

Validation Test for Climate Control on Air-Loss Supports

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ABSTRACT. Reger SI, Adams TC, Maklebust JA, Sahgal V. Validation test for climate control on air-loss supports. *Arch Phys Med Rehabil* 2001;82:597-603.

Objective: To develop a simple, reproducible validation test protocol for classification of air-loss support systems.

Design: Simultaneous experimental measurement of moisture loss and temperature reduction at the air-loss support surface–human body equivalent interface from a sweating human skin analogue.

Setting: A hospital department of physical medicine and rehabilitation.

Other Participants: These 3 manufacturers contributed 14 support surfaces.

Interventions: Test support surfaces and a standard foam mattress were placed on a hospital bed. Water was circulated to a loading gauge, placed on a dry moisture reservoir, and connected to a water bath to keep the interface at $37^{\circ} \pm 0.5^{\circ} \text{C}$. The loading gauge and support surface was adjusted 23cm below the water bath level and the air flow through the interface initiated. After the dry moisture reservoir came to temperature equilibrium for 30 minutes, it was replaced with a wet one that was saturated with 36g of saline. The temperature change and evaporation rate were recorded throughout a 90-minute test period.

Main Outcome Measures: Temperature of support surface interface and evaporation rate.

Results: Clustered data from temperature reduction and standardized rate of moisture loss yielded 3 groups of support surfaces in categories of no air loss (control), low air loss (LAL), and high air loss. The mean values of the characteristic temperature reduction and rate of moisture loss differed significantly between the groups. By multiple comparisons with Bonferroni's adjustment, the group means differed significantly for average temperature reduction ($p < .017$) and for standardized rate of moisture loss ($p = .0001$). The measured temperature change at any instant of time reflected the effect of evaporation and the opposing effect of thermal conductivity.

Conclusion: Measurements of support interface climate change allowed for selective grouping of LAL surfaces according to rate of moisture evaporation and the resulting temperature reduction. Neither temperature change nor evaporation rate alone was sufficient to determine the microclimate characteristics of the support surface. Combined, these characteristics can effectively describe the performance of any LAL

support system and may be used to define standards of performance.

Key Words: Pressure ulcers; Thermal conductivity; Rehabilitation; Skin temperature; Sweat.

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DYNAMIC LOW-AIR-LOSS (LAL) support surfaces have been used to prevent and treat pressure ulcers in both acute and chronic care settings.¹⁻⁴ There are various designs from which to choose. Air loss designs range from mattress overlays and replacement mattresses, to complex adjustable low- to high-air-loss beds. The quality of LAL support is a function of both interface pressure and the microclimate (temperature, humidity, air flow) at the patient support contact.⁵ Control of pressure and moisture at the patient support surface interface was initially suggested by Scales and Hopkins.⁶ In their design, temperature-controlled air was contained in 21 vapor-permeable and water-impermeable cushions that could deform congruently to the body and, hence, support the patient with evenly distributed pressure.⁷ Today, specialized blower-inflated, porous air cushions produce body immersion, increased contact area, and reduced pressure at the support interface. The flowing air creates the tendency to float the user on a cushion of air. Pressure is reduced by adjusting the air cushion inflation according to body weight and size while maintaining constant flow through the cushions. Some designs use a loose fitting, vapor-permeable and water-impermeable cover over the air cushion and below the patient. Others, without a cover over the cushions, allow air to escape directly onto the patient interface. Both of these LAL designs control the pressure and airflow under the patient. The flowing air evaporates skin moisture and keeps a stable, drying environment with reduced temperatures.

Without airflow over the skin or vapor diffusion through the cover, moisture can accumulate at the support interface. Moisture accumulation on the skin is an important physical factor predisposing to the occurrence of pressure ulcers, and body fluids and chemical irritants from fecal and urinary incontinence have been associated with tissue break down.^{8,9} Excessive moisture on the skin softens the stratum corneum (maceration), reduces the cross linking of the collagen molecules, and reduces the stiffness and the strength of the connective tissue. Overhydration of the skin also increases the coefficient of friction that contributes to adhesion of skin to the support surface. This adherence of the weakened skin structures add to shear effects and can promote abrasion, sloughing, and ulceration as a patient moves across the bed surface.¹⁰ Skin moisture buildup also dilutes the skin acidity, which reduces the antibacterial properties of the epidermal layers and increases the risk of infection.

