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# A quantitative study of transepidermal water loss (TEWL) on conventional and microclimate management capable mattresses and hospital beds

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ABSTRACT

*Background:* Transepidermal water loss (TEWL) is regarded as one of the most important parameters characterizing skin barrier integrity and has found to be higher in impaired skin barrier function. Reduced or low TEWL instead indicates skin barrier integrity or improvement. We evaluated if different mattresses/hospital beds can influence this skin barrier function by measuring TEWL before and after subjects lying in conventional and microclimate management capable mattresses/hospital beds.

*Methods:* We included 25 healthy subjects in our study. Measurements were made using Courage & Khazaka Multi Probe Adapter MPA with Tewameter TM300 to determine TEWL before and after the subjects were lying in conventional (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ 2 mattress, Hill-Rom GmbH Essen, Germany) or microclimate management capable mattresses/hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany).

*Results:* While there was no statistically significant difference in standard mattresses/hospital beds (22.19 ± 12.99 and 19.80 ± 11.48 g/hm$^2$), the decrease of TEWL was statistically significant in both microclimate management capable mattresses/hospital beds we investigated (16.89 ± 8.586 g/hm$^2$ and 17.41 ± 7.203 g/hm$^2$) compared to baseline values (35.85 ± 24.51 g/hm$^2$).

*Conclusion:* As higher TEWL announces impaired skin barrier function these findings indicate that the choice of the mattress/hospital bed is important for skin barrier function and microclimate management systems improve skin barrier function of the skin.

## 1. Background

A pressure ulcer or pressure injury is defined as “localized damage to the skin and/or underlying soft tissue usually over a bony prominence or related to a medical or other device” [1]. Pressure ulcer prevalence in hospital ranges from 0.3% to 46% and has an incidence from 0.8% to 34% all around the world [2]. Therefore, pressure ulcers are regarded as a great challenge for medical professionals as well as the healthcare system.

While the cost of pressure ulcer prevention per patient at risk per day varies between 2.65 Euro and 87.57 Euro, the costs of pressure ulcer treatment per patient per day are much higher (between 1.71 Euro and 470.49 Euro) [3]. Ulcers often develop upon specific risk factors, which are also the main basis for ulcer prevention. The Braden Scale for Predicting Pressure Sore Risk [4,5] was developed by Barbara Braden and Nancy Bergstrom to help healthcare professionals, especially nurses, assess a patient's risk of developing a pressure ulcer. Aside from a reduction in sensory perception, activity and mobility, friction and shear forces, and a poor nutritional status, skin moisture is an important risk factor for developing a pressure ulcer as well [6]. Regarding skin moisture the differentiation between superficial pressure ulcers and moisture-related skin damage seems to be challenging [7].

There is growing evidence that microclimate factors such as temperature, humidity and air flow on and near the skin play an important role in the development of pressure ulcers [8–11]. Damp or wet skin is more permeable to irritating substances and more readily colonized by microorganisms. In addition less friction is required to abrade or blister skin when it is damp [12]. Previous studies showed that the dynamic

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shear modulus for stratum corneum decreases with increasing relative humidity [13] suggesting that moisture influences the resilience of the upper skin layers. Other data [14] indicate that increasing skin hydration seems to cause gender-specific changes in the mechanical properties of human skin, leading to skin softening and increased real contact area, friction and adhesion. In conclusion abnormal skin hydration increases the risk for infections and pressure ulcers [15].

Transepidermal water loss (TEWL) is defined as the volume of water (g/m2/hour) passing from inside to the bodysurface through the epidermal layer and is regarded as one of the most important parameters for characterizing skin barrier function. It has found to be higher in impaired skin barrier function [16]. Reduced or low TEWL instead indicates skin barrier integrity or improvement [17]. An agreed upon definition of a physiological/reference TEWL does not exist, since absolute values can differ depending on anatomic sites, climate conditions, age, and measurement devices [18] and therefore are only comparable to a limited extent.

Beside damaged skin, TEWL has been found to be impaired in skin around chronic venous leg ulcers as well [19] and thus is a promising parameter for investigating the risk for developing a pressure ulcer or for detection of vulnerable skin.

Although this might be an important topic and potential target for future prevention strategies against pressure ulcer development, only few data are published regarding the question if hospital beds actively influence skin microclimate. While there are already various [20] products to reduce pressure on predilection sites for pressure sores to prevent pressure ulcers (data exists which showed changes of TEWL due to sustained loading [21]), there are only few hospital beds which actively influence skin microclimate.

