

ALTERNATIVE THERMODYNAMIC RIGID CUSHION LOADING INDENTER FOR MICROCLIMATE CHARACTERIZATION IN FULL BODY SUPPORT SURFACES

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ABSTRACT

Aim: Pressure injuries frequently occur in hospital environments and can lead to secondary infections and complications in patient condition. The onset of pressure injuries is facilitated through the microclimate environment at the patient-surface interface of a full body support surface (i.e. a mattress, pad, and/or overlay). Specifically, the temperature and humidity are the primary contributors to microclimate conditions and, consequently, to the risk of pressure injury development. Standard testing methods aim to characterize microclimate conditions through the measurement of these two variables. Microclimate characterization is critical in the determination of a surface's viability for use, especially with patients possessing a higher risk for pressure injury. Current methods employ the use of circulating water to delivery heat and moisture. A novel system is described to provide improved functionality without the sacrifice of repeatability and reliability—the Bronze Thermodynamic Rigid Loading Indenter (BTRLI).

Materials: The BTRLI is casted from bronze to form the rigid buttock of the indenter. Microclimate conditions were assessed using four powered low air loss mattresses manufactured by KAP, Hill-Rom, and Freedom Medical.

Methods: Testing was performed in triplicate for three hours on each surface, with the BTRLI temperature maintained at 37 ± 1 °C and weighted to achieve a total load of 285 ± 10 N. The BTRLI was loaded with 200 mL of distilled water to provide consistent moisture delivery. Five sensors measured temperature and percent relative humidity (RH) were placed on the ischial tuberosities (ITs), perineum, and thighs of the indenter.

Results: Temperature and %RH measurements were similar for all support surfaces tested.

Conclusion: The BTRLI is a repeatable system, able to perform to specification during extended testing, providing reliable characterization for full body support surfaces.

INTRODUCTION

Clinical prevalence of pressure injury is a substantial issue in US healthcare. Pressure injuries account for approximately \$6-15 billion in annual healthcare costs in the US (Markova & Mostow, 2012). In addition to monetary concerns, pressure injuries impose a great degree of discomfort and risk to patients, affecting up to 38, 23.9, and 17% of those in acute, long-term, and home care respectively (Jalali & Rezaie, 2005). Severely limited or restricted movement is a high pressure injury risk factor (Ferguson-Pell, Wilkie, Reswick, & Barbenel, 1980). Unrelieved pressure is one mechanism in the cascade of pressure ulcer development. Specifically, pressure injuries are a result of ischemic soft tissues evolving into open sores and skin lesions (Regan, Teasell, Wolfe, Keast, Mortenson, & Aubut, 2009). The breach in the dermis/epidermis and the chronic nature of pressure injury can frequently lead to secondary, and possibly life-threatening, infection (Russo, Steiner, & Spector, 2006).

Along with mechanical factors (such as pressure, friction, and shear), microclimate (temperature and moisture) conditions are implicated in pressure injury formation (Brienza & Geyer, 2005). Therefore, it is essential to characterize the microclimate of a full body support surface in order to assess its viability for patients with low-to-restricted mobility. The current US standard for microclimate testing of full body support surfaces is RESNA SS-1:2014 Section 3. It specifies the use of a

Thermodynamic Rigid Cushion Loading Indenter (TRCLI) to load a support surface while delivering heat and moisture (ANSI/RESNA). The indenter provides consistent microclimate delivery and a geometric shape analogous to the buttocks to simulate *in vivo* conditions (ISO/FDIS) (Ferguson-Pell, Hirose, Nicholson, & Call, 2009). However, using the TRCLI for multiple tests requires intensive maintenance. This manifests in the form of microbial growth or biofouling in the pores of the TRCLI moisture-permeable membrane—limiting function and eventually blocking moisture delivery completely. Another proposed indenter utilizes a plaster molded polyurethane indenter and a peristaltic pump to deliver moisture (Freeto, Cypress, Amalraj, Yusufshaq, & Bogie, 2016). An alternative system is described to alleviate the moisture delivery issue of the TRCLI and to provide a simple, but effective method for microclimate characterization—the Bronze Thermodynamic Rigid Loading Indenter (BTRLI).

MATERIALS

The BTRLI was designed to match the functionality of the TRCLI specified in RESNA SS-1:2014, Section 3 and ISO 16840 Part 2 Annex A Table 1A, with improved efficiency between test periods. The BTRLI was casted out of bronze as a shell to match to the geometry and moisture pore pattern of the TRCLI. The choice of bronze was twofold, to maintain structural stability under load and to provide conductive mass—allowing for the distribution of heat. To deliver moisture, a moisture reservoir was employed, using evaporation as a delivery mode. Specifically, two water-loaded towels with high evaporative capacities were placed inside the bronze shell, covering the moisture delivery pores. This allows moisture vapor to pass through the pores of the indenter onto the surface of the mattress as the water evaporates from the heat. The BTRLI's heat was provided via two 120 V, 280 W silicone rubber strip heaters. The heaters were adhered to the inner surface of the bronze shell (Fig. 1). Heat output was controlled with a digital 100/240 VAC PID temperature controller, PT100 thermocouple, and a 10 A solid state relay. System temperature and humidity at the test interface

