Journal of Tissue Viability 29 (2020) 2–6

Contents lists available at ScienceDirect

Journal of Tissue Viability

journal homepage: www.elsevier.com/locate/jtv

A quantitative study of hydration level of the skin surface and erythema on conventional and microclimate management capable mattresses and hospital beds

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ARTICLE INFO

Keywords:
Pressure ulcer
Skin microclimate
Hospital bed
Skin hydration
Erythema

ABSTRACT

Background: In addition to pressure itself, microclimate factors are gaining more attention in the understanding of the development of pressure ulcers. While there are already various products to reduce pressure on sore-prone areas to prevent pressure ulcers, there are only a few mattresses/hospital beds that actively influence skin microclimate. In this study, we investigated if microclimate management capable mattresses/hospital beds can influence skin hydration and skin redness/erythema.

Methods: We included 25 healthy subjects in our study. Measurements were made using Courage & Khazaka Multi Probe Adapter MPA with Corneometer CM825 and Mexameter MX18 to determine skin hydration of the stratum corneum and skin redness/erythema 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 difference in skin redness/erythema on the different mattresses/hospital beds, skin hydration of the stratum corneum decreased significantly in an air fluidized bed compared to baseline values and values measured on standard mattress/Viskolastic® Plus.

Conclusion: Air-fluidized therapy reduces skin hydration and therefore could contribute to prevent moisture associated ulcers. Changes in skin hydration as one important factor of skin microclimate can be detected after a short time of incubation and even before an erythema appears.

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 hospitals ranges from 0.3% to 46% and incidence from 0.8% to 34% all around the world [2]. For this reason, pressure ulcers are still a great challenge for medical professionals as well as the healthcare system.

The costs of pressure ulcer treatment per day (between 1.71 Euro and 470.49 Euro) are much higher than the cost for pressure ulcer prevention per patient at risk per day (2.65 Euro and 87.57 Euro) [3]. Since ulcers often develop upon specific risk factors, these risk factors are the basis for pressure ulcer prevention and often part of clinical scoring systems. The Braden Scale for Predicting Pressure Sore Risk [4,5] was developed by Barbara Braden and Nancy Bergstrom and is a clinically established score for health professionals, especially nurses, which enables to assess this risk for developing an ulcer. Aside from a reduction in sensory perception, activity and mobility, friction, shear forces, and poornutritional 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 often seems to be challenging [7].

Several studies indicate that microclimate factors such as temperature, humidity and airflow on and near the skin play an important role in the development of pressure ulcers [8–12]. Damp or wet skin is more

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https://doi.org/10.1016/j.jtv.2019.12.001
Received 9 July 2019; Received in revised form 23 November 2019; Accepted 8 December 2019
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permeable to irritating substances and more readily colonized by microorganisms. In addition, friction is required to abrade or blister skin when it is damp [13]. Previous studies showed that the dynamic shear modulus for stratum corneum decreases with increasing relative humidity [14] suggesting that moisture influences the resilience of the upper skin layers. Other data [15] 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 [16].

For this reason, it is essential to provide optimal conditions concerning microclimate in mattresses/hospital beds especially for bedridden patients which have a high risk for developing ulcers. Although this might be an important topic, only few data are published regarding the question if and how mattresses/hospital beds actively influence skin microclimate. While there are already various products to reduce pressure on predilection sites for pressure sores to prevent pressure ulcers, there are only few mattresses/hospital beds that actively influence skin microclimate. We previously showed that microclimate management capable hospital beds can reduce transepidermal water loss and in consequence improve skin barrier function [17] so it is likely that other skin microclimate factors such as skin hydration level and erythema could be influenced by these surfaces too.

Inspection and palpation of skin redness/erythema is an important part of the diagnosis and classification and blanchable redness is defined as pressure ulcer stage 1. Altered skin status even can be used for risk assessment as people with non-blanchable erythema may be more likely to develop new pressure ulcers than those without non-blanchable erythema [18]. Based on the literature review we focused on skin hydration and redness as important factors to evaluate biophysical and microclimate skin properties as predictors for the development of pressure ulcers in different 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).

2. Methods

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

Healthy volunteers were recruited from the hospital staff (physicians, nurses, students, scientific staff). Before participation in 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 trauma center Tuebingen with closed doors to ensure a minimum of air draft under almost identical conditions regarding temperature and humidity with regards to the different measurement of one test subject. Room temperature for all measurements in total 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 was made. Afterwards, the subjects had to lie as still as possible on their backs in the different mattresses/hospital beds for 5–7 min, then had to turn on their side and right after that the measurements were performed.

We used the Courage & Khazaka Multi Probe Adapter (Courage + Khazaka, Köln, Germany) with Corneometer CM825 (Courage + Khazaka, Köln, Germany) and Mexameter MX18 (Courage + Khazaka, Köln, Germany) for all our measurements.