Skin water loss ranges from insensible perspiration (a form of passive water diffusion) to profuse active sweating that reduces heat buildup and control body temperature. The cutaneous water loss is determined by the ambient temperature, humidity, and the local and neural regulatory mechanisms of the body. Mechanisms elevating the body temperature will increase the metabolic activity of tissues. For every 1°C increase in body temperature, there is a 10% increase in meta-

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bolic rate.¹¹ Thus, a 3°C fever will induce an approximate 30% increase in energy and oxygen needs at the cellular level. A feverish patient with impaired local circulation from pressure can have tissues starving. Cellular metabolism may then cease from lack of energy and the accumulation of waste products. Studies have confirmed an increase in skin temperature both from the insulating effect of a support cushion¹² and from reactive hyperemia after removal of local pressure on the skin.¹³

An experimental animal study on pressure ulcers¹⁴ further demonstrated the progressive nature of local pressure-induced tissue injury with increasing temperature. A 5-hour application of 100mmHg pressure on the skin increased partial-thickness soft-tissue injury at 35°C and 40°C, and full-thickness injury at 45°C.¹⁵ In contrast, the same pressure and duration resulted in no damage to the tissues at 25°C, strongly suggesting that soft-tissue injury at normal pressure can be prevented by temperature modulation.¹⁴⁻¹⁶

On the skin surface, evaporative water loss acts as a heat sink that can result in significant cooling of deep and surface body temperatures. From physical measurements, it has been determined that the latent heat of vaporization can remove 580Kcal of heat for every kilogram of water evaporated from the surface. The reported daily water loss¹⁷ through the skin due to insensible perspiration and active sweat loss is summarized in table 1.

Thus the cooling power of the water loss through the skin for an average person with 1.8m² skin surface area at the lowest rate of total water loss is calculated to be $(26.7\text{g}/(\text{m}^2 \times \text{hr}) \times .58\text{Kcal/g} \times 1.8\text{m}^2) = 27.9\text{Kcal/hr}$. Water loss from the skin cools through evaporation. Evaporation is driven by the difference in vapor pressure of water at the skin surface and in the air. Thus when air is stagnant, humidity is high, the difference is low and evaporation is not effective. With air movement, low-humidity air is brought near the skin, evaporation increases, and effective cooling occurs. Air flow on the surface will regulate skin temperature and prevent sweating at moderate ambient temperatures.¹⁷ Absent airflow, absorptive moisture removal (or wicking) will not cause temperature reduction at the support interface. The effectiveness of air-loss surfaces, therefore, must be evaluated by their ability to evaporate moisture and to reduce temperature build up at the support surface.

Flam et al¹⁸ compared the change in skin temperature and skin moisture on a LAL support system and a standard hospital mattress. The results over a 3-hour test period indicated a significant reduction in skin temperature increase (1.2°F or 0.7°C) and the reduction of skin moisture retention (87%) on the LAL system at a constant (113L/min) airflow through the support surface. In contrast, the increased skin temperature and moisture retention on the standard hospital mattress demonstrated induction of active sweat production that was prevented by airflow on the LAL support system.

Despite the significance of the airflow through the support interface, there are no guidelines for how much a LAL support system should remove moisture and reduce temperature. Flam¹⁹ has suggested that the airflow should be at least the

amount needed to remove the insensible perspiration and the sweat of an average person at rest in a moderate climate.

There are also no guidelines for the selection of the LAL supports for patient application. Absent selection criteria, the clinician is required to prescribe support surfaces, arbitrarily considering only the cost, claims of the suppliers, and prior experience. To improve the selection process and patient care outcome, measurable parameters need to be developed to match LAL support performance to patient need. The work reported here suggests a systematic method of assessing the moisture removed and temperature reduced to indicate LAL support performance. In future studies, these indexes will be available for clinical trials designed to discover patient-specific selection criteria for LAL supports and to produce quantitative parameters for clinical trials of air-loss supports.

