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Original Article

Relationship between Pressure Ulcers in Elderly People and Physiological Indices of the Skin

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This study examined the relationship between skin physiological indices and pressure ulcers in elderly people. The subjects were 55 bedridden elderly Japanese patients with a median age of 85 years. The following parameters were measured using non-invasive devices: skin surface temperature, moisture content in the stratum corneum, moisture content in the dermis, transepidermal water loss as an index of skin barrier function, skin erythema and skin elasticity. The sacral and 2 heel areas were observed as sites predisposed to pressure ulcers. Within one month after measuring the skin physiological indices, we confirmed pressure ulcers of National Pressure Ulcer Advisory Panel classification Stage II or worse based on medical records. Among the 55 patients, 4 (7.3%) prospectively developed a total of 5 pressure ulcers within 16 days. Only the skin erythema score was significantly higher with than without pressure ulcers ($p < 0.001$). We performed a binary logistic regression analysis and confirmed a significant relationship between pressure-ulcer development and the level of erythema (odds ratio = 1.026; 95% confidence interval: 1.011-1.042). Skin erythema increased before the development of pressure ulcers. Taken together, our results show that the high skin erythema score can be a predictive indicator of pressure ulcers.

Key words: elderly people, erythema, pressure ulcer, skin

Pressure ulcers, which lead to a lower quality of life [1] and have high treatment costs [2], are an important public health issue in elderly people despite the recent decrease in their prevalence [3, 4]. A survey conducted in 2016 in a rural area in Japan [5] showed that the majority of patients with pressure ulcers were malnourished elderly people with age-related illnesses. In elderly people, the skin is easily damaged owing to age-related physical changes (thinning of the skin and subcutaneous tissues and decreased resilience and elasticity) [6-8]. Such conditions create a large force inside the skin, causing tissue strain and ischemia [9]. Delayed cellular turnover caused by aging and consequent inadequate intercorneocyte lipids cause the skin of elderly people to be prone to dryness [10]. Dry skin conditions also increase friction and cause shearing, thereby damaging the skin and subcutaneous tissues [9]. Elderly people can easily develop pressure ulcers; thus, it is important to identify patients at risk of pressure ulcers and provide preventive care.

Pressure ulcer risk-assessment scales are beneficial for identifying patients who are at risk of pressure ulcers so that preventive measures can be implemented [11, 12]. These scales are scored on the basis of subjective assessments by the evaluator or the assessment of reports provided by the patients and their families. Furthermore, studies have been done on the potential

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of physiological indices of the skin, which are objective and numerical indices, to act as predictive factors [13-20]. The relationship between physiological indices of the skin, such as the moisture content in the stratum corneum [13, 14], skin barrier function [13], skin temperature [15, 16], and moisture content in the dermis (subepidermal moisture) [17-20], and an individual's susceptibility to pressure ulcers has been studied. However, no consistent results have been obtained as of yet, and the investigations are therefore ongoing. The subjects of these studies were young adults or middle-aged patients [13-15]. To date, no study has targeted elderly bedridden Japanese patients who are at high risk of pressure ulcers.

The objective of the present study was to examine the relationship between physiological indices of the skin in elderly people and the onset of pressure ulcers. We used non-invasive devices to measure physiological indices of the skin in elderly people who are at high risk of pressure ulcers.

Materials and Methods

Facility and subjects. This observational study was conducted in a facility with 200 beds and a convalescence ward located in a rural area in Kochi Prefecture, Japan, between October 2017 and August 2018. The study subjects had no visible injuries to the skin, were aged ≥60 years, and scored ≤18 on the Braden scale, which assesses the risk of pressure ulcers. The Braden scale comprises 6 subscales: sensory perception, activity, mobility, skin moisture, friction/shearing, and nutrition. Each item is scored between 1 and 4 (exceptions: friction and shearing are scored up to 3), and then the items are totaled; the risk of pressure ulcers is assessed using the total score, which falls between 6 and 23 [21]. The Braden scale considers a score of ≤18 as showing a high risk for pressure ulcers [22]. Those prone to changes in their physical conditions, such as fluctuations in their blood pressure, were excluded, because the subjects had to remain in the same position during the measurements of the physiological indices of the skin. The facility provided care that would help prevent pressure ulcers in accordance with the facility's policy, which consisted of guidelines for skin and continence care, regular turning and repositioning of the supporting surface mat on the bed to reduce pressure, and consultation with a nutritionist for bedridden patients. The study procedures were approved by the research ethics committees of the facility and participating institution (University of Kochi, Approval Number: 17-43), and they adhered to the guidelines stipulated in the Declaration of Helsinki. Written informed consent was provided by all participants involved in this study who were able to provide consent and by family members of those unable to provide consent.

