



Title	A nomogram to predict skin barrier dysfunction induced by mechanical irritation during skincare in hospitalized Japanese older adults
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A nomogram to predict skin barrier dysfunction induced by mechanical irritation during skincare in hospitalized Japanese older adults

Abstract

Mechanical irritation during skincare poses a risk of causing skin barrier dysfunction in older patients. Adequate skin assessment is thus required before skincare; however, no validated assessment method exists. This study developed a nomogram to predict skin barrier dysfunction induced by mechanical irritation during skincare in Japanese older patients using a subset of a randomized controlled trial dataset. The volar forearms of 149 older patients (≥ 65 years) underwent a mechanical irritation test. Skin barrier dysfunction was defined based on transepidermal water loss before and after the test. Candidate variables were obtained from medical records and skin assessments. We found that 26.2% of older patients experienced skin barrier dysfunction. The nomogram, comprising chronic kidney disease, purpura, dry skin, activities of daily living, and body mass index, demonstrated satisfactory discrimination, calibration, and clinical utility. This tool serves as an innovative and validated method for skin assessment, offering the potential to prevent skin disorders and deliver tailored, high-quality skincare.

Keywords

Aged; Hygiene; Skin care; Skin barrier function; Risk factors

Abbreviations

SBD: skin barrier dysfunction; TEWL: transepidermal water loss; RCT randomized controlled trial; TRIPOD: Transparent Reporting of a multivariable prediction model for the Individual Prognosis Or Diagnosis; CI: confidence interval; SD: standard deviation; ADL: activities of daily living; BMI: body mass index; AUC: area under the curve; DCA: decision curve analysis

Highlights

- Mechanical irritation during skincare can cause skin barrier dysfunction (SBD).
- A prediction model for SBD was developed to prevent skin disorders in older patients.
- Final predictors were chronic kidney disease, purpura, dry skin, ADL, and BMI.
- The nomogram indicated good discrimination, calibration, and clinical utility.
- Nurses can use the nomogram as a new skin assessment tool for tailored skincare.

Introduction

Skin health and care are core nursing topics in a super-aged society.¹ Skin barrier function in the stratum corneum plays a vital physiological role in preventing internal water loss and invasion by external substances (pathogens, allergens, and chemicals).² Skin barrier dysfunction (SBD) and decreased recovery ability with aging are thus associated with various skin disorders, including dry skin, infections, inflammation, pressure injuries, and skin tears.²⁻⁴ Therefore, maintaining skin integrity through appropriate daily skin care is a major goal in the clinical setting.⁵

Skincare is a hygienic activity consisting of “skin cleansing,” such as washing, bathing, and bed bathing to remove skin dirt, and “application of leave-on products” to maintain skin integrity.⁶ For patients who cannot self-care, skin care provided by nurses can create a “time of relief, temporarily forgetting the illness,” and promote comfort.^{7,8} Therefore, the goals of skincare are skin integrity, skin cleanliness, and comfort enhancement.^{6,9}

Adequate skin assessments are required to achieve these three goals before planning skincare.⁶ Because various factors influence the skin in older adults, nurses should assess skin symptoms and the whole individual, including functional disabilities, chronic diseases, and nutritional status.¹⁰ Unnecessary skincare, such as applying moisturizers to “healthy skin,” is not recommended in terms of patient harm, nurse labor, and cost-effectiveness.⁶ Thus, focusing on high-risk patients is a justified objective of skin assessment.^{1,6}

The umbrella review on skincare and assessment to maintain skin integrity reported only 12 systematic reviews of acceptable methodological quality.⁵ Among these, three reviews that focused on older adults indicated the effectiveness of low-irritating cleansing⁹ and leave-on product applications.^{11,12} When classified in terms of skin irritation, skincare can be categorized into mechanical and chemical irritation. Unlike chemical irritation, which depends on product ingredients, mechanical irritation can be modified by nurses’ techniques. Nevertheless,

mechanical irritation is closely associated with the risk of skin damage,^{13,14} probably because skin cleansing inevitably causes mechanical irritation, regardless of the type of care (e.g., bathing and bed bathing) or towel material. Unfortunately, mechanical irritation by skincare is one of the main causes of SBD and skin tears.^{15,16}

If nurses assess the risk for SBD caused by mechanical irritation before planning skincare, they can efficiently prevent skin disorders and provide tailored skincare. Chronic kidney disease and diabetes are the risk factors for SBD by wiping.¹⁷ However, more recent evidence highlights that risk factors for poor skin condition and validated assessment methods are still poorly understood.^{5,18} There is an urgent need to identify risk factors for SBD due to mechanical irritation during skincare and develop a comprehensive assessment tool that integrates various predictors.

Transepidermal water loss (TEWL) is among the most widely used types of skin barrier measurement.¹⁹ TEWL response to mechanical irritation has been used to assess SBD.² The increased TEWL by mechanical irritant test lasted 2 to 6 days, even in healthy adults.^{20,21} Moreover, SBD in older patients caused by wiping with ordinary pressure that nurses routinely use during bed baths did not recover even the next day.²² Once the skin barrier function in older adults is impaired by mechanical force, the recovery can be delayed or impossible.²³ This outcome induces many skin disorders, such as eczematous dermatitis, pruritus, and xerosis.^{4,24} Therefore, assessment of TEWL in response to mechanical irritation is essential for preventative skincare. Because of the limitation of clinical evaluation, that is, TEWL is not visible and requires expensive measurement equipment,²⁵ there is a need to develop a user-friendly risk assessment tool.