This study sought to develop a simple, reproducible validation test protocol for classification of LAL support systems and to produce quantitative parameters for clinical trials of air-loss supports. The protocol was designed to measure simultaneously moisture loss and temperature reduction on the support surface. This could then serve as valid quantitative criteria for classifying LAL support systems according to their microclimate control characteristics and establish their standards of performance. A performance index based on temperature and moisture loss may then be the foundation for the development of a quantitative prescription criteria for air-loss supports for clinical applications.

METHODS

An electric-powered elevating hospital bed^a was used in the horizontal position as a platform for the validation tests. If the support surface was an integral part of the bed frame, then the test was performed on the frame as supplied. The test support surfaces^{b,c,d} were placed on the bed, activated, and adjusted according to manufacturer's instruction, and elevated to test height. During the testing period, the room was closed to maintain stable humidity, ambient temperature, and air current. Instruments were placed near the support surface to monitor room temperature and relative humidity.

Water circulation to the loading gauge (water pad, 36 × 84cm)^e was implemented by a desk-top, 1-gallon capacity, constant temperature water bath with a 2.5-gal/min capacity submersible pump. The bath water temperature was adjusted to produce $37^\circ \pm 0.5^\circ\text{C}$ at the support surface-loading gauge interface. The loading gauge was placed on the support surface and the bed height adjusted to locate the support interface 23cm below the water bath level. This height differential assured flow and weight equilibrium in the loading gauge. The total weight of the loading gauge was adjusted with added weights to 100 pounds, to be equivalent to the weight of a 50th-percentile male torso. At the precise elevation, the loading gauge was suspended from above and the bed lowered slightly to provide access to the support-loading gauge interface for the placement of the interface temperature monitoring thermistor array^f and the moisture reservoir.

There were 9 thermistors used for temperature monitoring. Eight thermistors were located in 3 rows on the support 10cm apart laterally and 20cm apart longitudinally. The geometry was to approximate the relative pelvic, mid thoracic, and scapular positions on the supports (fig 1). The ninth thermistor was located in room air to monitor the ambient temperature during the validation tests. The evaporation rate and temperature measurements were repeated twice on each support surface, at a proximal site, and after a 10-cm distal displacement of the thermistor array, moisture reservoir, and loading gauge. The interface monitoring thermistors were attached with a flexible

Table 1: Loss of Water Through Skin for a Relaxed Person at Rest in a Moderate Indoor Climate

	mL/d	g/(m ² × hr)*
Insensible loss	50-350	1.2-8.1
Sweat loss	1100-2800	25.5-64.8

* Based on an average body surface area of 1.8m².

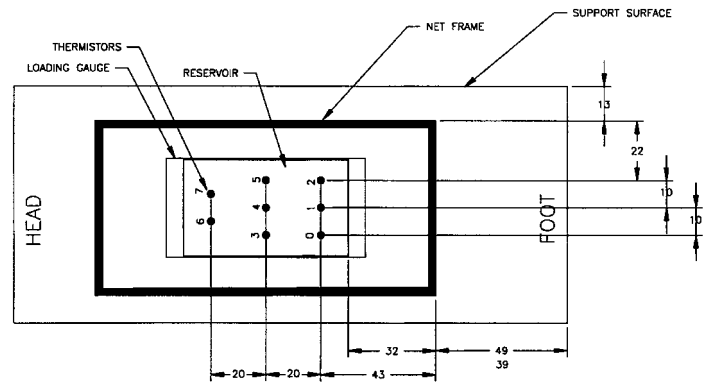


Fig 1. Proximal location of thermistor array on the support surface. All dimensions are in centimeters.

net fastened to a wood frame to facilitate rapid, accurate placement in the precise premeasured location on the support surfaces. The data acquisition was accomplished using a 16-channel analog interface and analog to digital converter system. A highly absorbent cloth (0.3 × 35 × 60cm Rayon) was chosen for the reservoir. The reservoir was saturated with isotonic saline (0.9% NaCl solution) and rolled to squeeze out extra moisture without twisting until the moisture content was 36 ± 1g. The weight of the reservoir was measured rapidly with an electronic balance with an accuracy of ± 0.1g. This amount of initial moisture was established by progressive approximation (trial and error) to maximize the moisture content in the reservoir without evidence of wicking or blotting on several support surface materials.