Procedures. We measured the physiological indices of the skin at sites predisposed to exhibiting pressure ulcers (the sacral region and both heels) using non-invasive devices. The physiological indices of the skin measured included the skin surface temperature, moisture content in the stratum corneum, moisture content in the dermis, transepidermal water loss (TEWL) as an index of the skin barrier function, skin erythema, and skin elasticity. Information related to each patient's age, sex, illnesses, blood test results, body mass index (BMI), and risk factors for pressure ulcers was collected while measuring the physiological indices of the skin. One month after the measurement, patients were assessed for skin conditions using the National Pressure Ulcer Advisory Panel classification system (NPUAP) [23] by facility nurses. In the NPUAP system, pressure ulcers are classified into stages I, II, III, and IV. Stage I is nonblanchable erythema, Stage II is partial loss of the dermis, stage III is full-thickness skin loss, and Stage IV is full-thickness skin and tissue loss. It is difficult to determine the difference between a nonblanchable erythema in Stage I and an incontinence lesion [24]. High skin pigmentation in patients makes the detection of Stage I more difficult [25]. Therefore, in the present study, we defined the development of a pressure ulcer as the appearance of a Stage II or higher worse ulcer. We collected information on pressure ulcers at Stage II or higher and their sites one month after the measurements from medical records.

Non-invasive devices. The THERMOFOCUS®-PRO (Tecnimed Srl, Vedano Olona, Italy), a non-contact thermometer that measures both skin surface temperature and body temperature, was used for measuring the skin surface temperature. The Corneometer® CM825 (Courage-Khazaka electronic GmbH, Cologne, Germany) was used to measure the moisture content of the stratum corneum, expressed in arbitrary units (a.u.), at a very superficial depth of 10-20 μm [26]. Moisture content in the stratum corneum of <60 a.u. in the upper body and < 50 a.u. in the legs indicates dry skin. The MoistureMeterD Compact® (Delfin Technologies, Kuopio, Finland) was used to measure the moisture content in the dermis. This device is a smaller version of the MoistureMeterD® and was developed to measure moisture content at a depth of 2.0-2.5 mm from the skin surface; it converts the moisture content into a percentage moisture rate in units of wt%. The Tewameter®TM300 (Courage-Khazaka electronic GmbH) was used to measure TEWL. This device measures moisture that evaporates from the skin surface (g/hm^2) [27]. Smaller TEWL values indicate better skin conditions, whereas values ≥ 25 g/hm^2 indicate poor skin conditions. The Mexameter®MX18 (Courage-Khazaka electronic GmbH) was used to measure skin erythema. This device measures the amount of hemoglobin in the skin (erythema) and expresses the degree of skin erythema in the range of 0-999 a.u. [28]. An erythema score of 0-170 a.u. indicates the absence of erythema, whereas 170-330 a.u. represents mild, 330-450 a.u. moderate, 450-570 a.u. severe, and > 570 a.u. extreme erythema. The Cutometer®MPA580 (Courage-Khazaka electronic GmbH) was used to measure skin elasticity. This device has a suction probe with an opening with a diameter of 4 mm. The skin to be measured is suctioned into this opening to measure the skin elasticity. This device expresses skin elasticity with a parameter ranging from R0 to R9. In the present study, we used R2, which represents the elasticity of the overall skin. R2 is expressed in the range of 0-1.00 a.u. [29]. The closer the R2 value is to 1, the higher the elasticity [29].