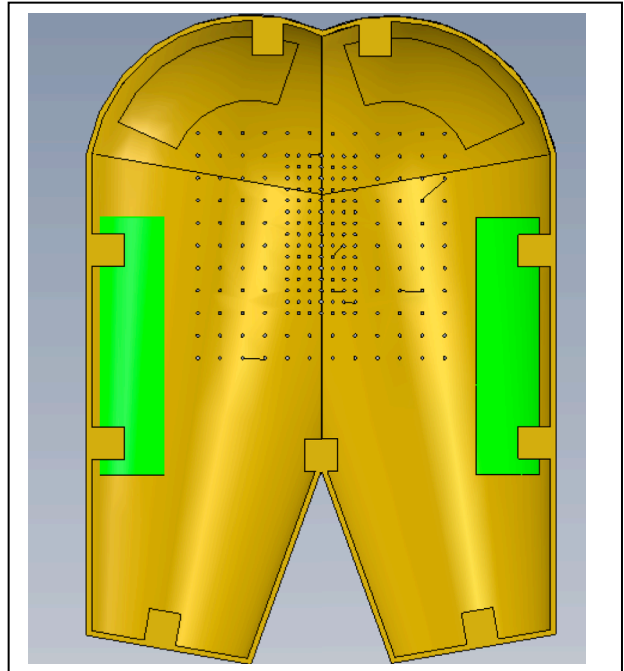


Figure 1: Strip heater locations on the inside of the bronze shell, highlighted in green.

was monitored with five heat and humidity sensors placed at the perineum, each IT, and each thigh. The BTRLI is mounted on a duo-uniaxial pneumatic loading frame, which allows the indenter to load a test surface via gravity through a linear bearing.

METHODS

Ambient conditions were measured throughout each trial. System temperature was set to 37 ± 1 °C and the BTRLI was allowed sufficient time for the temperature to reach equilibrium. The two evaporative towels were placed in the BTRLI while the indenter was heated. Each towel was primed with 100 mL of distilled water and placed back inside the indenter. The BTRLI was weighted to achieve a total load of 285 ± 10 N, before engaging the load onto the test surface. The temperature and humidity was measured and recorded every 30 s for a total of 180 minutes. Three trials were performed per surface. 60 minutes between identical surface trials was allowed in order for full surface recovery. Three full body support surfaces were used for testing: low air loss mattresses from KAP, Hill-Rom, and Freedom Medical.

Table 1: Average BTRLI-surface interface temperature and humidity at specified time points ($\alpha = 0.05$).

Average Temperature (°C)				
	60 minutes	120 minutes	175 minutes	Max
KAP	33.3 ± 0.2	33.3 ± 0.2	33.2 ± 0.2	33.4 ± 0.3
Hill-Rom 1	33.6 ± 0.1	33.8 ± 0	33.9 ± 0	33.9 ± 0
Hill-Rom 2	34.1 ± 0.1	34.3 ± 0.1	34.4 ± 0.1	34.4 ± 0.1
Freedom	34.2 ± 0.1	34.6 ± 0.2	34.7 ± 0.1	34.7 ± 0.2

Average Relative Humidity (%)				
	60 minutes	120 minutes	175 minutes	Max
KAP	83.1 ± 1.2	86.8 ± 0.6	88.3 ± 0.4	88.4 ± 0.4
Hill-Rom 1	72 ± 0.7	71.3 ± 0.5	71.4 ± 0.3	72.4 ± 0.5
Hill-Rom 2	80 ± 0.1	80.4 ± 0.1	80.4 ± 0.3	80.5 ± 0.2
Freedom	80.1 ± 0.5	81.9 ± 0.7	82.4 ± 0.8	82.5 ± 0.8

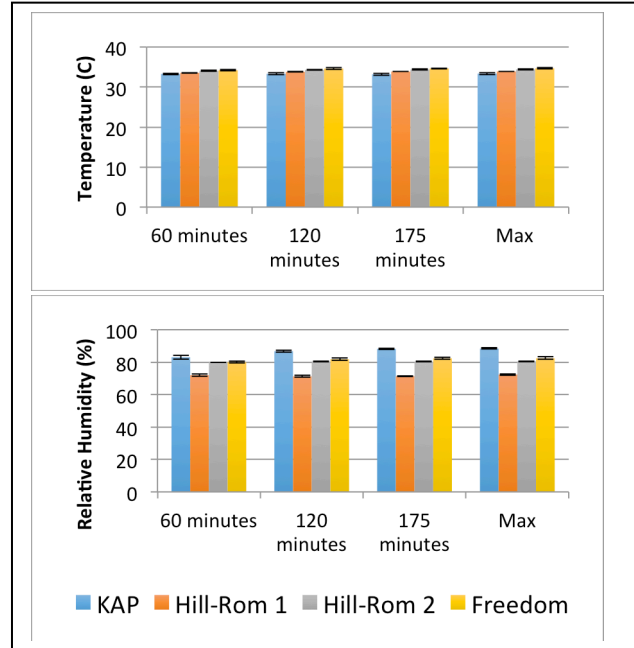


Figure 2: Interface temperature and humidity at specified time points ($\alpha = 0.05$).