A nomogram is a graphical representation of a prediction model that generates individual numerical probabilities of a clinical event by integrating diverse variables. This tool facilitates clinical decision-making and enables personalized care.²⁶ In this study, we aimed to develop a

nomogram to predict SBD induced by mechanical irritation during skincare in hospitalized older adults.

Material and methods

Study design, setting, and participants

To predict patients' response to an intervention, a randomized controlled trial (RCT) dataset is appropriate for developing predictive models.^{27,28} Thus, we used part of an RCT dataset that compared the effects of two consecutive days of bed bathing with ordinary (control group) and weak (intervention group) pressure on skin barrier recovery in Japanese older patients.²² We used data before the intervention on the first day in the control group. This study was conducted at a public core hospital in a secondary medical care area in northern Japan between September 26, 2022, and March 29, 2023. Our predictive modeling was categorized as Type 1b, in which the entire dataset was used for model development, and internal validation was performed using a resampling technique.²⁷ Furthermore, this study followed the Transparent Reporting of a multivariable prediction model for the Individual Prognosis Or Diagnosis (TRIPOD) statement (Supplementary Table 1).²⁷

The inclusion criteria were Japanese patients aged ≥ 65 years who could communicate daily. The exclusion criteria were patients 1) with excessive sweating to the degree that the skin became moist; 2) who had skin conditions requiring further dermatological treatment; 3) who had a fever of 37.5°C or higher or severe pain; and 4) with paralysis, peripheral venous catheter, or hemodialysis shunt on both forearms.

Mechanical irritation test

To assess TEWL response to skincare, the standardized mechanical irritation test was performed on one volar forearm of every patient. The test adopted wiping three times with 20–30 mmHg,²²

reflecting the main mechanical irritation factors (i.e., wiping pressure and number of wipes) that clinical nurses used in daily skincare.^{14,16} A well-trained researcher wiped from the periphery to the central area using a control towel (100% cotton; size, 35 × 34 cm; weight, 38 g; temperature, 45°C). To verify the reliability and validity, wiping pressure was monitored using a portable interface pressure sensor (Palm Q[®]: CAPE Co., Ltd., Yokosuka, Japan) as in previous studies.^{14,16,17} The intraclass correlation coefficient assessing the intra-rater reliability of wiping pressure was 0.86 (95% confidence interval [CI]: 0.82–0.89), indicating high reliability. The mean (standard deviation [SD]) wiping pressure applied to all participants was 24.0 (3.2) mmHg, which was a valid test.

Outcomes

TEWL indicates the flux density of water through the stratum corneum, with a high value indicating decreased skin barrier function.^{18,19} A well-trained researcher assessed TEWL on the volar forearm using a VapoMeter SWL5001 (Delfin Technologies Ltd., Kuopio, Finland) before and 15 min after the test. The volar forearm is the most stable measurement site, less affected by body hair and photoaging.^{29,30} This site is one of the most common areas where skin tears occur,^{31,32} with 56.4% occurring on the forearm in Japan.³³ Thus, it is one of the most feasible sites for risk prediction in terms of not underestimating the safety of the entire body. Although blinded assessments were impossible in this study, the evaluator received adequate training to mitigate bias according to international guidelines to minimize the influence of related factors.¹⁸ The participants were controlled to ensure they did not receive any other skin care on the day of the data collection. Moreover, the participants were acclimatized for at least 15 min before the TEWL measurements to eliminate the effects of sweating.¹⁸ The measurement environment had a mean (SD) room temperature of 25.6 (1.0) °C and humidity of 29.8 (9.5) %. Because the measurements were conducted in each patient's room, temperature and humidity could not be

strictly controlled. However, this limitation was addressed by using the VapoMeter, a closed chamber system that is not affected by environmental conditions or airflow.^{19,22}

SBD was defined by focusing on the change in TEWL (Δ TEWL = after the test–baseline). This criterion was set because TEWL has more clinical relevance regarding change within individuals than in terms of absolute values.³⁰ The smallest detectable change was used as the cut-off value for TEWL (1.99 g/m²/h).²² The value represents the real change beyond the measurement error calculated by measuring the baseline twice, often used as a cut-off value.^{22,34} Patients with Δ TEWL greater than the cut-off value were classified as experiencing SBD. Several previous studies support the clinical significance of this outcome. The increased TEWL of older adults after mechanical, heat, and moisture stimulation by bed baths usually returns to baseline after 15 min.³⁵ However, the increased TEWL of older patients who received the mechanical irritation test did not recover to baseline after 15 min.¹⁷ Moreover, this condition did not recover even on the next day.²² Therefore, this outcome is important for daily preventive skincare.