Measurement of physiological indices of the skin. The patients were positioned in the lateral position, and the measurement locations were determined by palpation. Referring to a previous study [30], to prevent any contact between the device and the skin from having an effect on the measured values, we first measured the skin surface temperature, followed by the skin erythema, moisture content in the stratum corneum, moisture content in the dermis, TEWL, and skin elasticity, in that order. The skin temperature, moisture content in the stratum corneum [31, 32], moisture content in the dermis, and skin erythema [28] were measured four times for each site, and the mean was calculated. For TEWL, we followed the user's manual of the device manufacturer and placed the probe head against the skin for 30 sec to take the measurements, then selected the value with the smallest deviation. Skin elasticity was measured thrice per site to calculate the mean [33]. The measurements took 30 min to perform. The room temperature and humidity were set to 22-24°C and 40-50%, respectively. Measurements were taken in the afternoon to avoid any impact of the circadian rhythm on the physiological indices of the skin.

Statistical analysis. For the clinical characteristic data of the patients and the physiological indices of the skin, categorical variables were expressed as percentages, and continuous variables were expressed as medians and ranges or interquartile ranges. We first compared the physiological indices between skin with and without pressure ulcers for all of the sites (sacral region and heels) using the Mann–Whitney *U*-test. We next used Spearman's rank-order correlation to examine the correlations among the physiological indices of the skin, performed a binary logistic regression analysis with forced entry, and examined the relationship between the development of pressure ulcers and the physiological indices of the skin. We used SPSS Ver25 (IBM, Armonk, NY) as the statistical software. The significance level was set at 0.5%.

Results

We obtained data from 55 patients with a median age of 85 years (interquartile range, 75-89 years). There were 23 men (41.8%) and 32 women (58.2%).

Among the 55 patients, 4 patients (7.3%) developed pressure ulcers of NPUAP classification Stage II or worse within 16 days of the measurements of the physiological indices of the skin. There were 5 pressure ulcers in total. The sites and timing of the pressure ulcers and the skin condition at the time of measurement in these 4 patients are presented in Table 1. One patient had pressure ulcers in two locations, the sacral region and the right heel, whereas the other patients each had one pressure ulcer at one site. As for the pressure ulcer locations, two were in the sacral region, two were on the right heel, and one was on the left heel. All pressure ulcers were assessed as NPUAP classification Stage II. The date of onset was one day after the measurement for the shortest case and 16 days after the measurement for the longest. At the time of the measurement, skin discoloration was observed on the skin where the pressure ulcers developed. This skin showed slightly red or red-purple discoloration. The detection of blanchable erythema using finger palpitation was difficult due to the original skin pigmentation.

The characteristics of the patients with pressure ulcers are shown in Table 2. All patients had low serum albumin levels (range: 2.3-3.3 g/dl) and Braden scale values (range: 7-12 points). All patients with pressure ulcers were unable to change position by themselves. They received both continence care and interventions to reduce pressure, including regular postural change and the use of an air mattress.

A comparison of clinical characteristic data between patients with and without pressure ulcers is shown in

Table 1 Sites and timing of pressure ulcers and skin condition at the time of the measurement

Patients with pressure ulcers	Site	Timing counted from the measurement date	Skin condition at the time of the measurement
A	left heel	2 days later	slightly red-purple skin on the left heel
B	right heel	14 days later	slightly red-purple skin on the right heel
C−1	sacral region	9 days later	slightly red skin in the sacral region
C−2	right heel	1 day later	slightly red-purple skin on the left heel
D	sacral region	16 days later	slightly red skin in the sacral region

