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Basic research

Development of a Sitting MicroEnvironment Simulator for wheelchair cushion assessment

Tyler Freeto [a, b], Allissa Cypress [b], Sarah Amalraj [b], Mohamed Shaif Yusufishaq [b], Kath M. Bogie [a, b, c, *]

[a] Advanced Platform Technology Center, Louis Stokes Cleveland Department of Veterans Affairs Medical Center, Cleveland, OH 44106, USA
[b] Department of Biomedical Engineering, Case Western Reserve University, Cleveland, OH 44106, USA
[c] Department of Orthopaedics, Case Western Reserve University, Cleveland, OH 44106, USA

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A B S T R A C T

Study aim: Pressure ulcers (PU) are a common comorbidity among wheelchair users. An appropriate wheelchair cushion is essential to relieve pressure and reduce PU development during sitting. The microenvironment, specifically excessive heat and moisture, impacts risk for PU development. An effective wheelchair cushion should maintain a healthy microenvironment at the seating interface. Measurement of heat and moisture can characterize microenvironmental conditions at the wheelchair cushion interface under load. We describe the development of a Sitting MicroEnvironment Simulator (SMES) for the reliable assessment of wheelchair cushion microenvironments.
Materials: The prototype SMES was developed for use mounted on a Materials Testing Systems (MTS) 810® uniaxial servo-hydraulic loading rig and used to assess microenvironmental conditions for Jay Medical Jay 2®, Roho High Profile Dry Floatation® and Low Profile Dry Floatation® cushions and a novel modular gel cushion.
Methods: Each cushion was assessed for two hours in triplicate. The SMES was used to load the cushions to 300N ± 10N, with an interface surface temperature of 37 °C ± 1 °C and fluid delivery of 13 mL/h ± 1 mL/h of water. Interface temperature and humidity were measured at the left ischial tuberosity (IT) region every five minutes.
Results: Heat and moisture responses were similar for the three commercial cushions. The modular gel cushion stayed cooler for at least 15 min longer than any commercial cushion.
Conclusions: The SMES maintained performance to technical specifications for over one hundred hours of total testing and is a reliable tool for characterizing the microenvironmental conditions of wheelchair cushions.

Introduction

Many individuals with limited mobility including the elderly, diabetics, and those with spinal cord injury rely on a wheelchair for activities of daily living [1,2]. An essential component of the wheelchair support system is the wheelchair cushion, which is integral to pressure ulcer (PU) prevention for these individuals. Prolonged pressure due to sitting can lead to ischemia of overlying soft tissues, and ultimately cause tissue necrosis and PU development [1]. Patients suffering from PUs can experience extreme discomfort. PUs can also lead to serious, life threatening infections [1,3]. 17.9%–23.0% of wheelchair users suffer from persistent PUs, and as many as 85.7% have experienced at least one PU [4,5]. Furthermore, PUs are a major contributor to healthcare costs: in the US the healthcare cost burden has been estimated at $6 – $15 billion per year [6], and it may even be as a high as 5% of all healthcare costs [7].

There are multiple risk factors which impact the risk of PU development [8], spanning multiple domains [9]. In the biomechanical domain, the microenvironment between the individual and support surfaces is known to be a factor in increased PU risk [10,11]. Increased risk for PU, due to high local temperature, is mediated by a resulting increase in metabolic activity in tissue.

* Corresponding author. Cleveland Advanced Platform Technology Center, Louis Stokes Cleveland Veterans Affairs Medical Center, 10701 East Boulevard, Cleveland, OH 44106, USA. Tel.: +1 216 368 5270.
E-mail address: kmb3@case.edu (K.M. Bogie).

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When tissue perfusion is insufficient to meet the metabolic needs, ischemia occurs and can eventually progress to tissue damage [12,13]. Moisture from the skin, often a result of sweating or incontinence, has been shown to weaken the crosslinks between the collagen in the dermis and soften the stratum corneum [14]. Moisture can also increase the skin's coefficient of friction, leading to increased damage due to shear stress [10]. The combination of high pressure over bony prominences and a decrease in skin tolerance due to the microenvironment makes the ischial tuberosity (IT) and sacral regions most prone to PU development [15,16] and thus the microenvironment at the cushion interface under load should be characterized.

Currently available commercial wheelchair cushions attempt to address the concerns of PU formation by distributing and reducing the interface pressure at the support surface between the device and the user. These cushions must also promote postural stability as individual sits in the wheelchair [17,18]. No single cushion can meet every user's needs and many different materials are used for wheelchair cushion construction, including standard foam, viscoelastic foam, gel, viscous fluid, and air [19]. The International Organization for Standardization (ISO) specifies a variety of methodologies for testing the performance and efficacy of wheelchair cushions. Standard 16480-2 describes four tests to determine the mechanical properties of wheelchair cushions: hysteresis, impact damping, recovery properties, and the cushion's response to being overloaded [20]. Two indenters are specified by the standard to mimic important aspects of human anatomy. The rigid contour loading indenter (RCLI) matches the geometry of the soft tissue of the human seating surface, although it does not deform under test conditions. The Loaded Contour Jig (LCJ) mimics both the geometry and loading conditions of the skeleton, specifically the ischial tuberosities and femoral trochanters, on the cushion. The ISO-standard indenters have been used in a number of studies [21,22]. However, these devices do not provide physiological simulation of the microenvironment at the interface between the user and support cushion.