The Corneometer has been used in various previous studies [19–23] for determining skin hydration level. The measurement is based on the capacitance measurement of a dielectric medium and can detect even slight changes in the hydration level. It measures the change in the dielectric constant due to skin surface hydration changing the corneoprinzcapacitance of a precision capacitor. Values are given in arbitrary units (AU). We performed 3 measurements in nearby skin areas according to the manufacturer's recommendations and calculated the mean value for further analysis (repeated measurements on the same skin area lead to higher values due to accumulation of moisture).

The Mexameter MX18 (Courage + Khazaka, Köln, Germany) has been used in various previous studies [23–26] for determining erythema and melanin level of the skin. The device emits 3 specific light wavelengths and a receiver measures the light reflected by the skin. As the quantity of emitted light is defined, the quantity of light absorbed by the skin can be calculated. The melanin content is measured by specific wavelengths chosen to correspond to different absorption rates by the pigments. For the erythema measurement, specific wavelengths are also used, corresponding to the spectral absorption peak of hemoglobin and to avoid other colour influences. Values are given in arbitrary units (AU). We performed 3 measurements in a darkened room according to the manufacturer's recommendations and calculated the mean value for further analysis.

We investigated skin hydration level, erythema and melanin level of the skin 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). Since it is likely that the devices with microclimate management function influence skin properties and in consequence could distort subsequent measurements on conventional hospital beds, we tested the conventional systems prior to the microclimate management capable mattresses so that potential carry-over effects could be excluded. The subjects had to rest about 3 min before lying on the next support surface.

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

The Duo™ 2 (Hill-Rom GmbH Essen, Germany) [27] 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) [28] 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 the 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 at 30 °C, which is - according to the manufacturer - a common setting in daily routine. The mattress was covered with a standard cotton mattress cover.

The PEARLS AFT (Hill-Rom GmbH Essen, Germany) [29] 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 at 30 °C, which is - according to the manufacturer - a common setting in daily routine. The bed was covered with a standard cotton mattress cover.

All data are given as median, quartiles and ranges presented in box

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

and whisper plots. 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).

(*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; n.s. = not significant).

3. Results

3.1. Collective of subjects

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

3.2. Skin hydration

Skin hydration measurements revealed baseline values of 66,85 ± 23,38 AU. All mattresses/hospital beds (Fig. 1) showed lower skin hydration values (Viskolastic® Plus: 59.16 ± 17.97 AU; Duo™ 2: 52.19 ± 12.03 AU; ClinActiv + MCM™: 51.31 ± 15.05 AU). The PEARLS AFT air fluidized bed showed significant ($p \leq 0.01$ and $p \leq 0.001$) lower skin hydration levels (42.71 ± 11.73 AU) when compared to the baseline group or the standard hospital mattress/

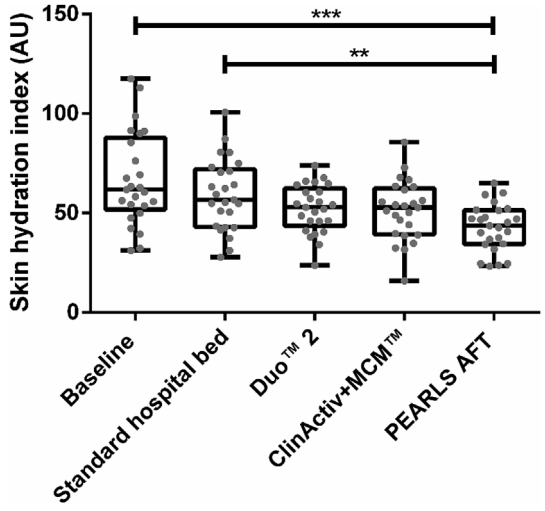

Fig. 1. Corneometer values in the sacral region of different mattresses/hospital beds
Measurements were performed before (baseline) and after 5–7 min of resting in different mattresses/hospital beds (**$p \leq 0.01$; ***$p \leq 0.001$, n = 25).

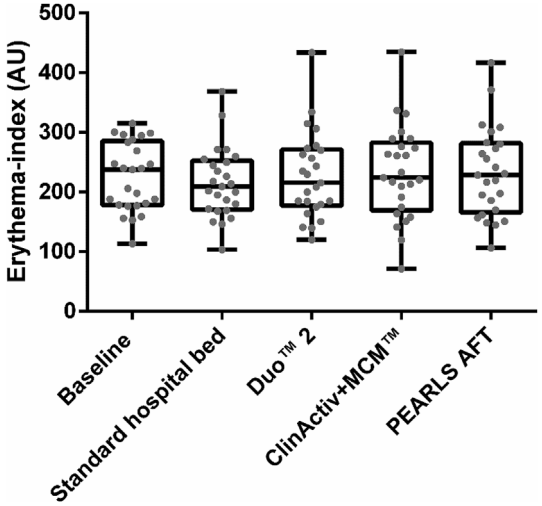

Fig. 2. Erythema values in the sacral region of different mattresses/hospital beds
Measurements were performed before (baseline) and after 5–7 min of resting in different mattresses/hospital beds. There were no statistically significant differences ($p \leq 0.05$, n = 25).