Candidate predictors

Candidate predictors were selected based on previous studies.^{3,17,18,36} Variables routinely accessible to nurses in various clinical settings were selected. Before the test and outcome assessment, researchers extracted the following data from electronic medical records:

- **Demographic characteristics:** Age, sex, and hospitalization days were recorded.
- **Functional characteristics:** Activities of daily living (ADL) were assessed using the Barthel Index.³ The scale is used by various medical workers worldwide, with a maximal score of 100 indicating independence in ADL. We recorded validated data assessed at admission or regularly by a physical therapist at the facility.
- **Medical histories:** History of diabetes mellitus, dyslipidemia, chronic kidney disease,

hemodialysis, stroke, heart disease, cancer, skin tears, and pressure injuries was recorded. We selected medical history rather than illness as the reason for hospitalization as predictors. This was because many participants had missing or unknown values for hospitalization reasons. This selection is reasonable because ambiguous definitions of predictors are undesirable in the clinical prediction model.³⁷

- **Medications:** Use of steroids, anticoagulants, antiplatelets, diuretics, insulin, and polypharmacy was recorded. Polypharmacy is defined as the daily intake of five or more medications containing different pharmaceutical agents.³
- **Nutritional status:** Body mass index (BMI: kg/m²) was recorded. Patients were categorized as underweight (BMI < 18.5), normal weight (18.5 ≤ BMI < 25.0), or overweight (BMI ≥ 25.0).³⁸
- **Skin condition:** A trained nursing researcher directly evaluated the skin conditions of the forearm, including dry skin, edema, purpura, pigmentation, and pruritus. Dry skin was assessed using the Japanese version of the overall dry skin score²⁵ and was defined as a score of ≥1.³⁶

Sample size

The sample size was calculated using an interactive tool to develop a clinical prediction model (<https://mvansmeden.shinyapps.io/BeyondEPV/>). This tool does not rely on empirical rules for the sample size of binary outcomes and has often been used in recent prediction studies.³⁹ Based on a similar outcome proportion of 0.48,¹⁷ an error rate of 0.10, and five predictor variables, the minimum sample size was 140 (13.8 events per variable). Ideally, the number of predictors in the final model is 5–10 because larger models are less practical; we assumed five variables would be included in the final model.³⁷

Statistical analysis

We used JMP[®] 17 Pro (SAS Institute Inc., Cary, NC, USA) and R version 4.3.1 (R Foundation, Vienna, Austria) at a significance level of 5%. Continuous and categorical variables are presented as medians (interquartile ranges) and frequencies (%), respectively. Multiple imputations by chained equations were performed because the BMI had three missing data points at random. This method effectively and validly handles missing data and minimizes selection bias caused by excluding such patients.²⁷ We used the R package “mice” to create and integrate 20 datasets based on final predictors.

Predictor selection

The final predictor selection was guided by subject knowledge and preliminary analysis of the distribution of candidate predictors.^{27,37} A three-step process was used to select the final model from the candidate variables. The process was rigorously discussed by an expert team comprising a statistician, a dermatologist, and nursing researchers until a consensus was reached.

- **Step 1: Selection based on a systematic review**

Based on the systematic review to identify the risk factors for SBD in older adults,¹⁸ the following candidate variables were retained in this study: sex, ADL, BMI, diuretic use, chronic kidney disease, diabetes mellitus, dry skin, purpura, and pruritus. In particular, chronic kidney disease and dry skin were regarded as essential factors.¹⁸

- **Step 2: Preliminary analysis for the distribution of candidate predictors**

We confirmed the data distribution and analyzed the bivariate associations with events for all candidate variables (Table 1). The following candidate variables were regarded as appropriate for data distributions and were significantly related to the outcome: ADL, steroid use, chronic kidney disease, heart disease, dry skin, edema, and purpura.

- **Step 3: Exploratory final model evaluation**

Among the variables remaining in Step 1 and 2, sex, diuretic use, diabetes, and pruritus were excluded because of lack of predictive performance. Subsequently, the combination with the highest goodness-of-fit based on the Akaike information criterion was analyzed (Supplementary Table 2 and 3), The five-factor model was optimal, except for heart disease, edema, and steroid use. In addition, the final model was considered clinically relevant and practical by the expert discussion.

Development of nomogram and evaluation of model performance

We conducted a multivariate logistic regression analysis using the final predictors to create a nomogram for predicting SBD. We used the “shiny” and “DynNom” packages to develop a web-based dynamic nomogram. The model performance was evaluated using discrimination, calibration, and clinical usefulness. For internal validation to correct this optimism, we employed 1000 bootstrap resampling. Discrimination was assessed using the c-statistic, equivalent to the area under the receiver operating characteristic curve (AUC). An AUC value ≥ 0.7 indicated good discriminative performance.²⁸ Calibration involved drawing a calibration plot to evaluate the degree of agreement between the observed outcomes and the predicted probabilities, and the Hosmer–Lemeshow test was performed.²⁸ Clinical utility was evaluated using decision curve analysis (DCA), illustrating the threshold probability on the x-axis and net benefit on the y-axis. A higher net benefit model is preferable for various threshold probabilities (preferences).⁴⁰ We employed several R packages, including “rms”, “boot”, “dcurves”, “tidyverse”, and “ggplot2”, for the assessment of model performance.

Ethical considerations

Nursing managers conducted patient enrolment based on the eligibility criteria. All enrolled

patients received written and oral communications from the researcher detailing the purpose of the study. They were informed about their right to decline participation without any negative consequences and assured that their anonymity and confidentiality would be maintained throughout the study. Written informed consent for study participation and publication was obtained from willing patients. This study was conducted following the Declaration of Helsinki after approval by the authors' affiliated university (register no: 22–46).