We evaluated the TEWL as one of the most important parameters for characterizing skin barrier function and skin integrity on conventional (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ *2* mattress, Hill-Rom GmbH Essen, Germany) or microclimate management capable mattresses/hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany). The aim of this study was to investigate if micromanagement capable mattresses/hospital beds can actively influence or even improve skin barrier function and thus skin integrity.

## 2. Methods

The study was approved by the ethics committee of the University of Tübingen (280/2018BO2).

Healthy volunteers were recruited from the hospital staff (physicians, nurses, students, scientific staff). Before participation into the study, a detailed informed consent was obtained. A total of 25 caucasian subjects (13 females and 12 males) were included in the study. Exclusion criteria were: Skin disorders, wounds, scars or erythema in the study area, hyperhidrosis, hypohidrosis, smokers, vascular diseases.

The research was carried out under standardized and constant conditions according to manufacturer's instructions. All measurements were performed by the same investigators in a recovery room of the BG traumacenter Tuebingen with closed doors to ensure a minimum of air draft under almost identical conditions regarding temperature and humidity. Room temperature ranged from 23.4 °C to 27.0 °C and air humidity ranged from 44.7% to 60.5%. The measurements were performed central in the sacral region 2 cm caudal of the spinous process of L5. All volunteers were allowed to acclimatize in the room for at least 15 min before measurements were taken to allow full adaptation of their skin to the environmental conditions. Before the beginning of the experiment one baseline measurement in upright position with no external influence such as pressure on the skin was made. Afterwards the subjects had to lie as still as possible on their backs on the different mattresses/hospital beds for 5–7 min, right before the measurements were performed.

We used the Courage & Khazaka Multi Probe Adapter (Courage + Khazaka, Cologne, Germany) with Tewameter TM300 (Courage + Khazaka, Cologne, Germany) for our investigations, which has been successfully used in previous studies [17,21–30]. It measures TEWL with an open chamber system with two pairs of sensors for temperature and relative humidity inside a hollow cylinder which allows to determine indirectly the density gradient of water evaporation from the skin. Measurements were taken every second, according to manufacturer's recommendations until standard deviation of the current value to the mean value was lower than 0.2. TEWL is calculated then with the measured values based on Fick's law of diffusion by the via Courage & Khazaka MPA software. The room temperature and humidity for every TEWL measurement is documented by the system.

We investigated transepidermal water loss (TEWL) before and after the subjects were lying in two conventional (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ *2* mattress, Hill-Rom GmbH Essen, Germany) and two microclimate management capable mattresses/hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany).

As a first control we used a standard hospital mattress (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany) without any additional properties which could influence skin humidity or evaporation. The mattress was covered with a cotton mattress cover.

The Duo™ 2 (Hill-Rom GmbH Essen, Germany) [31] is a non microclimate capable alternating pressure mattress replacement system that is used to prevent and treat pressure ulcers from stage I to IV in low to very high-risk adult patients and was used as a second control. It provides low tissue interface pressures and maximal distribution of patient weight by reducing high peak pressures. The mattress was covered with a standard cotton mattress cover.

The ClinActiv + MCM™ (Hill-Rom GmbH Essen, Germany) [32] mattress replacement system is also used to prevent and treat pressure ulcers in low to very high-risk adult patients by providing either alternating or continuous low-pressure redistribution. According to manufacturer the patented MCM system also helps to manage the patient's microclimate and reduces the risk of tissue breakdown as a result of excessive heat and/or moisture. The temperature of the device was set on 30 °C. The mattress was covered with a standard cotton mattress cover.

The PEARLS AFT (Hill-Rom GmbH Essen, Germany) [33] is an air fluidized hospital bed. According to the manufacturer Air Fluidized Therapy (AFT) maximizes patient envelopment and microclimate management capabilities, while significantly reducing shear, friction, and interface pressure. The temperature of the device was set on 30 °C. The bed was covered with a standard cotton mattress cover.

All data are given as means with standard deviation (SD) and are plotted in figures as means with 95% confidence interval (CI). Data were analyzed using Kruskal-Wallis Test with Dunn's multiple comparison test to analyze differences between groups. Statistical significance was defined as $P \leq 0.05$. All analyzes were performed using the GraphPad Prism statistical software package (version 6, GraphPad Software, La Jolla, USA).