Viskolastic® Plus mattress.

3.3. Erythema

No statistically significant differences ($p \leq 0,05$) were observed in skin redness/erythema within the groups (Fig. 2) after incubation. The baseline value was 225.4 ± 57.53 AU. Both controls showed similar skin redness/erythema units (standard hospital matress/Viskolastic® Plus: 215.3 ± 58.76 AU, Duo™: 2227.5 ± 72.22 AU) than microclimate management capable mattresses/hospital beds (ClinActiv + MCM™: 232.4 ± 78.83 AU; PEARLS AFT: 233.0 ± 75.12 AU).

3.4. Melanin

There were no statistically significant differences ($p \leq 0.05$) between baseline (103.8 ± 46.62 AU) or controls (standard hospital mattress/Viskolastic® Plus: 89.67 ± 47.04 AU; Duo™ 2: 96.57 ± 49.59 AU) and microclimate management capable mattresses/hospital beds (ClinActiv + MCM™: 87.57 ± 43.22 AU; PEARLS AFT: 91.12 ± 40.91 AU).

4. Discussion

Skin that is damp or wet 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 [13]. Therefore, it is essential to provide optimal conditions concerning microclimate in mattresses/hospital beds especially for bedridden patients who have a high risk of developing ulcers. There is growing evidence that microclimate plays an important role in the development of ulcers [8–10,12]. Although this might be an important topic only few data are already published regarding the question if mattresses/hospital beds can 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 mattresses/hospital beds that actively influence skin microclimate.

Our data indicate that air fluidized therapy reduces skin hydration while skin redness/erythema is not affected after 5–7 min of resting on the different surfaces. All devices showed lower skin hydration levels after incubation indicating that all mattresses/hospital beds we tested reduced the skin hydration level at least in part. This possibly could be

due to the contact of the fabric with the skin.

Kleesz et al. [23] investigated the baseline values at 16 anatomical sites in 125 human subjects with the same devices we did. Skin hydration values ranged between 27.7 and 84.9 AU, whereas the highest values were measured in the spine region. Although they performed no measurements in the sacral region our baseline measurements correspond well to their baseline measurements. Skin redness/erythema ranged between 556.8 AU and 643.9 AU which is higher than the values we obtained. Since the studies cited below reported similar results as we did, it remains unclear why these subjects had such high baseline erythema indices. As only 14 of 125 volunteers in this study were females it might be that these differences were gender-specific (they discussed their male-dominated collective of subjects as limitations of their study). External influences such as temperature and humidity could have caused additional bias.

Scheel-Sailer et al. [16] investigated the skin hydration and redness in the unloaded sacral region of healthy persons after lying in supine position on a standard mattress and bed sheet (80% cotton, 20% polyester) and reported slightly lower values for skin redness (mean 163.2 ± 48.3 SD AU) and skin hydration (mean 29.7 ± 12.8 SD AU). In a later study [30] they investigated the biophysical skin properties in the sacral region again with the same devices as we used (Corneometer CM 825 and Mexameter MX18) and determined hydration, redness, elasticity and perfusion of the unloaded skin in spinal cord injury patients suffering from a grade 1 pressure ulcer. Measurements were performed after test subjects reclined for half an hour in the supine position in a standard hospital bed with a standard mattress. They found that the affected skin of spinal cord injury patients with pressure ulcers showed elevated redness (median 595.5 AU, quartiles 440.4–631.6 AU) and perfusion while unaffected skin areas showed significant lower AU values (median: 270.5 AU; quartiles: 200.6 and 305.4 AU). The same was observed in spinal cord injury patients without pressure ulcer (median: 206.5; quartiles: 182.1 and 250.1 AU) and the abled-bodied reference group (median: 156.8 AU, quartiles: 120.1 and 188.4 AU). Hydration measurements revealed no clear differences between spinal cord injury patients with pressure ulcers (median: 25.6 AU; quartiles: 20.1 and 32.0 AU) and their unaffected skin area (median: 26.4 AU; quartiles: 23.0 and 39.4 AU). Both control groups showed similar values as well (spinal injury chord patient without pressure ulcer median 25.0 AU; quartiles: 17.1 and 32.9 AU and abled-bodied reference group median: 28.1 AU; quartiles: 22.3 and 37.7 AU). Our measurements of skin redness/erythema measurements do not differ greatly after 5–7 min lying in the different hospital beds probably due to a too short resting time in the bed. While there are existing data which indicate that microcirculation is impaired already after 5 min [31], this seems not to have an effect on skin redness/erythema. We observed lower skin hydration values in the air fluidized bed. Since they performed measurements only with one hospital bed and only after test subjects reclined for half an hour in the supine position, data in this regard are hardly comparable.