Results

Participant characteristics

A total of 164 patients were initially assessed for eligibility; 14 declined to participate, and one was excluded due to sweating during the test. Consequently, the final analysis included 149 patients, 26.2% ($n = 39$) of whom developed skin barrier dysfunction by mechanical irritation. Table 1 presents the demographic and clinical characteristics of patients at baseline. The median age, hospitalization days, ADL, and BMI were 84 (range: 65–99) years, 9 (2–1695) days, 55 (0–100) points, and 21.9 (13.3–46.9) kg/m^2 , respectively. Only five patients were independent with regards to ADLs, and nearly 90% of the patients required partial to full assistance.

Table 1. Baseline characteristics of study populations

Characteristics	Total (n = 149)	Skin barrier dysfunction (n=39)	Non-skin barrier dysfunction (n=110)	Statistics	P-value
Age [years]	84 (77–88)	84 (81–88)	83 (76–88)	1.29	.200 ^a
ADL (BI) [point]	55 (25–75)	50 (10–65)	55 (35–75)	–2.66	.008 ^b
Hospitalization days [days]	9 (5–20)	11 (5–22)	9 (5–19)	0.56	.574 ^b
BMI [kg/m ²] *	21.9 (19.7–24.2)	21.8 (19.2–26.5)	21.9 (20.0–23.7)	0.41	.679 ^b
Underweight	25 (17.1%)	8 (20.5%)	17 (15.9%)		
Normal weight	93 (63.7%)	20 (51.3%)	73 (68.2%)	3.91	.142 ^c
Overweight	28 (19.2%)	11 (28.2%)	17 (15.9%)		
Sex					
Female	85 (57.0%)	22 (56.4%)	63 (57.3%)		
Male	64 (43.0%)	17 (43.6%)	47 (42.7%)	0.01	.926 ^c
Diabetes mellitus					
Yes	100 (67.1%)	28 (71.8%)	72 (65.5%)		
No	49 (32.9%)	11 (28.2%)	38 (34.5%)	0.52	.469 ^c
Dyslipidemia					
Yes	41 (27.5%)	15 (38.5%)	26 (23.6%)		
No	108 (72.5%)	24 (61.5%)	84 (76.4%)	3.17	.075 ^c
CKD					
Yes	40 (26.8%)	20 (51.3%)	20 (18.2%)		
No	109 (73.2%)	19 (48.7%)	90 (81.8%)	16.06	<.001 ^c
Hemodialysis					
Yes	10 (6.7%)	4 (10.3%)	6 (5.5%)		
No	139 (93.3%)	35 (89.7%)	104 (94.5%)	1.06	.303 ^c
Stroke					
Yes	36 (24.2%)	8 (20.5%)	28 (25.5%)		
No	113 (75.8%)	31 (79.5%)	82 (74.5%)	0.38	.536 ^c
Heart disease					
Yes	71 (47.7%)	24 (61.5%)	47 (42.7%)		
No	78 (52.3%)	15 (38.5%)	63 (57.3%)	4.08	.043 ^c
Cancer					
Yes	22 (14.8%)	5 (12.8%)	17 (15.5%)		
No	127 (85.2%)	34 (87.2%)	93 (84.5%)	0.16	.690 ^c
Steroid					
Yes	14 (9.4%)	7 (17.9%)	7 (6.4%)		
No	135 (90.6%)	32 (82.1%)	103 (93.6%)	4.54	.003 ^c
Anticoagulant					
Yes	12 (8.1%)	4 (10.3%)	8 (7.3%)		
No	137 (91.9%)	35 (89.7%)	102 (92.7%)	0.35	.556 ^c
Antiplatelet					
Yes	16 (10.7%)	6 (15.4%)	10 (9.1%)		
No	133 (89.3%)	33 (84.6%)	100 (90.9%)	1.19	.275 ^c
Diuretic					
Yes	40 (26.8%)	13 (33.3%)	27 (24.5%)		
No	109 (73.2%)	26 (66.7%)	83 (75.5%)	1.13	.287 ^c
Insulin					
Yes	10 (6.7%)	4 (10.3%)	6 (5.5%)		
No	139 (93.3%)	35 (89.7%)	104 (94.5%)	1.06	.303 ^c
Polypharmacy					
Yes	76 (51.0%)	25 (64.1%)	51 (46.4%)		
No	73 (49.0%)	14 (35.9%)	59 (53.6%)	3.63	.057 ^c
History of skin tear					
Yes	7 (4.7%)	3 (7.7%)	4 (3.6%)		
No	142 (95.3%)	36 (92.3%)	106 (96.4%)	1.06	.304 ^c
History of pressure injury					

Characteristics	Total (n = 149)	Skin barrier dysfunction (n=39)	Non-skin barrier dysfunction (n=110)	Statistics	P-value
Yes	11 (7.4%)	2 (5.1%)	9 (8.2%)	0.39	.531 ^c
No	138 (92.6%)	37 (94.9%)	101 (91.8%)		
Dry skin (ODS \geq 1)				10.94	<.001 ^c
Yes	89 (59.7%)	32 (82.1%)	57 (51.8%)		
No	60 (40.3%)	7 (17.9%)	53 (48.2%)		
Edema				5.06	.025 ^c
Yes	19 (12.8%)	9 (23.1%)	10 (9.1%)		
No	130 (87.2%)	30 (76.9%)	100 (90.9%)		
Purpura				11.91	<.001 ^c
Yes	41 (27.5%)	19 (48.7%)	22 (20.0%)		
No	108 (72.5%)	20 (51.3%)	88 (80.0%)		
Pigmentation				3.52	.061 ^c
Yes	21 (14.1%)	9 (23.1%)	12 (10.9%)		
No	128 (85.9%)	30 (76.9%)	98 (89.1%)		
Pruritus				1.56	.212 ^c
Yes	35 (23.5%)	12 (30.8%)	23 (20.9%)		
No	114 (76.5%)	27 (69.2%)	87 (79.1%)		