Ferguson-Pell et al. [23] proposed the thermodynamic rigid cushion loading indenter (TRCLI), which maintained the geometry of human anatomy and also provided physiological sweat and heat conditions. While the TRCLI was functional, it accumulated microbial growth in the pores of the membrane used to secrete water. This severely limited function, preventing water flow and rendering the device unusable after only a few tests [23]. The goal of the current study was to create a device that reliably and repeatedly monitors the microenvironment under load, while reducing failure due to biofouling.

Materials and methods

SMES description

The Sitting MicroEnvironment Simulator (SMES) was developed to address the issue of efficacy over multiple experiments faced by prior testing devices. Fig. 1.

In order to accomplish interface microenvironment assessment of the cushions, the SMES was designed and constructed to match the functional technical specifications of Ferguson-Pell et al.'s TRCLI with increased reliability and longevity.

Ergonomics specifications were defined as.

a) Body shape: Geometry of the indenter to match the RCLI
b) Body weight: Stable under a constant load of 300N ± 10N for 2 h
c) Body heat: Stable 37 °C ± 1 °C at the interface surface when exposed to air
d) Body moisture: Sweat mimicked by delivery of 13 mL/h ± 1 mL/h water to the interface surface [24].

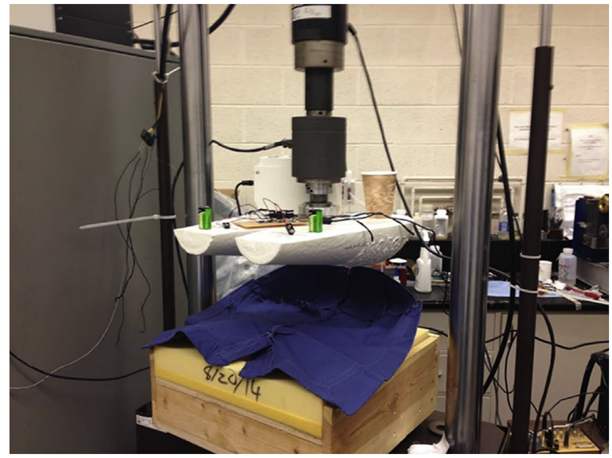

Fig. 1. The SMES and test cushion mounted in the MTS machine. The canvas cloth (blue) has been removed to enable viewing of the heating elements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In order to meet the specification for body shape, the SMES structure was cast out of polyurethane resin using a plaster mold created from the RCLI. The polyurethane casting resin was rigid with a compression failure load an order of magnitude higher than the maximum applied load, thus meeting the specification for stability under load. The other components of the SMES did not appreciably affect its interface geometry, thus loading profiles of the RCLI and the SMES were comparable. A coupling was used to attach the SMES to a Materials Testing Systems (MTS) 810® uniaxial servo-hydraulic loading rig with a 5,000lb (2267 kg) load cell, at a ± 250lb (113 kg) load range, and ± 63.5 mm displacement measurement range.

The thermal component of the SMES was provided by nichrome resistive heating wire sealed to the interface surface using silicone. A thermistor embedded in the left IT region along with a potentiometer formed part of a Wheatstone bridge (Fig. 2). This served as the control circuit to regulate the amount of current delivered to the two loops of resistive wire from a 12V, 1.25A DC power supply as shown in Fig. 3. Prior to each use of the SMES, the control circuit was calibrated using the potentiometer so that when exposed to ambient air, the surface temperature of the SMES reached an equilibrium temperature of 37.2 °C ± 1 °C. The surface temperature of the SMES was monitored without load for 60 min, thus meeting the specification for mimicking body heat.

In order to deliver moisture to the interface, water was pumped from an external reservoir via a peristaltic pump. The external reservoir was primed with a fixed volume of water prior to testing and the pump adjusted to deliver 13 mL/h ± 1 mL/h water (Fig. 4). Water was pumped through IV tubing from the rear to front of the SMES along the midline. 0.5 mm holes spaced 1 cm apart in the tubing allowed moisture to leak from the tube at equilibrium at a rate of 13 mL/h. Canvas cloth fitted to the SMES surface wicked the moisture away from the tubing and distributed the moisture over the interface surface in a physiologically relevant manner. It was observed that the majority of the moisture flux was delivered between the IT and perineal regions then gradually dissipated with distance radially. The volume of water remaining in the reservoir after testing was recorded in order to verify that that pump had operated to meet the body moisture specification.