Kottner et al. [32] 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 periods skin surface temperature, stratum corneum hydration, transepidermal water loss and erythema were measured in these areas. They found that skin erythema increased after prolonged loading from 166 ± 56 AU to 221 ± 60 AU after 90 min while stratum corneum hydration remained stable (40.0 ± 11.7 AU to 45.1 ± 10.8 AU after 90 min). As their investigation mainly focuses on the pressure associated changes while our setting is more focused on changes of microclimate, the duration of the time the subjects had to lie in the bed differs. It might be possible that there are also changes in skin redness/erythema between the different mattresses/hospital beds we used when subjects would have been lying longer in the beds.

Schario et al. [33] 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 transepidermal water loss. Additionally, these changes seemed to be dependent on the fabric which was in direct contact with 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 (which could be more or less permeable for air) could have influenced our measurements.

Tomova-Simitchieva et al. [34] 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 transepidermal water loss, 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 transepidermal water loss, 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. They argued that higher values for transepidermal water loss, stratum corneum hydration, and skin temperature are based on the limited air convection and radiation with an increase of skin temperature and an accumulation of water molecules in the stratum corneum. After off-loading evaporation of the accumulated water leads to a normalization of the measurements. Air fluidized beds are considered to be the most drying support surface [11] as it uses air movement to influence temperature and humidity/moisture at the interface between skin and the support surface. In consequence, it is most likely that this could have caused the lower skin hydration values in the PEARLS AF bed since water didn't accumulate in the stratum corneum. We didn't find any changes in skin redness/erythema probably due to a much shorter resting time of the subjects.

Earlier studies already investigated the changes in the water balance due to air fluidized therapy: Flam et al. [35] showed that the moisture level on a low air loss support system was statistically significant lower than on a standard hospital mattress. They concluded that this can help to protect the skin against damage which is in accordance with our findings. McNabb et al. [36] studied the amount of evaporation of healthy subjects and patients in a fluidized bed. Whereas the water loss of the healthy subject 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 the temperature was elevated (94 °F = 34,44 °C). It is likely that the higher temperature could have increased the sweat gland activity and thus contributed to a higher loss of water in total.

Bates-Jensen et al. [37] showed that subepidermal moisture (SEM) was higher for erythema/Stage 1 pressure ulcers and concluded that SEM may assist in predicting early pressure ulcer damage. The same was observed in a population with dark skin tones [38] and a greater study population [37]. Because the Corneometer measurement depth is very small (10–20 μm) compared to subepidermal moisture measurements, it is difficult to compare these findings since there is no data about the effect of moisture in more superficial skin layers.

The measurement of skin redness/erythema is dependent on the absorption of a specific wavelength corresponding to the spectral absorption peak of hemoglobin and - according to the manufacturer - the influence of other colours is avoided. Nevertheless, it might be that ethnicity and skin color could influence the measurements and therefore might be a limitation of our study since it is known that skin properties can differ within different ethnicities [39,40].

It is important to mention that although moisture is one important risk factor, dry skin also showed to be a risk factor for developing heel pressure ulcers [41]: Lechner et al. showed that dry skin may be considered as a risk factor for heel pressure ulcer development while skin dryness might be less important in the development of sacral pressure ulcers. Therefore, it is difficult to draw a general conclusion concerning the possibilities for implementation of skin hydration measurements for

evaluation of the risk of pressure ulcer development in daily clinical practice since it might be that there are differences in pressure ulcer aetiologies between anatomical locations [41]. Additionally, it could be that longer incubation on the different surfaces leads to the accumulation of moisture despite the air convection at the interface between the skin and the support surface in the air fluidized bed. Since our study focuses on effects of short-time incubation, further studies are needed to address long-time effects.

5. Conclusion

According to our knowledge we have shown for the first time that it is possible to detect changes in skin hydration level even after a short time of incubation in microclimate management capable hospital beds with air fluidized therapy. Since abnormal skin hydration increases the risk for infections and pressure ulcers it is likely that air fluidized therapy besides reducing pressure on sore-prone areas improves skin microclimate and therefore could be used in the therapy and prevention of pressure and moisture associated ulcers.

Acknowledgments

Hill-Rom GmbH Essen, Germany kindly provided the Duo™, ClinActiv + MCM™ and PEARLS AFT hospital beds and the compensations for expenses for probands.

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