Table 2 Characteristics of patients with pressure ulcers

Patients with pressure ulcers	A	B	C	D
Age (years)	96	82	88	87
Illnesses	cerebral infarction, dementia, hypertension	cerebral infarction, lower limb ischemia, hypertension	heart failure, disuse syndrome	cerebral hemorrhage, heart failure, emphysema, hypertension
Serum Alb level (g/dL)	3.3	2.5	2.3	3.0
Serum protein (g/dL)	6.2	6.1	6.5	6.3
Hb level (g/dL)	11.9	9.6	11.4	13.9
BMI	20.2	15.2	16.2	18.5
The Braden scale				
Total points	7	8	12	12
Subscales (points, condition)				
Sensory perception	2, very limited	2, very limited	3, slightly limited	3, slightly limited
Skin moisture (presence of incontinence)	1, constantly moist (with bowl and urinary incontinence)	2, often moist (with bowl and urinary incontinence)	3, occasionally moist (with bowl incontinence and urethral catheter insertion)	1, constantly moist (with bowl and urinary incontinence)
Activity	1, bedfast	1, bedfast	2, chairfast	1, bedfast
Mobility	1, completely immobile	1, completely immobile	2, very limited	2, very limited
Nutrition (usual food intake pattern)	1, very poor (oral intake)	1, very poor (non-eating and receiving intravenous nutrition)	1, very poor (oral intake)	3, adequate (receiving a tube feeding)
Friction/Shearing	1, problem	1, problem	1, problem	2, potential problem
Others	bony prominence at sacral, and both lower limbs edema	joint contracture at both ankle, knee, and hip	joint contracture at hip	bony prominence at sacral, joint contracture at right knee, and a history of pressure ulcer at sacral

Alb, albumin; Hb, hemoglobin; BMI, body mass index.

Table 3. The serum albumin levels in patients with pressure ulcers were significantly lower than those in the patients without pressure ulcers ($p = 0.02$); however, there were no significant differences in any other items.

Table 4 shows the physiological indices of the skin for each site and comparisons of the physiological indices of the skin between skin with and without pressure ulcers for all sites. We measured physiological indices of the skin at 5 locations (2 sacral regions, 3 heels) with pressure ulcers and at 158 locations (51 sacral regions, 107 heels) without pressure ulcers. The skin erythema scores of the sites where pressure ulcers later developed were significantly higher than those of the sites without pressure ulcers for all sites ($p < 0.001$). The median skin erythema scores of the sites where pressure ulcers occurred were high within the range of reference values for "severe erythema" (450-570 a.u.) at all sites. In contrast, the median skin erythema scores at sites without pressure ulcers were within the range of reference values for "mild erythema" (170-330 a.u.) at all sites. There was no significant difference in the physiological indices of the skin for all sites other than for skin erythema.

Regarding the correlations among the physiological indices of the skin at all sites, there were statistically moderate-to-strong correlations among skin temperature, moisture content in the stratum corneum, moisture content in the dermis, and TEWL; however, there were no correlations between skin erythema and the other physiological indices of the skin (Table 5). Moreover, we performed a binary logistic regression analysis with forced entry and examined the relationship between the development of pressure ulcers with an NPUAP classification of Stage II or worse and skin erythema. The results showed a significant relationship between the development of pressure ulcers of Stage II or worse and the degree of erythema (odds ratio = 1.026; 95% confidence interval: 1.011-1.042) (Table 6).

Discussion

The present study measured six types of physiological indices of the skin at sites predisposed to pressure ulcers in elderly people (the sacral region and heels) and confirmed that high levels of skin erythema were significantly related with the development of Stage II pres-

Table 3 Comparison of clinical characteristic data between patients with and patients without pressure ulcers

