A Laboratory Study Examining the Impact of Linen Use on Low-air-loss Support Surface Heat and Water Vapor Transmission Rates

Rachel Williamson, BS; Charlie Lachenbruch, PhD; and Catherine VanGilder, MBA, BS, MT, CCRA

Abstract

Layers of linens are frequently placed under patients to manage moisture and/or assist with positioning immobile patients, including persons placed on a therapeutic surface because they are at risk for developing pressure ulcers. Because skin microclimate is believed to affect pressure ulcer risk, some therapeutic surfaces are designed to manage skin temperature and humidity (microclimate management). The purpose of this study was to measure the effects of linens and underpads on a low-air-loss (LAL) surface’s ability to disperse heat and evaporate moisture. Underpads and transfer sheet combinations (grouped by three common linen functions: immobility, moisture management, and immobility and moisture management) were tested using the sweating guarded hot plate method, which allows for the measurement of the evaporative capacity (g H₂O/m²*hour) and the total rate of heat withdrawal (Watts/m²) associated with nine different linen configurations placed on the support surface.

Total heat withdrawal and evaporative capacity of the LAL surface with a fitted sheet only was used for comparison (P <0.05) Compared with fitted sheet only, heat withdrawal was significantly reduced by five of eight combinations, and evaporative moisture reduction was significantly reduced by six of eight linen combinations (P <0.05). All combinations that included plastic-containing underpads significantly reduced the surface’s ability to dissipate heat and evaporate moisture, and use of the maximum number of layers (nine) reduced heat withdrawal to the level of a static, non-LAL surface. The results of this study suggest that putting additional linens or underpads on LAL surfaces may adversely affect skin temperature and moisture, thereby reducing the pressure ulcer prevention potential of these surfaces. Additional studies to examine the effect of linens and underpads as well as microclimate management strategies on pressure ulcer risk are needed.

Keywords: bedding and linens, pressure ulcers, materials testing, skin, support surface, microclimate

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Potential Conflicts of Interest: The authors are all employees of Hill-Rom, Inc, Batesville, IN.

Underpads and layers of linens are placed under patients for numerous reasons, including incontinence, drainage, patient transfer, repositioning, and patient comfort. The strong associations between incontinence, immobility, and pressure ulcers identified by statistical analysis of cross-sectional prevalence studies also indicate that these layers frequently should be used with patients in need of a therapeutic support surface. By mining large databases such as the International Pressure Ulcer Prevalence Survey™ (IPUP™), it is clear that four, five, and more layers of linens frequently are used in combination with all types of support surfaces. Therefore, the effects these layers have on the tissue is an important aspect of patient care. The literature addresses the effects of microclimate on the skin and support surface performance, but the effect of linens and underpads on therapeutic surfaces as used in the clinical setting remains largely unknown.

Effect of Microclimate on the Skin

The term skin microclimate refers to the temperature and humidity of the skin. It has gained interest in recent years because a less-than-optimal skin microclimate may increase pressure ulcer risk.14
The body constantly produces a certain amount of heat and moisture that normally flows from the skin to the environment. When a patient lies on a support surface, this natural flow is impeded by the presence of the mattress. As heat and moisture accumulate at the interface, the skin warms and may become moist. Results of preclinical studies have shown that because warming the skin increases its metabolic demand, the tissue becomes hypoxic more rapidly under a given load, making it more susceptible to breakdown. Additionally, highly controlled laboratory studies have shown skin warming stimulates local perspiration, further wetting the skin and increasing friction while significantly reducing its mechanical strength.

Because of these factors, caregivers need to have information concerning the effects on pressure and microclimate of any materials introduced between the support surface and the patient.