To produce the quantitative description of the microclimate characteristics of the LAL support surface, each evaporation test was completed in 2 steps. First, the steady state equilibrium conditions were established, and, second, the temperature change and the evaporation rate were measured. The test procedure is described in detail in the appendix. The equilibrium conditions were determined by placing the thermistors on the support surface, covering them with a dry reservoir and the loading gauge, and collecting temperature data until the temperature was constant within ± 0.1°C through a 30-minute interval. The temperature change and evaporation measurements were then initiated by replacing the dry reservoir with 1 loaded with saline. The temperature was recorded every 2 minutes. After 90 minutes, the test was stopped and the damp reservoir was weighed. The loss in weight of the reservoir during the test represented the amount of evaporated moisture. If more than 90% of the moisture evaporated, the evaporation test was repeated, collecting data for only 45 minutes following equilibrium. The evaporation rate and temperature profiles for each thermistor were calculated for use in the data analysis.

RESULTS

In a series of preliminary experiments, the variables affecting the temperature measurement and evaporation rate determination were investigated. The resulting observations confirmed the function and stability of the experimental apparatus, and defined the reliability of the temperature and evaporation measurements. Thermistors were calibrated in ice and boiling water, and repeatability was found to be ± 0.1°C; the temperature distribution on the surface of the loading gauge was found to be within ± 0.5°C. Observation of other temperature changes indicated that the presence of the dry reservoir acted as a thermal insulator between the loading gauge heat source and the support surface. When airflow through the support surface was initiated, a cooling of the support interface was observed.

Moisture in the reservoir—in the absence of airflow and evaporation—acted as a thermal conductor; and when evaporation from the reservoir was allowed, cooling beyond the effect of colder airflow was confirmed.

The effect of airflow in the absence of evaporation required several hours to reach temperature equilibrium on the support surface below the reservoir. To confirm the stability of the steady-state conditions, the temperature equilibrium was monitored for at least 30 minutes before the initiation of evaporation. The effect of evaporation significantly reduced the support surface-reservoir interface temperature. The minimum temperature was surface location- and time-dependent. Between locations, the time to reach minimum temperature varied between 15 to 210 minutes. Most of the thermistor locations reached minimum temperature within 90 minutes after the beginning of evaporation.

The support surfaces that reduced temperature the most achieved the minimum temperature in the shortest time. The rapid drying times for these surfaces required measuring the evaporation during a 45-minute test. Validation tests were completed on the air-loss support products supplied by the project sponsors. The support surfaces were commercial items that represented various low- to high-airflow conditions. The supports were adjusted in agreement with the manufacturers' directions to support the weight of a 50th-percentile male subject. Tests were completed with the regular cover in place and when requested by the sponsor, the tests were repeated without the regular cover. The support surface tests with and without cover are shown in alphabetical order in table 2. For comparison, and to observe the effect of absent airflow conditions, a standard foam hospital mattress^g was also tested and the observable temperature change and "evaporation" rates determined.

Table 2: Support Surface Tests

Model	Cover	Without Cover
First Step ^b	Yes	Yes
Flexicare ^c	Yes	Yes
KinAir bed ^b	No	Yes*
PUP ^d	Yes	No
Silk Air ^c	Yes	Yes
3500 S ^d	Yes	No
Turn Q ^d	Yes	Yes
Standard foam ^g	Yes	No

* Reconfigured 3 times to represent low-, intermediate-, and high-air loss modes, respectively.
Abbreviation: PUP, pressure ulcer prevention.