Variable	No pressure ulcers N = 51	Pressure ulcers N = 4	*P*-value
Age, years	83 (74–89)	88 (85–92)	0.23[a]
Sex/men (N, %)	20 (39.2)	3 (75.0)	0.19[b]
Illnesses (N, %)			
Mental disorders	13 (25.5)	1 (25.0)	0.74[b]
Extrapyramidal tract disorders	10 (19.6)	1 (25.0)	0.60[b]
Hypertension disorders	19 (37.3)	3 (75.0)	0.17[b]
Heart disorders	10 (19.6)	2 (50.0)	0.20[b]
Cerebrovascular diseases	35 (68.6)	3 (75.0)	0.64[b]
Muscle disorders	9 (17.6)	1 (25.0)	0.56[b]
Serum Alb level (g/dL)	3.5 (3.1–3.8)	2.8 (2.4–3.2)	0.02[a]
Serum protein (g/dL)	6.8 (6.4–7.3)	6.3 (6.2–6.4)	0.07[a]
Hb level (g/dL)	11.5 (10.4–13.4)	11.7 (10.5–12.9)	0.96[a]
Hct level (%)	35.0 (31.5–40.0)	35.7 (30.7–40.4)	0.91[a]
BMI	20.2 (17.0–22.5)	17.4 (15.7–19.4)	0.18[a]
The Braden scale	13 (9–15)	10 (8–12)	0.32[a]
Pressure ulcer risk factors (N, %)			
Inability to change position by themselves	34 (66.7)	4 (100.0)	0.22[b]
Bony prominence	14 (27.5)	2 (50.0)	0.33[b]
Bowel incontinence	39 (76.5)	4 (100.0)	0.34[b]
Urinary incontinence	47 (92.2)	3 (75.0)	0.33[b]
Edema	23 (45.1)	1 (25.0)	0.41[b]

N, the number of person; Alb, albumin; Hb, hemoglobin; Hct, hematocrit; BMI, body mass index. Values are presented as median (interquartile range) unless otherwise indicated. [a]Mann-Whitney *U*-test, [b]Fisher's exact test.

Table 4 Comparison of physiological indices of the skin at all sites between skin with and without pressure ulcers

Variable		No pressure ulcers		Pressure ulcers		*P*-value
Skin temperature (°C)	all sites	N = 158	32.2 (28.2–34.7)	N = 5	30.6 (26.4–35.2)	0.916
	sacral region	N = 51	34.8 (32.8–36.5)	N = 2	35.2 (34.7–35.7)	
	heels heels	N = 107	29.8 (23.6–36.9)	N = 3	30.1 (22.7–30.6)	
Moisture content in the stratum corneum (a.u.)	all sites	N = 158	17.9 (10.2–27.3)	N = 5	18.4 (10.5–37.2)	0.610
	sacral region	N = 51	29.6 (6.1–71.8)	N = 2	37.2 (36.2–38.2)	
	heels heels	N = 107	12.7 (2.2–46.7)	N = 3	13.1 (8.0–18.4)	
Moisture content in the dermis (Wt%)	all sites	N = 158	36.0 (29.1–49.8)	N = 5	33.5 (30.3–54.1)	0.892
	sacral region	N = 51	55.0 (28.0–76.3)	N = 2	54.1 (50.0–58.3)	
	heels heels	N = 107	33.0 (10.3–67.0)	N = 3	31.5 (29.0–33.5)	
TEWL value (g/hm^2)	all sites	N = 158	13.3 (8.3–19.8)	N = 5	16.2 (8.7–23.2)	0.715
	sacral region	N = 51	7.0 (2.3–16.2)	N = 2	8.7 (6.3–11.0)	
	heels heels	N = 107	17.6 (5.4–53.2)	N = 3	18.4 (16.2–27.9)	
Skin erythema (a.u.)	all sites	N = 158	237.1 (189.8–300.8)	N = 5	487.8 (371.5–500.8)	<0.001
	sacral region	N = 51	242.0 (150.5–448.3)	N = 2	429.6 (371.5–487.8)	
	heels heels	N = 107	234.8 (97.5–491.3)	N = 3	500.8 (339.0–571.5)	
Skin elasticity (R^2) (a.u.)	all sites	N = 158	0.64 (0.57–0.71)	N = 5	0.68 (0.53–0.72)	0.981
	sacral region	N = 51	0.68 (0.43–0.88)	N = 2	0.61 (0.54–0.69)	
	heels heels	N = 107	0.62 (0.22–0.83)	N = 3	0.68 (0.53–0.75)	

N, the number of locations; TEWL, transepidermal water loss; a.u., arbitrary units. Values are presented as median (interquartile range) at all sites and as median (range) at sacral region and both heels. Mann-Whitney *U*-test.