**Effect of Linens and Pads on Microclimate Management**

Studies measuring the effects of incontinence pads or bed linens on microclimate management have not been published. One multicenter clinical trial conducted in 18 facilities compared the abilities of two incontinence pads — the test pad (PatientGuard Under pad™, PatientGuard Products, Pittsburgh, PA) and the reference pad (Large Super Duper Under pad Quilted, Dundee Under pads™, Dundee Healthcare Products, New York, NY) — to keep skin relatively dry, but the data were limited primarily to patient responses to questionnaires. Participants included 58 patients in the test group and 49 patients in the reference group. Mean Braden Scale scores in both groups were approximately 13, mean age (years) mid-70s, mean weight approximately 135 lb, and both groups were approximately two thirds female. The reference pad was ranked significantly higher than the test pad (PatientGuard Under pad™, PatientGuard Products, Pittsburgh, PA) and the reference pad (Large Super Duper Under pad Quilted, Dundee Under pads™, Dundee Healthcare Products, New York, NY) — to keep skin relatively dry, but the data were limited primarily to patient responses to questionnaires. Participants included 58 patients in the test group and 49 patients in the reference group. Mean Braden Scale scores in both groups were approximately 13, mean age (years) mid-70s, mean weight approximately 135 lb, and both groups were approximately two thirds female. The reference pad was ranked significantly higher than the test pad (P < 0.05) in four of eight categories of daily assessment (keeping skin dry, keeping clothing dry, no pooling of fluid, and patient comfort), with no significant differences in the remaining four categories (odor control, keeping bed linen dry, keeping the skin from reddening, and overall skin appearance). Of the patients exhibiting clinical improvement in skin status, 79% were included in the test group, suggesting the clinical importance of effective underpad performance by the categories selected for review. No information was reported regarding surface type or how the pad performance may have interacted with the surface to affect warmth or moisture.

Because of the dearth of information regarding linen layers and microclimate management, the current study was conducted to determine the effect of adding incontinence pads and sheet layers on a therapeutic low-air-loss (LAL) surface. Specifically, the intent was to determine the extent to which different product types impede two critical measures of microclimate management performance: heat withdrawal and evaporative capacity.

**Key Points**

- Patients who have or are at high risk for developing pressure ulcers frequently require skin moisture management, mobility assistance, and placement on a low-air-loss surface (LAL).
- To evaluate the effect of additional linen and underpad layers on moisture evaporation and heat, researchers tested these variables with a variety of linen layers.
- Almost all combinations reduced heat withdrawal and moisture evaporation, especially those that included plastic-containing underpads.
- The results of this sample of linen combinations suggest that clinicians should restrict extra linen use on these surfaces as much as possible.

**Methods**

LAL surface performance was assessed in two ways. The sweating guarded hot plate (SGHP) method was used to quantitatively measure total heat withdrawal capacity and evaporative capacity of a variety of linen configurations in the sacral region of a LAL surface. Infrared (IR) images then were obtained of a single human participant’s back following 3-hour exposure to two different linen/surface configurations. These IR images provided qualitative support for the less familiar SGHP measurements.

**Products.**

**Support surface.** The base surface for all linen testing was an Envision® E700 LAL surface (Hill-Rom, Batesville, IN), a high-end therapeutic mattress used for pressure ulcer prevention in high-risk patients and/or for patients with existing pressure ulcers. The E700 surface was selected because pilot testing has shown it to have relatively high levels of heat and moisture withdrawal compared with other surfaces on the market. The surface contains three zones (foot, pelvic, and head region) that are maintained at independent pressures to ensure optimal support. The surface automatically adjusts these support pressures for patients of different weights and for different head-of-bed angles. The upper layer of the surface is composed of a crushproof topper so air is able to flow under the body and withdraw excess heat and moisture despite compression of the surface due to the weight of the body.

**Linens.** Table 1 summarizes the linen and/or underpad configurations tested and the associated manufacturers. The baseline reference linen combination (combination 1) was a fitted sheet (60% cotton/40% polyester 0724 3400, Standard Textile Ultimate Knit Fitted Sheet, Cincinnati, OH) placed on the LAL surface. The other configurations tested were grouped by three common linen functions:
### Table 1. Linens and underpads evaluated