Notes: ADL (BI), activities of daily living (Barthel index); BMI, body mass index; CKD, chronic kidney disease; ODS, overall dry skin score; Skin barrier dysfunction, participants with a change in transepidermal water loss greater than the cut-off were classified as the skin barrier dysfunction group; a, Student's t-test (*t*-statistics); b, Mann–Whitney U test (*z*-statistics); c, Pearson's chi-squared test (χ^2 -statistics). * Missing data, n = 3.

Development of nomogram

Multivariate logistic regression analysis included five predictors, indicating an overall predictive performance (Brier score = 0.152). The final predictors were chronic kidney disease, purpura, dry skin, ADL, and BMI; the detailed results are shown in Table 2. Based on these results, we developed a nomogram to predict skin barrier dysfunction by mechanical irritation during skin care in Japanese older patients (Figure 1). Moreover, we created a web-based dynamic nomogram that can be conveniently accessed at <https://konya2023.shinyapps.io/launch> (Figure 2).

Table 2. Predictors of skin barrier dysfunction by multivariate logistic regression analysis

Variables	B	SE	Wald	P-value	OR	OR (95% CI)	
						Lower	Upper
CKD	1.21	0.46	6.81	.009	3.34	1.35	8.36
Purpura	0.98	0.46	4.41	.036	2.66	1.06	6.66
Dry skin	0.75	0.51	2.16	.142	2.12	0.80	6.06
BMI: Underweight ^a	0.68	0.57	1.42	.233	1.97	0.63	5.99
BMI: Overweight ^b	1.13	0.54	4.45	.035	3.11	1.08	9.07
ADL	-0.02	0.01	3.65	.056	0.98	0.97	1.00
Intercept	-1.94	0.64	9.12	.003	-	-	-

Notes: ADL, activities of daily living (Barthel index); B, regression coefficient; BMI, body mass index; CI, confidence interval; CKD, chronic kidney disease; OR, odds ratio; SE, standard error; a, BMI < 18.5 kg/m² (ref: normal weight), b, BMI ≥ 25.0 kg/m² (ref: normal weight).

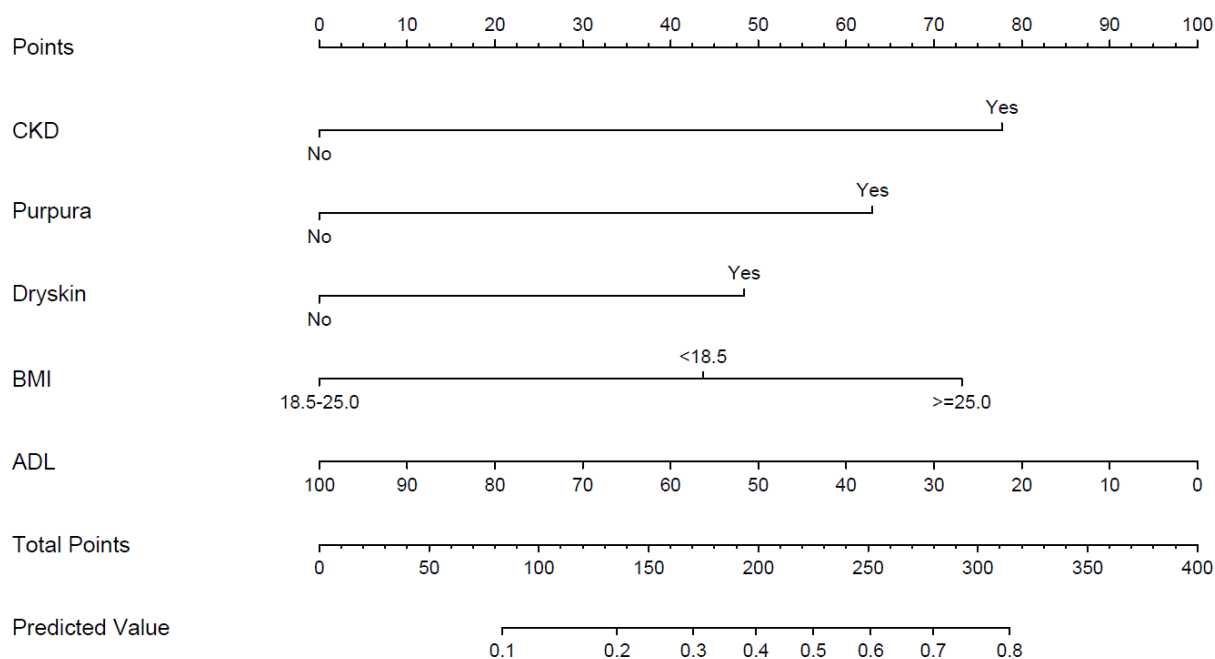


Figure 1. A nomogram predicting skin barrier dysfunction by mechanical irritation during skincare

Notes: ADL, activities of daily living (Barthel Index); BMI, body mass index; CKD, chronic kidney disease. The user draws a vertical line upward from each variable to the "Points" bar. The sum of the points is transformed into a "Predicted Value" by drawing a vertical line downward from the "Total Points" bar.