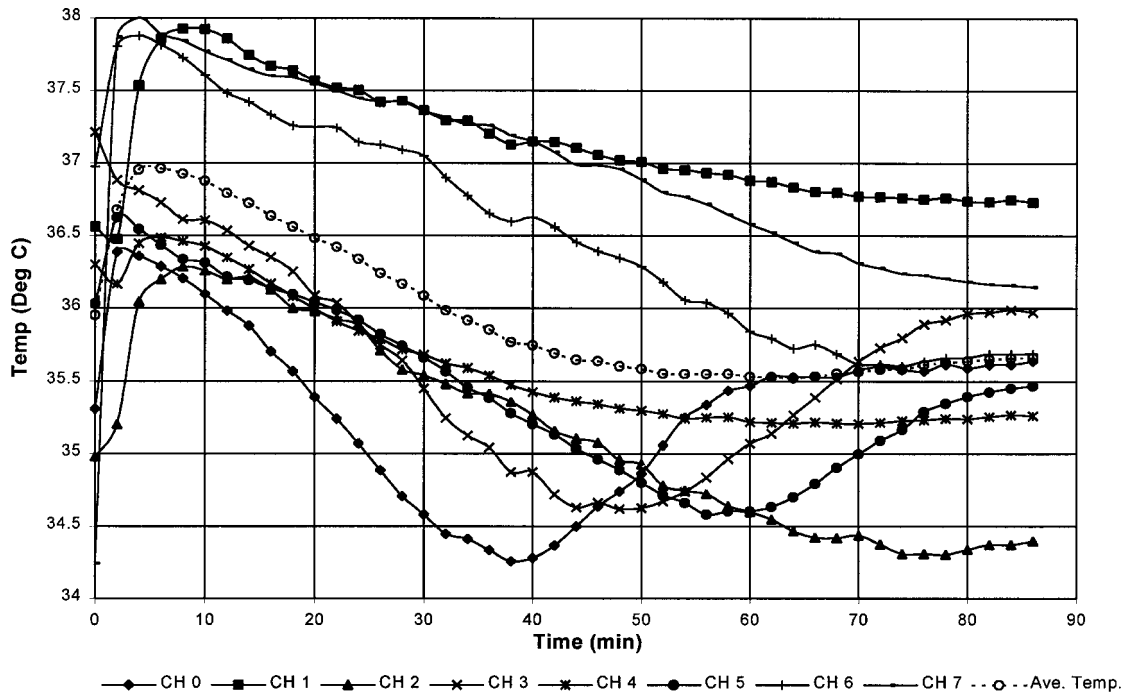


Fig 2. A representative sample of thermistor outputs and the calculated average temperature for a typical 90-minute evaluation test. Abbreviation: CH, channel.

From the proximal and distal test locations, the rates of moisture loss were averaged and recorded with the also averaged temperature reductions to account for potential local airflow variations.

A typical change in temperature is shown in figure 2 for each of the 8 thermistor locations for a 90-minute evaporation test, along with the calculated average temperature at each sampled instance of time. The temperature offset at time zero resulting from the placement of the wet reservoir before the start of evaporation is also shown in figure 2. For analytical purposes, the offset was corrected to not include this early data as part of the temperature reduction caused by evaporation. From the average temperature curve, the maximum temperature drop was extracted. This value is referred to as the decrease of the average temperature in units of °C. This change tends to show the largest surface averaged reduction of temperature at 1 instant of time during the validation test.

The temperature difference was also calculated by averaging 8 maximum temperature reductions. This value is referred to as average temperature reduction, in units of °C. Calculating the

change by this method tends to show the average of 8 largest temperature reductions occurring in different locations and thus at different times.

A comparison plot of these temperature changes (fig 3) uses all the data from the validation tests, and shows a linear relationship that can be expressed as:

$$\text{Decrease of average temperature} = (\text{constant}) \times \text{average temperature reduction} - .18,$$

where the constant equal to .85 is the slope of the best fit line ($R^2 = .91$) through all data points generated for 14 pairs of validation tests (fig 3). Thus, the temperature reductions by the 2 methods are similar but not identical, and the average temperature reduction was selected for the index of temperature change due to evaporation at the support interface. The equation above can be used to calculate the value of the other index of temperature change.

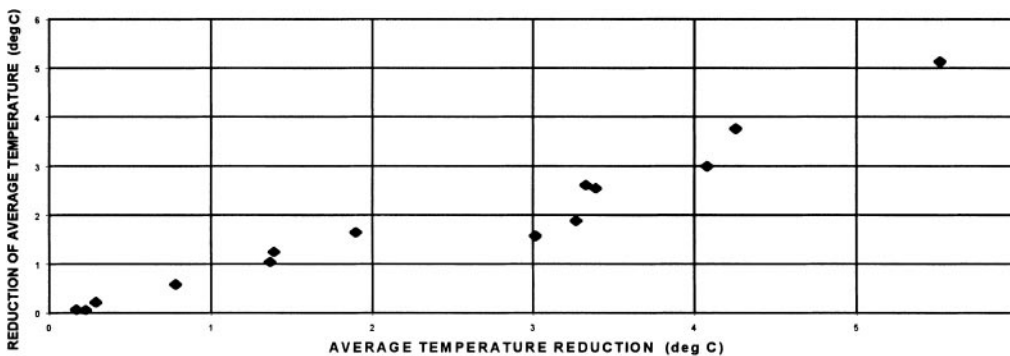


Fig 3. Comparison of 2 methods of calculating the average reduction of support interface temperature (n = 14).