<table>
<thead>
<tr>
<th>Grouping</th>
<th>Abbreviation</th>
<th>Linen or Description</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>1) FS</td>
<td>Fitted Sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td><strong>Immobility configurations</strong></td>
<td>2) FS, RS</td>
<td>Repositioning sheet</td>
<td>MIP Patient Positioning Device PTD-5 (Montreal, Quebec)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td></td>
<td>3) FS, QC:</td>
<td>Quilted Chux</td>
<td>Standard Textile Comply Excel Wrappel T Barrier 30”x36” 60% cotton/40% polyester 61059102 (Cincinnati, OH)</td>
</tr>
<tr>
<td>(ST) NP</td>
<td></td>
<td>without a plastic backing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td></td>
<td>4) FS, QC:</td>
<td>Quilted Chux</td>
<td>Angelica Reusable Pad (29”x32”) (Alpharetta, GA)</td>
</tr>
<tr>
<td>(ANG) P</td>
<td></td>
<td>with a plastic backing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td><strong>Moisture management</strong></td>
<td>5) FS, UP:</td>
<td>Plastic-backed</td>
<td>Attends Classic Underpad – Extra Absorbency 30”x36” 86679-24501 (Greenville, NC)</td>
</tr>
<tr>
<td>configurations</td>
<td>(ATT) D P</td>
<td>disposable pad</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td></td>
<td>6) FS, UP:</td>
<td>Paper-backed</td>
<td>Attends Air-Dri Breathables Plus Layered Underpad 30”x36” 86679-23948 (Greenville, NC)</td>
</tr>
<tr>
<td>(ATT) D NP</td>
<td></td>
<td>disposable pad</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td></td>
<td>7) FS, UP:</td>
<td>Paper-backed</td>
<td>Medline Ultrasorbs AP 31”x36” ULTRASORB3136 (Mundelein, IL)</td>
</tr>
<tr>
<td>(MED) D NP</td>
<td></td>
<td>disposable pad</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td><strong>Immobility and moisture management</strong></td>
<td>8) FS, RS, UP: (ATT) D NP</td>
<td>Disposable pad</td>
<td>Attends Air-Dri Breathables Plus Layered Underpad 30”x36” 86679-23948 (Greenville, NC)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Repositioning sheet</td>
<td>MIP Patient Positioning Device PTD-5 (Montreal, Quebec)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
<tr>
<td><strong>6 linen layers</strong></td>
<td>9) FS, BB,</td>
<td>Quilted Chux</td>
<td>Angelica Reusable Pad (29”x32”) (Alpharetta, GA)</td>
</tr>
<tr>
<td>FS, QC-Plastic, BB, QC - Plastic</td>
<td></td>
<td>with a plastic backing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bath blankets (2)</td>
<td>Standard Textile Bravado Bath Blanket 50% cotton/50% polyester 72”x90” 80155110 (Cincinnati, OH)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quilted Chux</td>
<td>Angelica Reusable Pad (29”x32”) (Alpharetta, GA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with a plastic backing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flat sheet folded</td>
<td>Bibb Hospitality Flat Sheet 50% cotton/50% polyester 81”x108” T-180 (Atlanta, Georgia)</td>
</tr>
<tr>
<td>into quarters</td>
<td></td>
<td>into quarters</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fitted sheet</td>
<td>Standard Textile Ultimate Knit Fitted Sheet 60% cotton/40% polyester 0724 3400 (Cincinnati, OH)</td>
</tr>
</tbody>
</table>

**Abbreviations:** FS = fitted sheet, BB = bath blanket, QC = quilted Chux, UP = underpad, DP = disposable, P = plastic-backed, NP = nonplastic-backed, RS = repositioning sheet, ST = Standard Textile, ANG = Angelica, ATT = Attends, MED = Medline, MIP = Med-I-Pant
1) repositioning of immobile patients (immobility), 2) moisture management, and 3) immobility and moisture management. The immobility configurations are represented by a fitted sheet and reusable pad (with or without plastic) that may aid in patient repositioning or turning. These included the fitted sheet plus a repositioning sheet (Medi-I-Pant [MIP] Patient Positioning Device PTD-5, Montreal, Quebec — combination 2); the fitted sheet and a quilted Chux without plastic backing (60% cotton/40% polyester 61059102, Standard Textile Comply Excel Wrap T-Barrier 30” x 36”; Cincinnati, OH — combination 3), and the fitted sheet with a quilted Chux with plastic backing (Angelica Reusable Pad 29” x 32”, Cincinnati, OH — combination 4).

The moisture management configurations comprised a fitted sheet and disposable pad (with or without plastic) frequently used to manage incontinence or excessive fluid. These included the fitted sheet plus a plastic-backed disposable pad (Attends Classic Under pad — Extra Absorbancy 30” x 36” 86679-24501, Greenville, NC — combination 5), the fitted sheet plus paper-backed disposable pad (Attends Air-Dri Breathables plus layered under pad 30” x 36” 86679-23948, Greenville, NC — combination 6); and the fitted sheet plus a second paper-backed disposable pad (Medline Ultrasorbs AP 31” x 36”, ULTRASORB 3136, Mundelein, IL — combination 7).

The immobility and moisture management configuration (combination 8) involved a Standard Textile fitted sheet, the MIPS repositioning sheet, and an Attends Air-Dri Breathables incontinence pad.

The final combination (combination 9) included the fitted sheet, a flat sheet folded into quarters (Bibb Hospitality Flat Sheet 50% cotton/50% polyester 81” x 108” T-180; Atlanta, GA), two bath blankets (Standard Textile Bravado Bath Blanket 50% cotton/50% polyester, Cincinnati, OH), and a quilted Chux with plastic backing (Angelica Reusable Pad 29” x 32”, Alpharetta, GA). Because this sheet was folded, this configuration included a total of 11 layers of linen between the surface and the test device.