(*$p \leq 0{,}05$; n. s. = not significant).

## 3. Results

### 3.1. Collective of subjects

We included 25 subjects, 13 females and 12 males (Table 1).

### 3.2. TEWL measurements

After acclimatization and before further measurements we performed one initial baseline measurement to determine the individual TEWL at rest without any further external influence. The baseline was 35.85 ± 24.51 g/hm$^2$ (Fig. 1). All mattresses/hospital beds showed a lower TEWL, while the differences were statically significant only in the

**Table 1**
Collective of subjects.

| Variables | Mean (Range) |
|---|---|
| Females | 13 |
| • Age [years] | 28.08 (18–44) |
| • Height [m] | 1.70 (1.58–1.76) |
| • Weight [kg] | 67.92 (51–95) |
| • Body Mass Index [kg/m$^2$] | 23.40 (19.10–30.67) |
| • Diagnosis | Hypothyreosis (2x) |
| • Current medication | Oral contraception (3x), Levothyroxine (2x) |
| • Smokers | None |
| Males | 12 |
| • Age [years] | 33.92 (25–54) |
| • Height [m] | 1.82 (1.73–1.98) |
| • Weight [kg] | 87.58 (65–120) |
| • Body Mass Index [kg/m$^2$] | 26.32 (20.06–36.11) |
| • Diagnosis | Arterial hypertension (1x), Non-alcoholic steatohepatitis (1x) |
| • Current medication | Ramipril, Ursofalk |
| • Smokers | None |

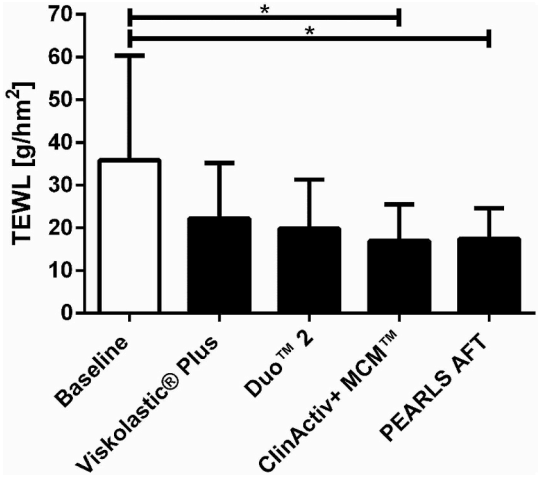


**Fig. 1.** TEWL on conventional (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ 2 hospital bed, Hill-Rom GmbH Essen, Germany) and microclimate management capable hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany) (n = 25, Mean ± SD, *p ≤ 0.05).

microclimate management capable mattresses/hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany) and not on standard mattresses (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ 2 mattress, Hill-Rom GmbH Essen, Germany).

TEWL measured on the standard hospital mattress (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany) was 22.19 ± 12.99 g/hm$^2$ (Fig. 2). The difference was not statistically different compared to baseline (*p ≤ 0.05).

Compared to the baseline values, TEWL was also reduced on Duo™ 2 hospital mattress (19.80 ± 11.48 g/hm$^2$, Fig. 3) but values were not statistically significant different (*p ≤ 0.05).

TEWL in the ClinActiv + MCM™ mattress decreased by mean (16.89 ± 8.586 g/hm$^2$) compared to baseline (Fig. 4). The difference was statistically significant (*p ≤ 0.05) and the standard deviation of the values became smaller.

Just as in the ClinActiv + MCM™ mattress, the TEWL in PEARLS AFT hospital bed decreased by mean (17.41 ± 7.203 g/hm$^2$) compared to baseline (Fig. 5) whereby the difference was statistically significant (*p ≤ 0.05). The values showed the lowest standard deviation of all investigated mattresses/hospital beds.