Dynamic Nomogram

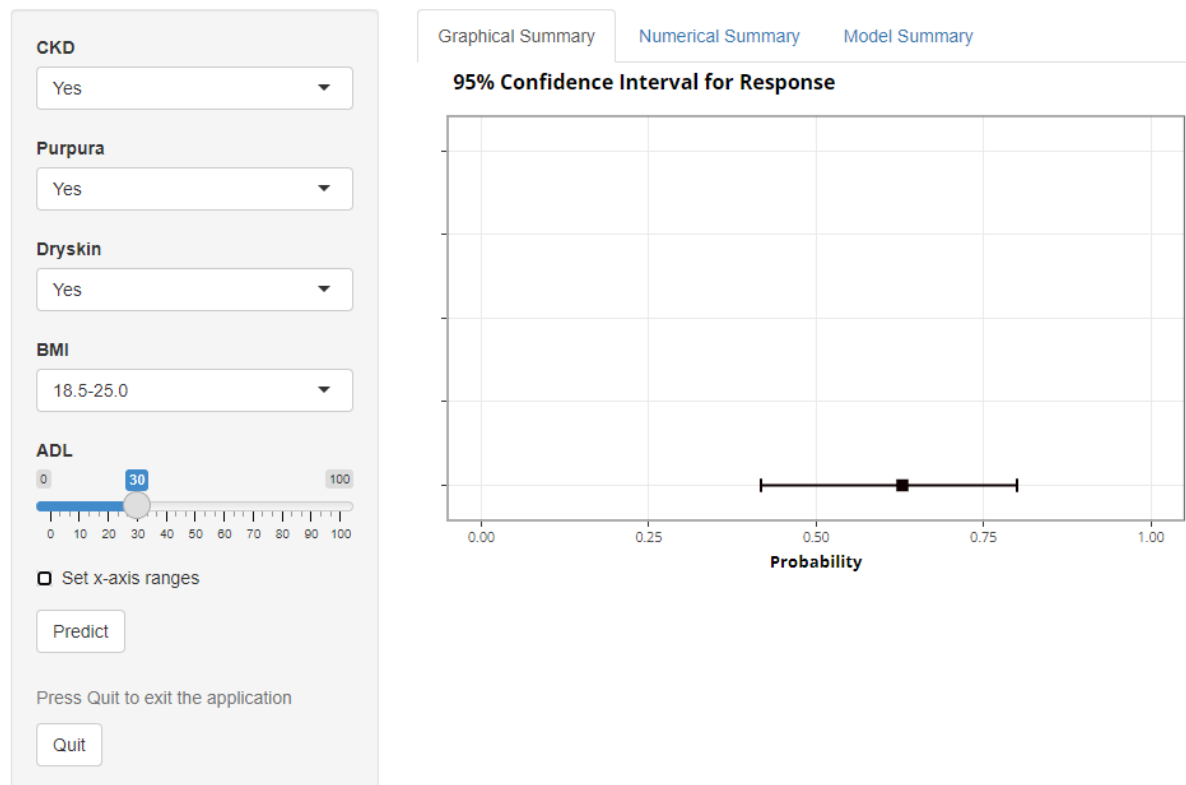


Figure 2. A dynamic nomogram predicting skin barrier dysfunction by mechanical irritation during skincare

Notes: Predicted values can be conveniently calculated online at <https://konya2023.shinyapps.io/launch/>. For example, the predicted value for one patient (CKD = yes, Purpura = yes, Dry skin = yes, ADL = 30 points, and BMI = 22.0 kg/m²) was 0.63.

Model performance: discrimination

The AUCs before and after bootstrapping were 0.800 (95% CI: 0.725–0.876) and 0.760 (95% CI: 0.689–0.839). The Youden index was 0.468, and the corresponding cut-off value was 0.155. The sensitivity and specificity of the model were 0.923 and 0.545, respectively. The model showed good discrimination even after optimism was corrected.

Model performance: calibration

The calibration plot corrected by bootstrapping (Figure 3) showed good agreement between the observed and predicted probabilities (Hosmer–Lemeshow test, $P = .230$). Although the calibration plots tended to slightly underestimate risk with anticipated probability in the 20% range, the calibration slope was 0.812, which is an acceptable slope.