**Microclimate management capability measurement.** Evaporation, a component of microclimate, was measured by the SGHP method using a test device adapted specifically for use with support surfaces (ST-2 Comfort Test System, Measurement Technologies, Seattle, WA) as described by Nicholson et al. The method is used to measure the rate at which heat and water vapor are withdrawn from the skin and transmitted through the support surface and into the environment. The method was recently approved by the National Pressure Ulcer Advisory Panel’s (NPUAP) Support Surface Standards Initiative (S3I) as a national standard for testing microclimate management performance. The SGHP test device was calibrated before the study by the manufacturer (Measurement Technologies, Seattle WA) to ensure accurate measurement of all temperature and flux sensors.

**Procedure.** The surface testing involved two phases. First, a thermal test device (the SGHP) was placed in the center of the mattress to measure the mattresses’ heat transmission characteristics. This initial measurement, termed the dry flux (expressed in Watts/m²), indicates the degree to which heat is transmitted through the surface. Foam surfaces transmit little heat (ie, the dry flux is low), therefore, heat accumulates, causing the skin to warm. LAL surfaces typically facilitate much higher levels of dry flux or heat transmission through the surface, less heat accumulation, and less warming of the skin. The clinical importance of the dry flux through a surface is that it determines the effect of a given support surface on skin temperature. If the dry flux is low, the skin will be relatively warm and vice versa.

In a second phase, the test is repeated with a constant flow 200 g/m²•hour of water introduced to the test surface. This rate was selected because it was determined through pilot work to exceed the evaporative capacity of the surface with all linen configurations. Due to infection-control policies, hospital mattresses are generally designed to only allow individual H₂O molecules to pass through the mattress cover in order to mitigate the risk of surface contamination by bodily fluids. Thus, any water passing through the cover and into the surface must enter as vapor rather than liquid water. Because a known amount of energy must be supplied to vaporize 1 g of water, this facilitates quantification of the moisture that has been evaporated by the rate that additional energy is consumed during the wet test. The wet flux is the additional rate of energy consumption that can be attributed to the evaporation of water; therefore, its clinical importance is that it is used to determine the evaporative capacity of a support surface using the simple conversion equation between wet flux (Watts/m²) and evaporation rate (g/m²•hour) that is derived below. The equation is useful because it allows determination of the amount of evaporation that has taken place using only wet flux measurements.

A specific amount of energy must be absorbed from the environment to free individual molecules to permeate the surface, because only free molecules are allowed to pass through. The energy absorbed when a given amount of water is transformed from the liquid to gaseous phase is called the latent heat of vaporization. It is 2,528 Joules (J)/g at the test plate temperature of 35°C; and it is used to convert the rate of energy consumption measured by the SGHP to the value of clinical interest, evaporation rate.

The evaporation rate from the test plate per unit area can be calculated from the rate that heat energy is supplied to the test plate and the energy required for vaporization. Using the fact that 2,528 J of energy are required to evaporate 1.00 g of water, the evaporation rate for a flux of 1.00 W/m² then would be:

\[
\text{Evaporation Rate} = \frac{W}{m^2} = \frac{1}{2528} \frac{J}{g}
\]

Substituting 1 W = 1 J/s into (1) gives (2)
Evaporation Rate = \( \frac{(1/\text{g}) + (1/\text{g})}{2528} \text{#/g} \) 

(2)

To express the evaporation rate on a per-hour basis, (2) is multiplied by the number of seconds in an hour.

Evaporation Rate = \( \frac{(1/\text{g}) + (1/\text{g})}{2528} \times 3600 \text{s/hr} \) 

(3)

= 1.42 \( \frac{\text{g}}{\text{m}^2\cdot\text{hr}} \) 

(4)

Equation (4) is the conversion factor that was used to convert wet flux to evaporative capacity.

Dry trials: measurement of surface dry flux. For baseline, the support surface was covered with a standard fitted sheet and set to operate in its standard therapeutic support mode. The thermal test device — ie, the SGHP — was placed in the center of the support surface with the test plate facing downward. It was loaded with weight sufficient to bring the mean interface pressure over the bottom of the test device to approximately 25 mm Hg. This loading was selected to mirror the typical mean loading in the pelvic region for a 50th percentile weight patient.17 The SGHP was covered with a medium-weight cotton blanket folded in quarters. Through pilot study, it was determined that when the blanket is folded to create more than one layer over the top of the SGHP, the amount of heat that escapes upward — ie, not downward through the support surface itself — is negligible. This allows one to assume for purposes of analysis that all heat that is withdrawn from the test device is transmitted through the support surface.15 The test plate was set to maintain a constant temperature of 35.0˚ ± 0.1˚ C. The power flux (W/m²) required to hold this temperature was measured continuously and allowed to reach equilibrium. Equilibrium was defined as the point at which the power required to maintain the test plate at a constant temperature was constant within ± 0.5% over an interval of 30 minutes. Three trials were conducted in the sacral region of the surface. Dry flux was calculated as the mean of these three trials.