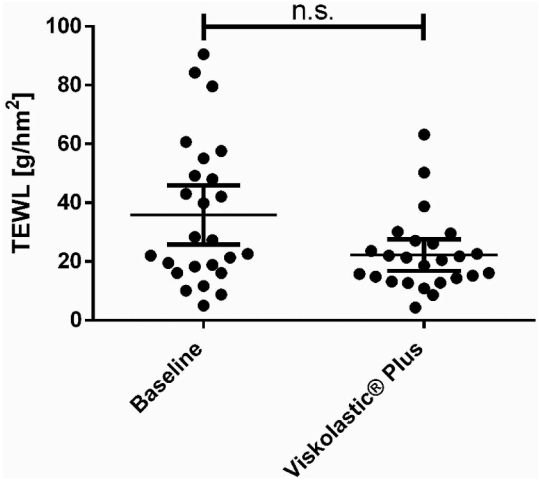


**Fig. 2.** Comparison of TEWL in the sacral region between Baseline and standard mattress. Measurements were performed before (Baseline) and after 5–7 min of resting on a standard hospital mattress (n = 25, n. s. = not significant).

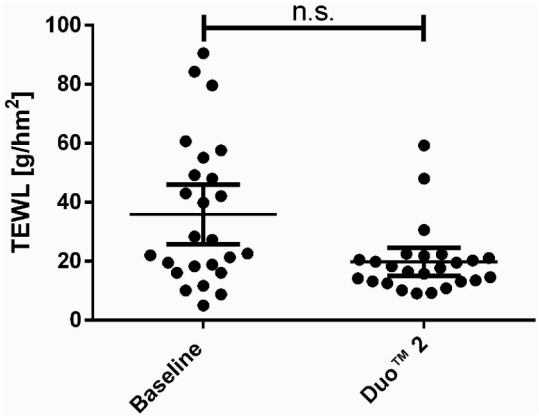


**Fig. 3.** Comparison of TEWL in the sacral region between Baseline and Duo™ 2 mattress. Measurements were performed before (Baseline) and after 5–7 min of resting on Duo™ 2 mattress (n = 25, n. s. = not significant).

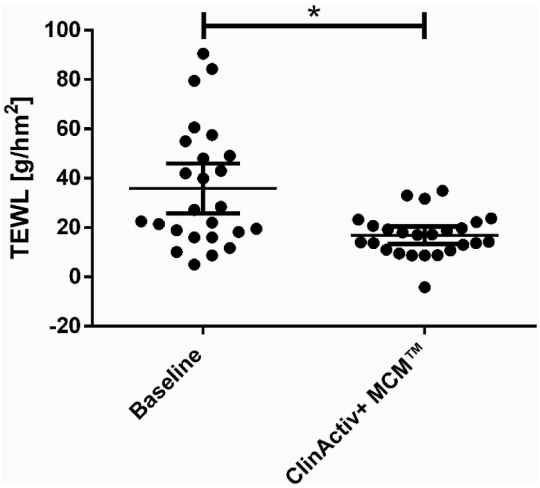


**Fig. 4.** Comparison of TEWL in the sacral region between Baseline and ClinActiv + MCM™ mattress. Measurements were performed before (Baseline) and after 5–7 min of resting on ClinActiv + MCM™ mattress (n = 25, *p ≤ 0.05).

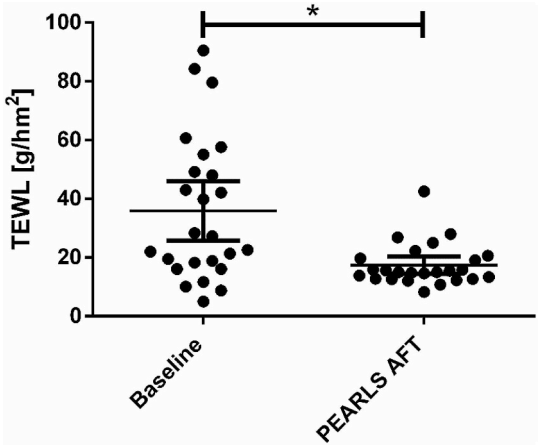


**Fig. 5.** Comparison of TEWL in the sacral region between Baseline and PEARLS AFT hospital bed. Measurements were performed before (Baseline) and after 5–7 min of resting in PEARLS AFT hospital bed (n = 25, *p ≤ 0.05).