Table 3: Temperature Reduction and Evaporation Characteristics of Support Surfaces

	Group 1 (n = 3) (Mean ± SD)	p*	Group 2 (n = 9) (Mean ± SD)	p*	Group 3 (n = 2) (Mean ± SD)
Average temperature reduction	.23 ± .06	.006	2.50 ± 1.15	.0169	4.70 ± .64
Reduction of average temperature (°C)	.11 ± .08	.006	1.79 ± .80	.0008	4.45 ± .96
Standard evaporation rate (g/[m ² × hr])	47.8 ± 6.9	.0001	97.7 ± 11.0	.0001	215.5 ± 14.9

* Probability of no significant difference.
p = .0169 or p < .017 for all p values.

Support Surface Classification

The results of paired proximal and distal tests on each support surface were combined, and the standardized rates of moisture loss and the average temperature reductions were calculated by both methods. Temperature reductions were plotted as a function of the standardized rate of moisture loss. On these plots 3 clusters or groups of data could be seen. Group 1 consisted of 3 validation tests, including 1 from the regular standard foam mattress and the others from mattresses with nonpermeable covers. Group 2 had 9 validation tests from LAL products, some without a cover. Group 3 included a high-air loss and a mixed high- and low-air-loss product. Table 3 shows the mean and standard deviation (SD) of the characteristic temperature reduction and rate of moisture loss for group 1, group 2, and group 3. Using multiple comparisons between the groups and Bonferroni's adjustment, the mean values were significantly different (p ≤ .017) for groups 1, 2, and 3, confirming the evaporating and temperature reducing characteristics of the air-loss support surfaces (table 3).

A plot of the variables clearly shows the difference among the groups. In figure 4, the average temperature reduction of the support surfaces are plotted as a function of the rate of moisture loss. For both the rate of moisture loss and the temperature change, the mean values obtained from all tested support surfaces are plotted for group 1 (no air loss), group 2 (LAL), and group 3 (high air loss). For comparison, the no air loss standard hospital foam mattress value is also plotted in group 1.

DISCUSSION

Support surfaces are prescribed to control the load and environment on the soft tissues. By selecting the proper support surface, a caregiver can control the pressure, shear, moisture,

and temperature that influences the health of the weight-bearing tissues. Waterlogged skin from constant wetness is more easily eroded by friction, more permeable to irritants, and more readily colonized by microorganisms than normally hydrated skin. If an individual is at risk for skin breakdown, resulting from excessive moisture against the skin, a support system with the ability to remove skin moisture is desirable. Many air loss systems control pressure, temperature, and moisture parameters by adjusting inflation pressure and airflow to the support; enhance heat transfer from the body to the environment; and reduce heat build-up, skin temperature, and hydration of the skin. Reducing skin temperature will slow metabolic activity, decrease circulatory demand, inhibit sweating, and lower skin hydration. The limits of desired levels of tissue temperature reduction and moisture removal, however, are not known. There are also no reported clinical trials that define the optimum level of moisture removal and temperature reduction by the air-loss support systems. Our study developed and validated clinically relevant, simple methods to measure the rate of moisture loss and the reduction of temperature on the air-loss supports at a range of airflow and inflation pressures. Applying these measurement techniques, new studies can be designed to investigate the influence of microclimate factors on the formation and healing of pressure ulcers. Several experimental observations call for further discussion of the results.