Wet trials: measurement of wet flux. The steps outlined were repeated on each surface with one exception: water was evenly supplied to the test plate at a rate set to ensure that some excess was always present, regardless of the capacity of the surface to withdraw moisture. Through pilot work, this rate was set to 200 g/m²·hour. The equilibrium flux again was determined as the mean of the three wet trials. This total equilibrium flux includes both the dry flux and the wet flux, the power associated with evaporation.14,15

The evaporative capacity was calculated from the wet flux using equation (4).

Data collection and analysis. Data were downloaded to a spreadsheet in Microsoft Excel.18 Differences between mean values of heat withdrawal and evaporative capacity were determined by one-way ANOVA with follow-up Fisher-Hayter test. Alpha level was set at 0.05. All statistical analyses were performed using the Excel Analysis Tool-Pak.18

IR imaging. Equilibrium skin temperature also was measured using an IR camera (Avio TVS-8500, NCE Avio Infrared Technologies Co, Ltd., Tokyo, Japan). The Envision LAL surface was placed on a VersaCare frame and set up according to manufacturer’s instructions. An NP100 foam surface was placed on an Advanta™ frame (all aforementioned products are from Hill-Rom, Inc, Batesville, IN). A fitted sheet was positioned over the support surface. The IR camera was positioned on a tripod approximately 15 feet away from the bed. The temperature scale (°F) on the camera was set to “Auto” to optimize the visual output of the image. The bed being tested was positioned at 30˚ head-of-bed elevation with an auto contour knee angle. The torso and seat section of the surface was completely covered with water.

The human participant was a 135-lb, healthy 61-year-old woman. She was selected to reasonably reflect a typical US hospital patient and was dressed in a standard hospital gown with no undergarments. She was instructed to lie supine with the entire underside of her body exposed to the surface. Care was taken to ensure her hospital gown was not underneath her. She remained in this position for 3 hours to ensure the skin temperature had reached steady state. Steady state was defined as ±0.5˚F over 15 minutes and determined from previous laboratory pilot tests of 10 test persons on five support surfaces with various levels of total heat withdrawal capacity. The 3-hour duration likewise was determined by extensive pilot work, during which it was established that this period allowed steady state thermal conditions to be achieved on all surface types tested. It is consistent with the test period used in the NPUAP/SII test of timed MCM performance.19 After 3 hours, the bed was positioned flat and the surface was put into maximum inflate mode to minimize immersion and allow for increased view of the back. Immediately after the woman was rolled to her side by a technician, an IR image was taken of the buttocks. Images were collected under three surface configurations: 1) after lying for 3 hours on the LAL surface with a fitted sheet only (configuration 1), 2) after lying for 3 hours on the LAL surface with a fitted sheet and breathable (nonplastic-backed) disposable incontinence pad (configuration 5), and 3) after lying for 3 hours on a foam surface with a fitted sheet only. The images were collected on three successive days.

Results

Effect of linens on LAL performance: heat withdrawal and evaporative capacity. The reported values for total heat withdrawal capacity are presented in Table 2 and graphically in Figure 1. They are indicative of the surface’s total ability to withdraw heat when unlimited moisture is present due to temperature differences between the skin and the stream of air, as well as to evaporation. The greater the total heat withdrawal, the better the surface’s ability to remove heat and combat excess warming of the skin.
Layers of Linens and Heat and Water Vapor Transmission

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total heat withdrawal capacity (W/m²)</th>
<th>Configuration</th>
<th>Total heat withdrawal capacity (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: LAL: FS</td>
<td>72.5</td>
<td>#2: FS, RS</td>
<td>74.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3: FS, Std Tex QC NP</td>
<td>56.9*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4: FS, Ang QC NP</td>
<td>34.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5: FS, Atd DP P</td>
<td>33.8*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6: FS, Atd DP NP</td>
<td>76.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7: FS, Med DP NP</td>
<td>61.6*</td>
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<tr>
<td></td>
<td></td>
<td>8: FS, RS, Atd DP NP</td>
<td>67.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9: FS, BB, FS x 4, QC, BB, QC</td>
<td>25.8*</td>
</tr>
<tr>
<td>Static air: FS</td>
<td>28.2*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total heat withdrawal on the LAL surface is shown for each linen layer combination (Column 4) when compared to the fitted sheet alone on LAL (configuration 1 shown in the left column). All but three configurations were significantly less (*P < 0.05). The bottom row shows a static air surface with fitted sheet alone and is also statistically significant (bP < 0.05) when compared to the LAL surface.