## 4. Discussion

Damp or wet skin is more permeable to irritating substances and more readily colonized by microorganisms. Less friction is required to abrade or blister skin when it is damp [12]. Therefore, it is essential to provide optimal conditions concerning microclimate in hospital beds especially for bedridden patients who have a high risk for developing pressure ulcers. Although this is an important topic, only few data are already published regarding the question if hospital beds actively influence skin microclimate. While there are already various products to reduce pressure on sore-prone areas to prevent pressure ulcers, there are only few hospital beds which actively influence skin microclimate. There is growing evidence that microclimate factors such as temperature, humidity and air flow on and near the skin play an important role in the development of pressure ulcers [8–11]. As transepidermal water loss (TEWL) is regarded as one of the most important parameters for characterizing skin barrier function, we investigated how conventional and microclimate management capable mattresses/hospital beds influence TEWL.

Beside skin disorders such as atopic dermatitis [34], ichthyosis [35], contact dermatitis [36] and cutaneous T-cell lymphoma [37] there is also evidence that TEWL is impaired when skin is exposed to irritants, including wet work [38,39]. Additionally, TEWL has been found to be impaired in skin around chronic venous leg ulcers [19] and thus is a promising parameter for investigating early stages of skin damage.

Since TEWL is dependent on external influences such as climate factors [40] all measurement were performed under constant and comparable conditions. It is known that there are regional differences in TEWL [30] so we investigated intra-individual changes of TEWL (=every measurement in the same anatomical region). Manufacturers instructions for TEWL measurements recommend specific test conditions (20–22 °C temperature and 40–60% humidity) only for long-time observations (higher temperature can increase water evaporation of the skin). Although our experimental conditions differed due to higher temperature it is not likely that this could have impacted our results: We did no long-time observations and all test conditions were held constant during the whole experimental setup which is still far more important.

Bashir et al. [16] removed the stratum corneum of human test subjects and showed that TEWL increases when deeper layers of the stratum corneum are exposed. Similar results were obtained when the stratum corneum of dogs was removed with tape stripping [41]; again TEWL increased with frequency of tape stripping. In conclusion TEWL corresponds with skins barrier function and integrity as the stratum corneum represents the most important barrier layer of the skin.

Dini et al. [19] examined 50 patients with chronic venous leg ulcers and found that the TEWL of the skin around the ulcer was significantly higher than compared with control site. Additionally, clinical scoring was significantly correlated with different levels of TEWL. Statistics showed an increase in TEWL values as the maceration clinical score increased. They concluded that TEWL can be considered an objective parameter even for monitoring perilesional skin maceration in venous leg ulcers.

Kottner et al. [21] investigated possible effects of long enduring loading on the skin barrier function at two pressure ulcer predilection sites (sacral and heel skin) in 20 healthy females. Before and after the loading period skin surface temperature, stratum corneum hydration, TEWL and erythema were measured in these areas. They found that skin surface temperature and erythema increased after prolonged loading while stratum corneum hydration remained stable. TEWL (adjusted to adjusted to a standard skin surface temperature to 30 °C) increased significantly after loading at the heel (from 16.6 ± 5.8 $g/m^2/h$ to 32.0 ± 12.2 $g/m^2/h$ after 90 min) but not at the sacral skin (from 12.7 ± 7.9 $g/m^2/h$ to 14.6 ± 6.4 $g/m^2/h$ after 90 min). They suggested that the increased TEWL at the heels indicates subclinical damages of the stratum corneum and thought of distinct pathways of pressure ulcer development at both skin areas. As the mattresses/beds we used for our investigations were anti-decubitus pressure reducing products with microclimate management properties, the reduced pressure could have influenced our measurements as well. However, the decrease in TEWL with the Duo™ 2 mattress, which is also an anti-decubitus system, was not statistically significant. In consequence it is not possible to attribute the effects we observed only to reduced pressure on the skin but to microclimate modulating effects, too.

Schario et al. [42] investigated skin responses to sustained loading in a sitting position (immobilization time 45 min) with 6 healthy females. Sitting on a hard surface caused skin barrier changes at the gluteal skin in terms of stratum corneum hydration and TEWL. Additionally, these changes seemed to be dependent on the fabric which was in direct contact to the skin. As the skin of the subjects in our study did not have direct contact with the mattresses and we used the same mattress cover for all mattresses/hospital beds, we can exclude that different mattress pads could have influenced our measurements.