Table 5 Correlations among physiological indices of the skin

Variable	Skin temperature	Moisture content in the epidermis	Moisture content in the dermis	TEWL	Skin erythema	Skin elasticity (R2)
Skin temperature	1.00					
Moisture content in the stratum corneum	0.51**	1.00				
Moisture content in the dermis	0.58**	0.86**	1.00			
TEWL	−0.44**	−0.56**	−0.58**	1.00		
Skin erythema	−0.03	0.10	0.05	0.02	1.00	
Skin elasticity (R2)	0.20*	−0.01	0.08	−0.15	−0.02	1.00

TEWL, transepidermal water loss. The Spearman's rank-order correlation, $^{**}p<0.01$, $^{*}p<0.05$.

Table 6 The relationship between the development of pressure ulcers of Stage II or worse and the degree of erythema

Variable	Partial regression coefficient	*p*-value	Odds ratio	95% confidence interval of odds ratio	
				Lower limit	Upper limit
Skin erythema	0.026	0.001	1.026	1.011	1.042
Constant term	−12.342	0.000			

N (the number of locations) = 163. A binary logistic regression analysis with forced entry. Model χ^2 $p<0.01$, Cox-Snell $R^2=0.132$, Nagelkerke $R^2=0.552$.

sure ulcers. Moreover, we showed that skin erythema precedes the onset of Stage II pressure ulcers.

In a study by Scheel-Sailer *et al.* [34], skin erythema in patients with spinal injury was measured using a Mexameter®MX18 to investigate a possible association with Stage I pressure ulcers (nonblanchable erythema) in the sacral region. They reported a high median skin erythema score of 595.5 a.u. for areas with Stage I pressure ulcers, which was higher than that at sites without pressure ulcers. In the present study, the median skin erythema scores of the sites where pressure ulcers developed within 16 days (observation period: one month) was 487.8 a.u., which was relatively high. Persistent erythema, which indicates Stage I in the NPUAP classification, is characterized by dilation of the capillaries and small veins in the dermis, causing red blood cell congestion [35]. The sites where Stage II pressure ulcers occurred in the present study had slightly red or red-purple skin along with high erythema scores. The minor discoloration of the skin made it difficult to assess the lesion as NPUAP classification Stage I. Even in a case with disappearing erythema that did not reach the Stage I level, there were changes in the tissue around the capillaries and small veins in the papillae of the dermis [36]. The Mexameter®MX18, which indicates the degree of erythema, actually measures the hemoglobin content in the skin. Therefore, a high skin erythema score suggests the presence of capillary congestion as well as possible vascular damage in the dermis, indicating a precursor to Stage II pressure ulcers, which are ulcers that penetrate the dermis.

In the present study, there were no differences in skin temperature, moisture content in the stratum corneum, or TEWL between skin with and skin without Stage II pressure ulcers. A previous study on skin temperature [16] could not clarify a relationship with pressure ulcers. A study that examined the relationship between skin temperatures and pressure ulcers using thermography found that the results were not consistent [37]. In a study by He *et al.* [13], the moisture content in the stratum corneum was reduced in the skin where pressure ulcers developed. Alternatively, in a study by Sanada *et al.* [14], a high moisture content in the stratum corneum was related to pressure ulcers. There are no consistent results regarding the relationship between moisture content in the stratum corneum and pressure ulcers. The present study found moderate-to-strong correlations with statistical significance among skin temperature, moisture content in the stratum corneum, and TEWL. However, these physiological indices showed no relationship with skin erythema, which was associated with pressure ulcers. These results suggest that skin temperature, moisture content in the stratum corneum, and TEWL cannot reflect the changes that occur in skin in the process of developing pressure ulcers.

