The goal of this research was to confirm US as an imaging modality for acquiring measurements of anatomical features associated with DTI. Tissue thickness measurements using US were reliable (ICC=.948) and highly correlated with MRI measurements (muscle r=.988, $p \leq .001$; adipose r=.894, $p \leq .001$; total r=.919; $p \leq .001$). US measures of muscle tissue thickness were 5.4 mm (34.1%) higher than MRI, adipose tissue thickness measures were 1.6 mm (11.9%) lower, and total tissue thickness measures were 3.8 mm (12.8%) higher. Given the reliability and ability to identify high-risk anatomies, as well as the cost effectiveness and availability, US measurements show promise for use in future development of a patient-specific, bedside, biomechanical risk assessment tool to guide clinicians in appropriate interventions to prevent DTI.

1. Introduction

A pressure ulcer is a common yet not well understood injury associated with increased and prolonged mechanical loading [1–3]. Development of a pressure ulcer increases the risk of secondary health complications and mortality. Each year in the US an estimated 2.5 million hospital patients have a pressure ulcer diagnosis, and the total cost of pressure ulcer care is estimated at $11 billion [4]. Costs for an average hospital stay for a stage IV pressure ulcer, as reported by Brem et al. in 2010, averaged $129,248 [5]. An estimated 60,000 patients in the United States will die from a pressure ulcer related condition [4]. Major risk factors include prolonged immobilization and decreased sensory perception [3,6,7]. Due to impaired sensation and mobility, many pressure ulcers develop in people with spinal cord injuries. The incidence rate of pressure ulcers in people with spinal cord injuries ranges 20–31% [8] and vary considerably by clinical setting [4]. In seated individuals, pressure ulcers commonly develop where most of the body weight is distributed, near the interface between the ischial tuberosity and overlying soft tissue [9].

Deep tissue injury (DTI) is a serious classification of pressure ulcer and commonly seen in wheelchair users. A DTI differs from other pressure ulcers because it begins at the deepest tissue and progresses towards the skin, while other pressure ulcers begin at the skin and progress deeper. This makes DTIs extremely hard to detect, and by the time the injury becomes visible, extensive damage to the underlying tissue has already occurred [10]. This damage often requires surgical intervention and aggressive medications, raising the cost of treatment for a single DTI to as high as $70,000 [11].

The severity and clinical challenges in treating pressure ulcers has motivated the development of risk prediction models based on biomechanical models of the buttock anatomy [12–14]. In seated individuals, pressures ulcers mainly form under the ischial tuberosities (IT). Three soft tissue layers can exist between

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the IT and the seat surface: muscle, adipose, and skin. The individual properties of these tissues play a major role in pressure ulcer formation and have been the focus of recent research [15–17]. A major risk factor is anatomy, which varies greatly among individuals and can result in correspondingly varied levels of tissue injury [18–20]. A recent meta analysis of the clinical evidence [21] revealed the significant pathophysiological changes that occur from chronic sitting, especially post-spinal cord injury, including weight loss and gain, disuse-induced muscle atrophy, fat infiltration of the muscles, and flattening of the ITs, all of which affect the transfer of load through the IT's and tissues of the buttocks, and directly affect the risk of tissue injury.

Studies have developed biomechanical, computational models to assess the risk for DTI, based on images obtained by magnetic resonance imaging (MRI) [12–14]. These risk models require the segmentation of the MRI images, where every tissue is identified. Next, these segmentations are run through customized programs called finite element models to measure internal tissue stress and strain. Once developed, these models can be modified to simulate the aforementioned changes in anatomy and compute relative risks that result. One recent study followed this process to analyze the effects of fifteen such body adaptations on the internal tissues stresses and strains of seated buttock tissue [22].

These fundamental studies have dramatically advanced the analysis and understanding of the potential internal risks of the seated individual, and provide tools to assess pressure ulcer risk based upon anatomy. Although MRI was used to produce these models and related research outcomes, MRI is not a clinically feasible method of capturing the unique, specific bone and soft tissue properties of an individual, and assessing their specific relative risks of tissue injury from these attributes. MRI imaging has three major clinical shortcomings: cost, time, and accessibility, and these issues simply cannot be overcome if the research is to be translated into clinical practice.