Shin et al. [29] investigated the effects of uncoated paper on skin moisture and TEWL in bedridden patients with the same devices we used. They showed that that skin moisture as well as the TEWL was significantly lower after application of an uncoated paper than observed after application of a disposable underpad and concluded that uncoated paper may avoid excess moisture and maintain better skin barrier function in the sacrum than application of disposable underpads. With regards to a non microclimate management capable underground such as uncoated paper reducing TEWL values this work seems to be contrary to our findings at first sight. They assumed that the use of an air mattress might have been a confounding variable in their study since all of their subjects used an air mattress with air circulation supply. We found that the air fluidized bed showed statistically significant lower TEWL values than the baseline measurements, it is likely that air fluidized therapy influences skin properties. It is not reported if there were differences in the permeability of the paper and disposable underpads. As normal disposable underpads often consist of a plastic foil which prevents fluids soaking through, it seems likely that the disposable underpads are less permeable than normal paper. In consequence it could be that the underpads shielded the skin of the patient from external influences such as air circulation from the air fluidized bed and therefore showed higher TEWL values than with uncoated paper, which normally has no barrier function.

In our data we see a trend toward decreased TEWL on an alternating pressure surfaces which is supported by other studies: Tomova-Simitchieva et al. [43] assessed the effects of 3 different pressure ulcer prevention support surfaces (reactive gel, active alternating air, basic foam) on the structure and function of heel and sacral skin of 15

females. They found an increase of median TEWL, temperature, erythema and stratum corneum hydration from baseline to immediately after 2 h loading on the sacrum as well as on the heel skin for all interventions. Values decreased again after 20 min of off-loading. The foam mattress showed the highest increases of TEWL, temperature and erythema, which was three times higher than on the gel mattress in the sacral area. Stratum corneum hydration only increased slightly. Similar results were obtained in the heel skin. Here, the temperature-adjusted TEWL was approximately twice as high compared with baseline values. They argued that higher values for TEWL, stratum corneum hydration and skin temperature are based on the limited air convection and radiation with increase of skin temperature and an accumulation of water molecules in the stratum corneum. After off-loading, evaporation of the accumulated water lead to a normalization of the measurements. As air fluidized beds are considered to be the most drying support surface [11] because they use air movement to influence temperature and humidity/moisture at the interface between skin and the support surface, it is most likely that this could have caused the lower TEWL in the PEARLS AF bed in our investigations since water didn't accumulate in the stratum corneum. In consequence it is likely that the air convection actively influences the microclima of the skin.

McNabb et al. [44] studied the amount of evaporation of healthy subjects and patients in a fluidized bed. Whereas the water loss in the group of healthy subjects was similar in a standard hospital bed and the air fluidized bed at low air-fluidized temperature (86 °F = 30 °C), it highly increased when temperature was elevated (94 °F = 34.44 °C). Since the measurement method was based on weight measurement and therefore includes sweat gland activity (which is not included in TEWL measurement), the results are only partial comparable. It is likely that higher temperature could have increased the sweat gland activity and thus contributed to a higher loss of water in total. As we found already statistically significant differences in TEWL between standard hospital beds and air fluidized beds, it could be that both sweating and TEWL are influenced by higher temperature of the device.

With regard to the preceding research studies, it is likely that mattresses/hospital beds being able to function as a resistor to heat and moisture loss from the skin. Accumulation of moisture and temperature at the skin surface might reduce skin barrier function and integrity and in consequence could cause skin damage. The usage of microclimate management hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany) showed lower TEWL values compared to standard mattresses/hospital beds (Viskolastic® Plus, Wulff Med Tec GmbH, Fedderingen, Germany and Duo™ 2 mattress, Hill-Rom GmbH Essen, Germany), indicating that these microclimate management systems could have actively improved skin barrier function and integrity by improving the air convention to the skin. Apart from optimizing the pressure on sore prone areas, this mechanism plays an important role in the development of ulcers. Our study provides first quantitative data that these microclimate management systems (beside reducing pressure on skin) improve skin barrier function.

## 5. Conclusion

Microclimate management capable mattresses/hospital beds (ClinActiv + MCM™ and PEARLS AFT, Hill-Rom GmbH Essen, Germany) actively influence the skin properties. We showed for the first time that these beds decreased transepidermal water loss (TEWL) even after a short time. As higher TEWL announces impaired skin barrier function these findings indicate that the choice of the mattress/hospital bed is important for skin barrier function and could prevent skin damage. Further research is required to reveal chances for implementation to prevent skin damage and ulcers due to non-optimal hospital beds especially for bedridden patients with a high risk for pressure ulcer development.

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