Abbreviations: FS = fitted sheet, BB = bath blanket, QC = quilted Chux, UP = underpad, DP = disposable, P = plastic-backed, NP = nonplastic-backed, RS = repositioning sheet, ST = Standard Textile, ANG = Angelica, ATT = Attends, MED = Medline, MIP = Med-I-Pant

Table 3 presents the evaporative capacity results of the LAL surface with a fitted sheet (left side of table) and the results of the same configuration with various additional linens (right side). Evaporative capacity of the LAL surface with the fitted sheet (configuration 1) alone was 60.6 g/m²*hour. Two configurations did not significantly reduce the surface’s ability to evaporative moisture: configuration 3 (fitted sheet plus Standard Textile nonplastic-backed quilted Chux, 56.9 W/m², P < 0.05), configuration 4 (fitted sheet plus Angelica reusable pad with plastic backing, 34.4 W/m², P < 0.05), configuration 5 (fitted sheet plus Attends disposable pad with plastic backing, 33.8 W/m², P < 0.05), configuration 7 (fitted sheet plus Ultrasorbs pad with nonplastic backing, 61.6 W/m², P < 0.05), and configuration 9 (fitted sheet plus two Standard Textile bath blankets, a flat sheet folded into quarters, and two Angelica Quilted Chux with plastic backing, 25.8 W/m², P < 0.05).

Figure 1. Total heat withdrawal capacity for different surface and linen configurations. Linen configurations are numbered on the X axis (see Table 1). Each bar represents the mean and 95% confidence intervals for three trials.

DO NOT DUPLICATE

DO NOT DUPLICATE
repositioning sheet with the Attends disposable underpad without plastic, 53.4 g/m²·hour, ns).

Five linen configurations resulted in significant reductions in evaporative capacity compared to the surface with the fitted sheet alone (60.6 g/m²·hour): configuration 3 (the fitted sheet with the Standard Textile Quilted Chux with nonplastic backing, 39.3 g/m²·hour, \( P < 0.05 \)), configuration 4 (the fitted sheet with the Angelica Quilted Chux with plastic backing, 7.9 g/m²·hour, \( P < 0.05 \)), configuration 5 (the fitted sheet with the Attends plastic-backed disposable pad (0.9 g/m²·hour, \( P < 0.05 \)), configuration 7 (the fitted sheet with the Medline nonplastic-backed disposable pad, 46.7 g/m²·hour, \( P < 0.05 \)), and configuration 9 (the fitted sheet, two Standard Textile Bath Blankets, flat sheet folded into quarters, and two Angelica Quilted Chux with plastic backing (4.8 g/m²·hour, \( P < 0.05 \)).

Also noteworthy was the observation that the combination of the fitted sheet with the Attends nonplastic-backed disposable pad (configuration 6) caused a significant increase in evaporative capacity (70.7 g/m²·hour, \( P < 0.05 \)).

IR images. Figures 3a, b, and c show the skin temperature distribution of a 135-lb woman after 3 hours lying supine at 30° head-of-bed elevation under three different surface configurations. The images provide a more visual illustration of the ability of a surface to manage skin microclimate. Because the surface was covered with moisture before lying down, the thermal images reflect both the ability of the surface to withdraw heat by evaporation and by other cooling mechanisms.

These images facilitate two primary observations. Figure 3a (after laying for 3 hours on the LAL surface with a fitted sheet only,
configuration 1) and 3b (after laying for 3 hours on the LAL surface with a fitted sheet and breathable disposable incontinence pad A, configuration 5) differ markedly; the second image exhibits a much warmer temperature distribution overall. Although both images were collected following 3 hours on the LAL surface, the increased areas of red and yellow on the second image demonstrate the increased warming associated with the use of the breathable disposable pad in comparison to no pad. The mean temperature on the LAL surface without the pad (see Figure 3a) was approximately 91.0˚ F versus approximately 93.0˚ F with the pad (see Figure 3b). Figures 3b and c (after laying for 3 hours on the LAL surface with a fitted sheet and the breathable disposable incontinence pad) present a second comparison. Unlike Figure 3a, Figures 3b and c both have notable areas of warm (red) skin, despite the fact that images 3a and b were taken following exposure to the LAL surface and 3c followed exposure to a foam surface. The mean temperature of the back in Figure 3b is approximately 93.8˚ F. The mean skin temperature following exposure to the LAL surface with the incontinence pad (93.0˚ F) therefore was closer to that of the foam surface (93.8˚ F) than to the LAL surface without the incontinence pad (91.0˚ F).