An alternative to MRI-based assessment is needed if the promise of incorporating anatomical feature-related risk factors into a clinically feasible assessment technique is to be realized. Ultrasound (US) may be such a viable alternative that improves on the shortcomings with MRI imaging. The tissues of the ischial region have previously been viewed using US for other clinical uses, including identifying sub gluteal anatomy, IT bursitis, and hamstring injury [23–25]. US has also been used to assess the development of deep tissue injuries in this area of the anatomy [26–29]. These studies have shown that signs of early deep tissue injury can be seen using US before the skin shows signs of injury. No studies have explored using US as a risk assessment tool. The purpose of this study was to confirm ultrasound as an imaging modality for acquiring measurements of anatomical features associated with DTI risk, using a basic ultrasound protocol that can be conducted at the bedside or in a clinic with standard medical equipment. If freehand ultrasound provides a viable measurement methodology for assessing anatomical structures (i.e., soft tissue properties and IT radius of curvature), it can be used to screen and classify pressure ulcer risk by identifying high-risk anatomies determined through multiple computational modeling studies [20,30–32].

2. Material and methods

2.1. Participants

Six participants were recruited: two control (non-spinal cord injury), two with a short-term spinal cord injury (SCI) (within one year of injury), and two with a long-term SCI (greater than five years post-injury). All participants were older than 18 years of age. Exclusion criteria included the following: current pressure ulcer on the seated surface of the pelvic region, body mass greater than 113 kg, and contraindications to MRI. Contraindications included pacemaker, defibrillator, aneurysm clips, spinal cord stimulator, new nonferrous (titanium or stainless steel) metallic implants ($<$ 8 weeks old), ferrous metallic implants, prosthetic heart valves, stents, surgical clips or staples, neurostimulators, recent surgery, new tattoos ($<$ 8 weeks old), pregnancy, medication patches, body piercings, cochlear implant, breast tissue expander, and metallic fragments in eyes. Participants with SCI self-reported the date of spinal cord injury, level of spinal injury, and whether the injury was complete or incomplete.

2.2. Instrumentation

B-mode ultrasound examinations were conducted using a Philips HD11 1.6 ultrasound machine with a 5–12 MHz 50 mm linear array transducer (Philips Medical Systems, Bothell, WA). Image field depth was set to 7 cm and gain was set at 100 dB for all test sessions. Ultrasound images were collected and recorded using Stradwin software (v4.7, Mechanical Engineering, Cambridge University, UK) [33]. Magnetic resonance imaging examinations were conducted using a 0.6 T Upright MRI (FONAR Corporation, Melville, NY, USA). T1 weighted images were collected in the coronal plane with a 256×256 matrix, $30\,cm \times 30\,cm$ field of view, slice thickness of 3.0 mm and inter-slice distance of 0.2 mm. The duration of each sequence was approximately 14 min. Magnetic resonance imaging was conducted by the same licensed radiological technologist for all participants.

2.3. Experimental procedure

All procedures were approved by a university institutional review board and written informed consent was obtained prior to experimental procedures.

2.3.1. Ultrasound examinations

Participants transferred to a plinth for all ultrasound imaging. Ultrasound images of the left and right pelvic IT and surrounding tissues were acquired prone and side lying. Images acquired in the prone posture did not result in good images and did not represent a seated anatomical posture and were therefore not included in this analysis. For the side-lying posture, the left IT was measured in a right side-lying posture and the right IT was measured in a left side-lying posture. Legs were positioned to approximately 90° of hip and knee flexion. The torso was maintained in a neutral position and participants rested their heads on a pillow.

Participants were asked to lower his/her pants and underwear on the side of the buttock that was being measured. The IT was palpated and ultrasound gel was applied to facilitate signal transmission. The transducer was placed at the IT and pressure was applied to visualize it on the sonogram. The IT border was identified as a solid white, curved structure that did not displace as pressure was applied. The transducer was maneuvered through multiple angles to confirm proper positioning and then orientate vertically to obtain images that were approximately in the coronal plane. The desired image included subcutaneous adipose tissue, gluteus maximus tissue, and IT. In some images, the biceps femoris, semitendinosus, and semimembranosus were visible. After proper position was obtained, ultrasound data were recorded at 19 Hz. Data recorded included reconfirmation of proper transducer position and then the transducer was gradually pulled away to unload the buttock tissues. Minimal contact pressure was used to allow visualization of the tissues without excessive tissue compression. All ultrasound images were collected by the same researcher (JA).