Preliminary experiments indicated that the absence of air flow through the support surface produced a temperature distribution from the loading gauge within ± 0.5°C. With airflow through the support surface at discrete locations, the temperature variation increased to ± 1°C. A temporary reduction in temperature was measured when the support surface was separated from the loading gauge to introduce a dry reservoir into

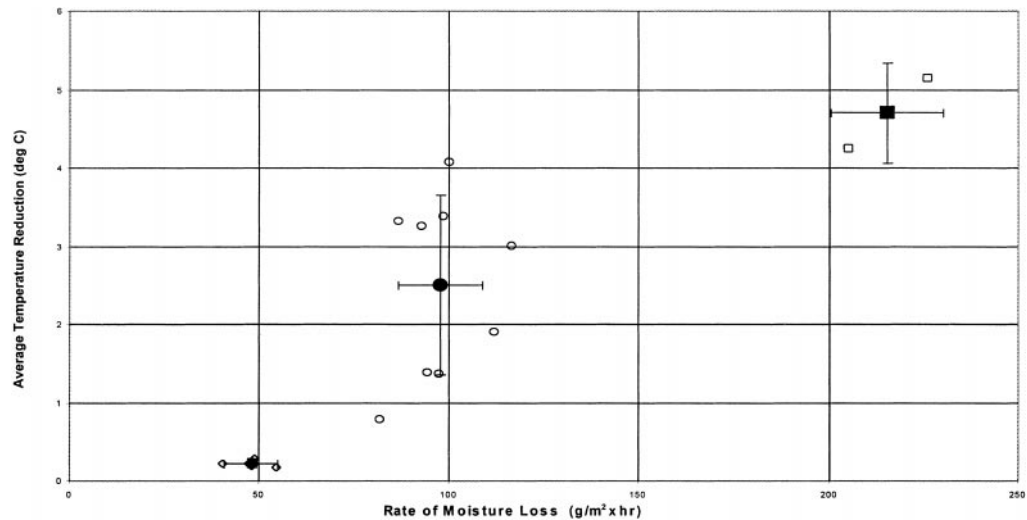


Fig 4. Average temperature reduction plotted as a function of moisture loss rate on the support surfaces. The solid lines through these points designate the SD of the mean for that group for both temperature change and moisture loss rate. (◇), non-airflow products; (○), LAL products; (□), high-air-loss products; (◆), average non-airflow products; (●), average LAL products; (■), average high-air-loss products.

the interface. Within 5 minutes of closure of separation, the pretest equilibrium temperature could be restored.

Introducing a moist reservoir at the start of the evaporation test increased the temperature variation. High airflow produced a high evaporation rate and a lower temperature. As the reservoir dried out in the region of high airflow, the evaporation rate decreased, and the temperature again approached the pretest equilibrium temperature. Areas with lower airflow did not dry out as rapidly and showed a continuous decrease in temperature throughout the test. Because the rate of evaporation was lower, the magnitude of temperature reduction was smaller than in the areas of higher airflow.

This complex relationship among airflow, moisture, and temperature strongly suggests that the mechanism for removing moisture with the LAL support is evaporation. Moisture without airflow acted as a thermal conductor in preliminary tests and produced interface temperatures close to the temperature of the loading gauge. Moisture with airflow, however, reduced the interface temperature well below the pretest equilibrium temperature with airflow but without moisture. The return of temperatures to pretest, dry reservoir equilibrium values, as the reservoir dried, confirmed that evaporation was the mechanism for both moisture loss and temperature reduction. The measured temperature at any instant of time reflected the effect of evaporation and the opposing effect of thermal conductivity.

A moisture loss of approximately $50\text{g/m}^2 \times \text{hr}$ was observed on support surfaces without airflow. The constant interface temperature without changes suggested the absence of evaporation and moisture transfer to the support surface by direct contact. Because the moisture transfer loss was also present with LAL surfaces at the start of the test, the temperature decrease during airflow indicated additional evaporation loss, thus removing moisture from the reservoir and the support surface. Although the increase in temperature with drying after an initial decrease with evaporation is important to confirm that evaporation is present, its effect on the 2 temperatures indices (reduction of average temperature, average temperature reduction) must be analyzed. A human body would continue to produce moisture and the reduced temperature would remain low. The localized drying of the fabric reservoir is therefore an artifact of the test protocol that increases the average temperature. For this reason, average temperature reduction is thought to be the most meaningful indicator of the effect of airflow and evaporation on the interface temperature.

CONCLUSION

The interface climate validation tests indicated the potential for grouping LAL support surfaces by temperature reduction and evaporation rate measurements. Each measurement alone, however, was not sufficient to determine the microclimate characteristics of the support surface. When the average temperature reduction and the standardized rate of moisture loss were plotted for all support surfaces, 3 regions of the graph were defined for no air loss, LAL, and high air loss, based on the mean value of each group and 1 or more SDs of the rate of moisture loss and the temperature reduction variables.