The images generally confirm that the presence of certain linen configurations placed between the skin and a high-end, LAL surface can reduce the heat withdrawal capacity to that of a passive foam surface.

Discussion

The results of this study indicate that the presence of linens or incontinence products between a support surface and the body can significantly affect the microclimate management capabilities of a support surface. Unfortunately, patients who are at risk for or already have pressure ulcers frequently are also incontinent and/or immobile. This study suggests that one factor adding to the risk of pressure ulcers may be the effect of linen and incontinence pad overutilization.

Pad construction appeared to play a role in the degree to which the pad interfered with the surface’s ability to remove heat and moisture from the skin/support surface. A comparison of configurations 5 (the fitted sheet with Attends disposable pad with plastic backing, “nonbreathable”) and 6 (the fitted sheet with Attends disposable pad with nonplastic backing, “breathable”) showed configurations with the plastic backing resulted in a reduction in total heat withdrawal capacity from 72.5 W/m² to 33.8 W/m² (53%). There was no reduction for configuration 6 (76.9 W/m²), which included the nonplastic-backed pad. Overall, the three configurations that included plastic-backed pads caused reductions in heat withdrawal of 53% (configuration 4), 53% (configuration 5), and 64% (configuration 9), compared with lesser reductions for those including nonplastic-backed pads: -2% (configuration 2), 23% (configuration 3), -6% (configuration 6), 15% (configuration 7), and 7% (configuration 8). Although heat withdrawal varied widely between configurations (33.8 W/m² for configuration 5 to 74.5 W/m² for configuration 2), it was still higher in all cases than the static air surface (28.2 W/m², P <0.05). Thus, none of the nonplastic-backed disposable pads completely negated the benefits of the LAL surface with respect to heat withdrawal.

Trends similar to those noted in the reduction of total heat withdrawal were evident with evaporative capacity. Configuration 5 with the plastic-backed pad caused a reduction from 60.6 g/m²*hour for the fitted sheet baseline to 0.9 g/m²*hour (99% reduction) versus 70.7 g/m²*hour for configuration 6 with the nonplastic backing (no significant reduction). Any configuration including a plastic-backed pad reduced evaporative capacity by 87% to 99% compared to the fitted sheet only. Generally, the impact of plastic versus nonplastic backing was greater on evaporative capacity than on total heat withdrawal.

Another interesting observation was the fact that one configuration — the combination of the fitted sheet with the Attends nonplastic-backed disposable pad — caused a significant increase in evaporative capacity. Although the mechanism is unclear, one possibility is that some pads may cause lateral wicking of moisture, increasing the wetted area and increasing exposure of this moisture to the evaporative surface. Some very recent evidence from the field may support the general concern that excess use of underpads and linens may increase pressure ulcer incidence. In response to an earlier presentation of a portion of the current work conducted by Williamson and Sauser, the hospital at the University of Pennsylvania instituted a “Less is Best” program focused on reducing the number of layers of linen under each patient. In Williamson and Sauser’s lab study, the SGHP method was used to assess the effect of linen combinations on LAL performance. Among other findings, they reported that adding a single quilted Chux to the same LAL surface used in the current study decreased the heat withdrawal capacity from 82.4 W/m² to 33.8 W/m², a reduction of 59% (P <0.001). Based on these results, the University of Pennsylvania instituted a linen audit to reduce the amount of linen layers placed between the support surface and the patient’s skin. Over a 6-month period, the proportion of patients with three or more layers was reduced from 58% to 26%, and the proportion with multiple incontinence pads was reduced from 26% to 0.4%. At the same time, the rate of facility-acquired pressure ulcers decreased from 7.2% to 3.1%, although actual numbers and significance were not reported.

In a recent cross-sectional study of 97,203 patient records included in the 2011 IPUP™ survey, the prevalence of pressure ulcers Stage II and above was calculated relative to the expected prevalence for each Braden score. When corrected for Braden Scale Risk score, prevalence of both overall and facility-acquired pressure ulcers Stage II and higher increased with number of linen layers. The Braden-adjusted rates of
overall and facility-acquired prevalence were equivalent for one through four layers of linen. However, for five plus layers, the Braden-adjusted rate of facility-acquired prevalence was significantly higher than the Braden-adjusted rate of overall prevalence \( (P = 0.0001) \). This observation is consistent with the possibility that high numbers of linen layers used in facilities leads to increases in facility-acquired pressure ulcers relative to the expected value according to Braden.