In terms of the moisture content in the dermis, inflammatory changes with tissue edema occur 3-10 days before the skin breakdown [38]; thus, the dermis gets damaged even in Stage I pressure ulcers [35], and the moisture content in the dermis increases. Bates-Jensen *et al.* [17-20] clarified that with erythema and Stage I pressure ulcers, the subepidermal moisture content increases, and this increase predicts the development of erythema and Stage I pressure ulcers one week later. However, in the present study, despite Stage II pressure ulcers developing between 1 and 16 days after the measurement, there was no difference in moisture content in the dermis between the sites with and without pressure ulcers. The MoistureMeterD Compact® used in the present study can measure moisture content at a depth of 2.0-2.5 mm from the skin surface; thus, it is believed it can measure moisture changes on the skin surface, in the dermis, and in subcutaneous tissues without being influenced by moisture changes in the stratum corneum. Because the thickness of the epidermis is 0.2 mm and that of the dermis is 2-3 mm, the MoistureMeterD Compact® measurements should reflect the moisture content in the dermis. In the present study, there was a strong correlation between the moisture content in the stratum corneum and that in the dermis. It can be assumed that the MoistureMeterD Compact® used in the present study was able to measure the moisture content in superficial parts of the skin. In the future, we need to use a device that measures the moisture content at much deeper sites.

In our study, there was no difference in elasticity between the skin with and the skin without Stage II pressure ulcers. The median skin elasticity values for the sacral region were 0.61 a.u. for the skin with pressure ulcers and 0.68 a.u. for the skin without pressure ulcers. In accordance with our observation, Scheel-Sailer *et al.* [34] measured skin elasticity using the Cutometer® MPA580 and reported no significant difference in the skin elasticity between skin in the sacral region with Stage I pressure ulcers (median, 0.834 a.u.) and skin in the sacral region without pressure ulcers (median, 0.879 a.u.). Our R2 values were lower than the values reported by Scheel-Sailer *et al.* The skin of elderly people is less elastic than that of young people [39,40]. Although extremely reduced elasticity may lead to the occurrence of pressure ulcers, the consistent results in these two studies do not imply a relationship between skin elasticity and susceptibility to pressure ulcers. The median BMI of the subjects of the present study was 20.2 in those without pressure ulcers and 17.4 in those with pressure ulcers, while the median BMI in the study by Scheel-Sailer *et al.* was 22.0 even in the subjects with pressure ulcers. A lower BMI means that the subject has less body fat or is lean. The discrepancy between these studies may come from racial differences among the subjects or the difference in the age of the subjects, which was 85 years old in our study and 62 years old in the study by Scheel-Sailer *et al.*

There are some limitations to the present study. Because our analysis involved a small number of pressure ulcers, the results of the comparison between the clinical characteristics of the patients and the results of the regression analysis have some uncertainties. We found a difference in the serum albumin levels between the participants with pressure ulcers and those without pressure ulcers (2.8 g/dl vs. 3.5 g/dl, $p=0.02$) despite there being a small number of participants. In the future, we would like to clarify the impact of the serum albumin level by increasing the number of subjects involved. We were also unable to examine changes in the erythema levels in normal skin. In the future, we would like to examine changes in the erythema levels during pressure ulcer development.

Our results clarified the usefulness of objective skin-color-measuring methods in predicting Stage II pressure ulcers in high-risk elderly patients. However, it is difficult to utilize the Mexameter®MX18 in common care homes and elderly facilities because of its high cost and research purpose. In the present study, the skin with pressure ulcers had a slightly red or reddish-purple color at the time of the measurement. All patients with pressure ulcers were bedridden and had lower serum albumin levels. Care providers in these facilities have to carefully observe the sites predisposed to pressure ulcers in bedridden elderly patients with malnutrition. They should also provide intensive care to reduce the local pressure immediately after detecting discoloration of the skin. The employment of body-pressure-dispersing material and topical vasodilators, such as dibutyryl cyclic AMP ointment and alprostadil alfadex ointment, may prevent the advancement of the stage of the pressure ulcer.

In conclusion, the present study showed that skin erythema measured with the Mexameter®MX18 was the only significantly elevated physiological indicator of the skin at sites where pressure ulcers later developed in elderly people who were at a high risk of pressure ulcers. We also showed that there is a significant relationship between skin erythema and the onset of Stage II pressure ulcers. Because skin erythema increased prior to the onset of Stage II pressure ulcers, skin color assessment (*i.e.*, the measurement of erythema) with the Mexameter®MX18 can be used as a predictive indicator for pressure ulcers.

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