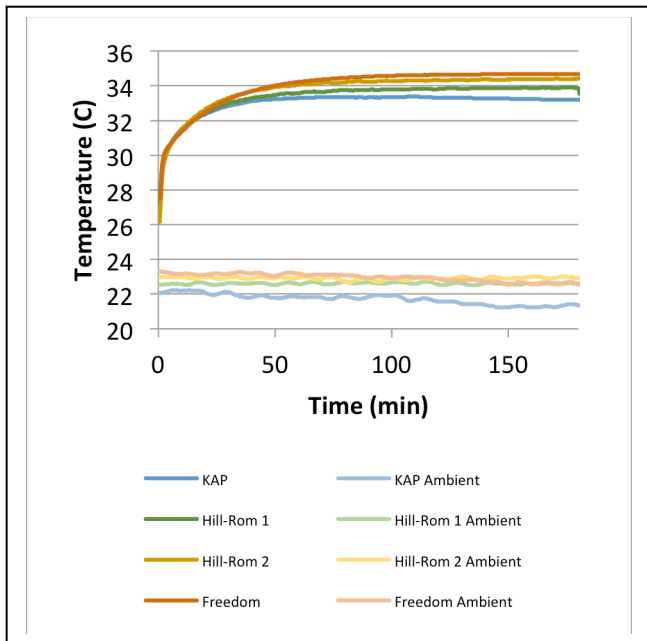


Figure 3: Average interface and ambient temperature over time, described for all surfaces.

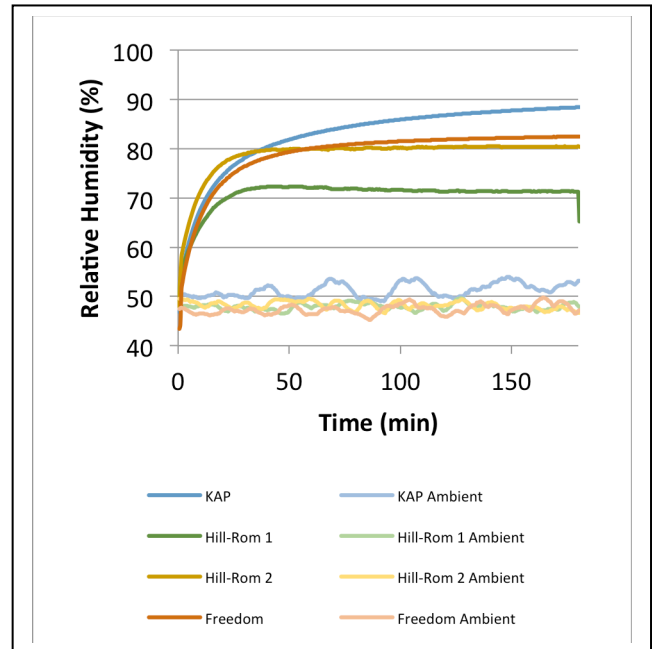


Figure 4: Average interface and ambient RH over time, described for all surfaces.

RESULTS

The BRLI performed to specification, allowing for the microclimate full body support surface characterization without failure or malfunction. Furthermore, the BTRLI

maintained its reliability and demonstrated repeatability throughout the duration of the testing period. Figure 2 – Figure 4 and Table 1 illustrate the test data.

DISCUSSION

The BTRLI temperature controller was programmed to maintain temperature at 37 °C. The observed maximum interface temperature across the four commercial low air loss mattresses was consistently similar, between 33-35 °C. Heat dissipation is the likely cause for the difference in controller and interface be the likely cause of the range in max relative humidity. Precise heat and moisture deliver was demonstrated with the BTRLI. This is substantiated by the low variance seen between trials for individual surfaces, across all surfaces, for both temperature and humidity.

No biofouling or microbial growth was observed while the BTRLI system was in use. Biofouling is one of the major and most cumbersome issues for the TRCLI. In the BTRLI, the moisture loaded evaporative towels provided a consistent method of moisture delivery, with little to no pore obstruction. In order to avoid microbial growth, the towels required drying after 8-12 hours of use. The BTRLI does face some limitations.

The most immediate limitation is the direct heating of the indenter perineum. The perineum is one of the warmest areas on the human body and the BTRLI system does not currently simulate that aspect. Another limitation is the corrosion of the bronze metal after repeated exposure to water. However, this is of little concern if maintenance is routine.

CONCLUSION

The BTRLI system is a repeatable and reliable alternative to the current TRCLI listed in microclimate testing standards. The system's method of moisture delivery avoids the complications of membrane biofouling and integrated maintenance. Constant heat and moisture delivery is observed through the commercial full body support surfaces tested.

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