The methods presented here can be reproduced in future clinical trials to quantify the independent variables of moisture removal and temperature reduction of air-loss supports, and to discover the clinically significant relations of these variables to the prevention and treatment of pressure ulcers. Further clinical significance was gained by the method of classification established for air-loss supports. Using a human body equivalent that represented an average temperature, weight, and moisture load, the measurement of climate control capacity allowed ranking of the supports according to their moisture removal and

temperature-reducing characteristics. Matching moisture removal and temperature control performance to the patient will enable the clinician to choose the optimum air-loss support for the patient.

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Suppliers

- a. Amedco Health Care Inc, 401 S Outer Service Rd, Wright City MO 63390.
- b. Kinetic Concepts, Inc, 8023 Vantage Dr, San Antonio, TX 78230.
- c. Hill Rom, 4349 Corporate Rd, Charleston, SC 29405.
- d. Invacare Corp, 899 Cleveland St, Elyria, OH 44036.
- e. Lotus Health Care Products, 31 Sheridan Dr, Naugatuck, CT 06770.
- f. Yellow Springs Instruments, 1725 Brannum Ln, Yellow Springs, OH 45387.
- g. No. 87810 mattress; Bio Clinic Co, 1032 Hwy 145 N, Baldwin, MS 38824.

APPENDIX: PROTOCOL FOR THE 2-STEP EVAPORATION TEST

Pretest to establish steady state:

1. Turn on the support surface airflow, water bath, pump, data-collecting instruments, and computer. Start the data acquisition program using the calibration file for the thermistors. Initiate the analog output 5V reference to the thermistors.
2. Adjust the height of the support surface to be 23cm below the water bath.
3. Lower the bed away from the loading gauge.
4. Place the thermistors in the proximal location on the support surface, as shown on figure 1.
5. Place a dry reservoir on top of the thermistors.
6. Elevate the bed to transfer the weight of the loading gauge completely to the reservoir and the support surface.
7. Collect temperature data and verify that the temperature at each thermistor has reached equilibrium (constant within $\pm 0.1^{\circ}\text{C}$ through a 0.5-hr interval) and the recorded temperature output is stable.
8. Cut another reservoir to size, $35 \times 60\text{cm}$.

Evaporation testing protocol:

1. Weigh the newly cut dry reservoir to $\pm 0.1\text{g}$ accuracy and record the mass.
2. Record the room temperature, humidity, and temperature of the water bath. The room temperature measured by the ninth thermistor should be between 15° and 25°C .
3. Pour isotonic saline solution into a container large enough to contain the cloth moisture reservoir.
4. Saturate the reservoir with the saline solution.
5. Roll and squeeze the reservoir without twisting to remove extra saline until the weight of the reservoir is

$36 \pm 1\text{g}$ (the amount of saline used for the test) greater than the dry reservoir. Use dry paper towels to absorb saline uniformly until the desired weight is reached. Record the initial mass of the reservoir with moisture in it to $\pm 0.1\text{g}$ accuracy.

6. Activate the data acquisition software to collect data for 60 scans at 30 scans/hr.
7. Lower the bed with the support surface to gain operating space under the loading gauge.
8. Replace the dry reservoir with the moistened reservoir on top of the thermistors.
9. Elevate the bed to transfer the weight of the loading gauge to the reservoir and the support surface. Guide the loading gauge to be aligned and properly located on the moisture reservoir, thermistor array, and support surface.
10. Record the time at the beginning of the test when the reservoir contacts the loading gauge.
11. Conduct the test for 90 minutes (see step 15 below).
12. Lower the bed to separate the loading gauge from the reservoir.
13. Record the time at the end of the test at the instant the reservoir is separated from the loading gauge.
14. Weigh the reservoir again to $\pm 0.1\text{g}$ accuracy and record the final mass.
15. If more than 90% of the saline has evaporated during the 90-minute test, repeat the test starting with the pretest, followed by 45 minutes of evaporation test protocol.

Calculate the evaporation rate, plot temperature for each thermistor, and complete the data analysis.