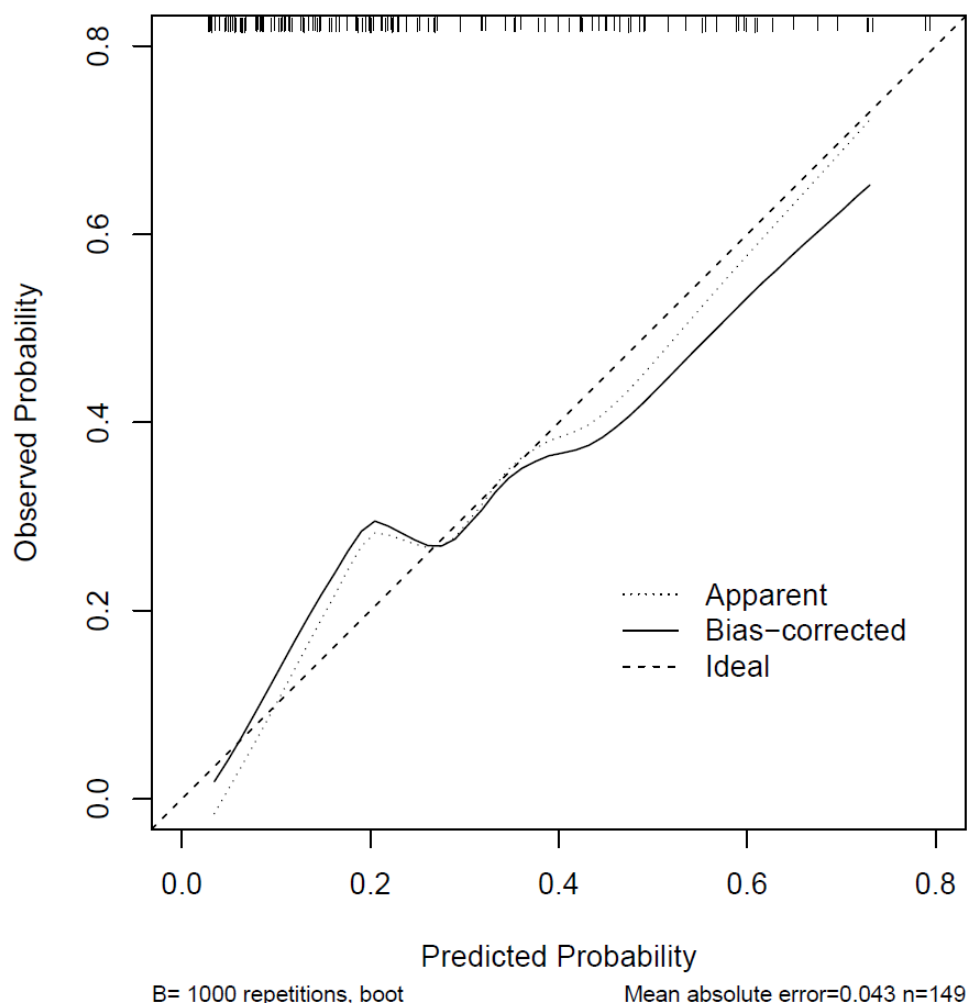


Figure 3. Calibration plot for nomogram predicting skin barrier dysfunction by mechanical irritation during skincare

Notes: The calibration plot presents the relationship between the predicted risk (x-axis) and the observed proportion of the actual outcome (y-axis). A perfect prediction coincides with the 45-degree line (slope = 1).

Model performance: clinical usefulness

The DCA showed that the nomogram has a higher net benefit than default strategies of “treat all” or “treat none” for reasonable threshold probability (Figure 4). The nomogram has potential clinical utility across a wide range of threshold probabilities, ranging from 5% to 75%.

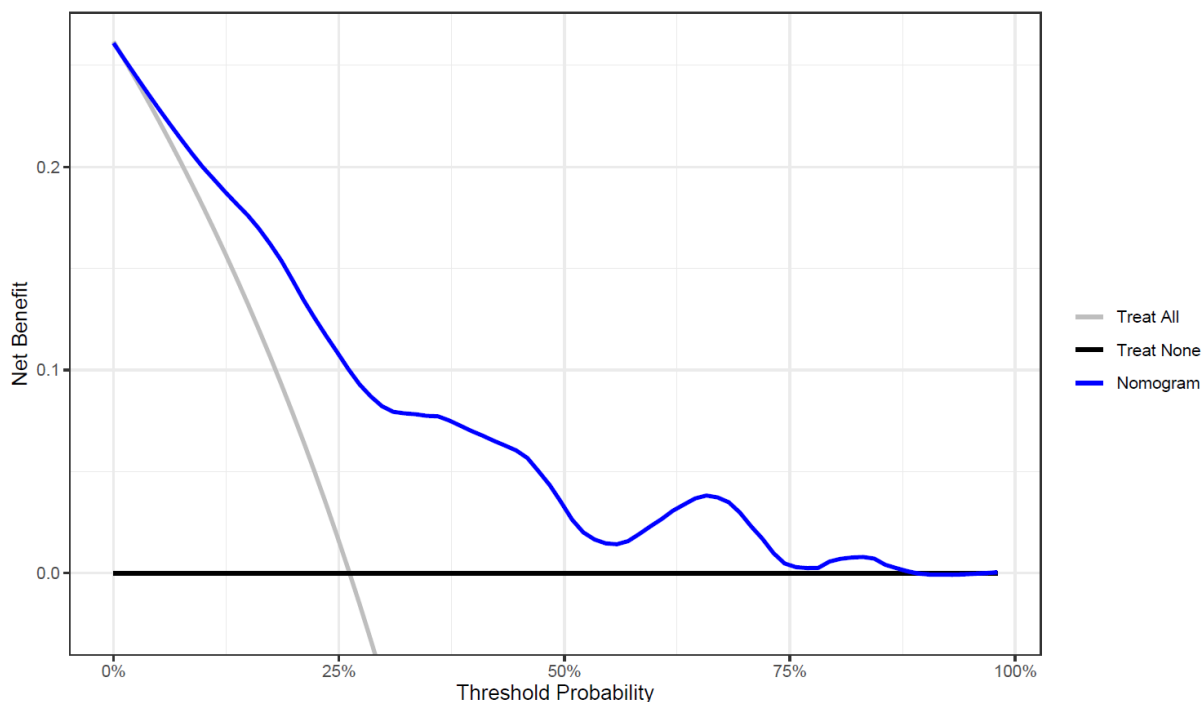


Figure 4. Decision curve analysis for nomogram predicting skin barrier dysfunction by mechanical irritation during skincare