This same study\(^2\) indicated 64.2% of patients had two or more linen layers between the support surface and the skin, 22% had three or more layers, and 5% had four or more layers. Additionally, this distribution of the number of linen layers was the same on LAL products to the distribution on passive foam surfaces, suggesting the connection between surface performance characteristics and the number of linen layers is not yet widely appreciated among caregivers.

In additional clinical evidence\(^1\) regarding the effectiveness of underpad performance with respect to moisture control, a reusable test underpad judged by caregivers to be better at keeping skin and clothing dry and minimizing pooling of fluid also was associated with better clinical outcomes than a reusable heavy quilted reference underpad. Overall, four times as many patients in the test group exhibited improvement in skin status than persons in the reference group.

The present study appears to be the first attempt to assess the effects of a broad range of linen and incontinence pad combinations on microclimate management. These results indicate that the presence of a repositioning sheet did not significantly decrease either the heat withdrawal or evaporative capacity of the test surface over the presence of a fitted sheet alone. They also illustrate the apparent importance of selecting a breathable incontinence pad, but not all breathable pads produce the same results.

The nonplastic-backed pad used in configuration 6 did not cause a reduction in either microclimate management variable. The nonplastic-backed pads used in configurations 3 and 7 produced statistically lower total heat withdrawal and evaporative capacity than the fitted sheet only configuration. By contrast, both plastic-backed configurations 4 and 5 reduced the heat withdrawal capacity to less than half the value with the fitted sheet alone. The evaporative capacity was reduced in both cases by approximately 90%. Therefore, the two nonbreathable (plastic-backed) incontinence pads reduced the heat withdrawal capacity on the high-performance LAL product to a

Figure 3. (A) Low-air-loss surface with fitted sheet. (B) Low-air-loss surface with fitted sheet and breathable disposable pad. (C) Standard foam with fitted sheet.
level only slightly higher than that of a powered, non-LAL static air surface. The evaporative capacity was, in fact, actually significantly less than that of the foam-topped static air surface.

The results reported here indicate that some combinations of incontinence pads and linens can adversely affect the ability of a LAL surface to manage the microclimate of the skin. More work is needed to build on the results of this study and to assess further the effect of the skin microclimate on pressure ulcer incidence.

Limitations
Data are not available to identify which specific variables (interface pressure or microclimate management) have a greater impact on the progression of skin damage that leads to pressure ulcer formation; the presence of linens have been reported to affect both. In addition, the number of combinations of linen products intended for surface use is very large; therefore, it is difficult to test anything beyond a small set of configurations. The present study only used a small portion of currently available products. More research is needed to determine the common characteristics of linen products that do and do not severely impact skin microclimate and other factors that may affect skin integrity. Although the SGHP method used is believed to accurately measure the heat and H2O withdrawal characteristics of the support surface/linen configuration, the fact that the linens were smoothed free of wrinkles for measurement reproducibility represents a departure from the true clinical situation. It is unclear what effect pad wrinkling would have on performance.

Conclusion
A less-than-optimal skin microclimate may increase the risk of skin breakdown. The results of this study illustrate that the presence of linens on the bed surface often reduces the ability of a LAL surface to combat heat and moisture accumulation at the skin/support surface interface. This suggests that caregivers should try to limit the presence of linens on the surfaces to products that are absolutely necessary. This is particularly true when using high-performance, therapeutic surfaces such as LAL, the performance of which is most likely to be affected. In this study, the use of a linen configuration had widely varying effects on surface heat withdrawal capacity depending on the specific configuration. Compared with heat withdrawal level of 72.5 W/m² for the fitted sheet alone, heat withdrawal levels for the various linen combinations varied from 25.8 W/m² to 76.9 W/m². Use of nine layers reduced the heat withdrawal to the level of a static non-LAL surface. Effects on evaporative capacity were also highly variable. One configuration caused a significant increase in evaporative capacity over the fitted sheet alone, while other configurations reduced evaporative capacity as much as 99%. The lowest evaporative capacity was associated with the use of a plastic-backed pad. In direct comparison, plastic-backed pads interfered with heat withdrawal and evaporative capacity more than nonplastic-backed pads. It is hoped that the data presented can assist caregivers with decisions regarding interventions.

REFERENCES