Notes: The threshold probability on the x-axis shows the relative weight of the benefit of a true positive and the harm of a false positive (odds ratio of harm to benefit). The threshold probability differs among patients and clinical settings. For example, in the case of a threshold probability of 10% (odds ratio 1:9), "missing skin barrier dysfunction by mechanical irritation during skincare is weighted nine times worse than unnecessary intervention." With a threshold probability of 20% (odds ratio 1:4), "missing skin barrier dysfunction by mechanical irritation during skincare is weighted as four times worse than unnecessary intervention." The net benefit on the y-axis shows the proportion of true-positive patients receiving net benefits after weighing the harms and benefits.

Discussion

Predictors for SBD by mechanical irritation during skincare

Our study revealed that 26.2% of Japanese older patients experienced SBD due to mechanical irritation in routine skincare, with 73.8% experiencing only minor effects within the measurement error. This finding highlights the need for risk stratification based on appropriate skin assessment to plan high-quality skincare. Hence, we developed a nomogram to predict SBD by mechanical irritation during skincare in Japanese older patients. Our nomogram consisted of chronic kidney disease, purpura, dryness, BMI, and ADL and demonstrated good discrimination, calibration, and clinical usefulness.

Notably, the nomogram indicated the need for a systemic assessment encompassing chronic disease, skin condition, physical function, and nutritional status. The association between chronic kidney disease and SBD is widely known.¹⁸ Chronic kidney disease has been reported as a risk factor for SBD due to bed bathing,¹⁷ consistent with our findings. Although the complete pathological mechanism remains unclear, possible causes of the vulnerability of the skin barrier caused by chronic kidney disease include metabolic imbalances, endocrine disorders, and peripheral neuropathy.⁴¹

Senile purpura is purpuric macules on the extremities involving decreased vessels and dermal thickness related to skin fragility in older adults.³¹ Dry skin pertains to persistent barrier dysfunction characterized by insufficient moisture retention within the stratum corneum.¹⁸ These two skin symptoms predict skin tears in the forearms of Japanese older patients,³¹ supporting our results.

Our findings indicate that maintaining an appropriate BMI is important for maintaining skin integrity. Obesity is linked to elevated TEWL and delayed barrier recovery, increasing the risk of skin diseases and impaired wound healing.⁴² Being underweight is associated with dry skin and reduced elasticity.²⁹ There was no correlation between BMI and skin barrier function

in an earlier study,⁴³ which may support our finding of a non-linear relationship between BMI and skin barrier function.

Previous studies detected no difference in TEWL in the forearm between bedridden and healthy older adults⁴⁴ and no connection between care dependency and skin barrier function.³⁶ However, recent studies have indicated that low ADL score predicts dry skin,⁴⁵ skin tears, and pressure injuries.³ Our findings seem reasonable, as aging is associated with low ADL and increased skin barrier dysfunction.

Prediction model for SBD by mechanical irritation during skincare

The new predictive model consisted of logically selected predictors based on literature review, data distribution, and expert opinion. This process was particularly appropriate for studies with relatively small sample sizes, resulting in model stability and less overfitting.³⁷

Our nomogram showed good discriminative ability, with an AUC of 0.800 and an optimism-corrected AUC of 0.760. The model had a higher sensitivity (92.3 %) than a specificity (54.5%). Given that high sensitivity over specificity is desired in safety management,⁴⁶ this result is consistent with the envisioned use of nomograms. Calibration plots tended to slightly underestimate risk with anticipated probability in the 20% range. In our context, careful attention should be paid to underestimation when the predicted probability is low instead of to overestimation when the predicted probability is high. However, the degree of discrepancy observed in this study would not greatly affect clinical judgment.²⁸ In fact, the Hosmer–Lemeshow test showed good agreement between the predicted risk and the observed proportion of the actual outcome. Discriminative ability is the primary requirement in model performances when the objective is to identify “high-risk” cohorts.³⁷ Therefore, we believe these results suggest good internal validity of our nomogram. DCA showed a higher net benefit of our nomogram than the default strategies in a spectrum of practical thresholds ranging from

5% to 75%, indicating its clinical utility. “Treat” refers to diverse interventions, including additional or specialized care.⁴⁰ In our context, this term implies skincare that prioritizes skin integrity, such as applying weak wiping pressure or leave-on products. Our nomogram can assist nurses in assessing patients’ need for such skincare and improving clinical outcomes according to various preferences influenced by discussions between nurses and patients.

Clinical implications

The new nomogram provides nurses with predictive values for the risk of SBD in skincare. This information, implying “skin vulnerability,” can assist in adequate skin assessment and allow risk stratification of older patients. Given that even the risk factors useful for skin assessment in skincare are unclear,⁵ our nomogram can potentially trigger innovations in skincare. To expand usability, we developed an interactive nomogram, which can be conveniently accessed in clinical settings (<https://konya2023.shinyapps.io/launch/>).

Based on the risk stratification of skin vulnerability, nurses can select optimal care considering the prioritization of the three primary goals of skincare. For high-risk patients, nurses can plan care that pays particular attention to skin vulnerability regarding mechanical irritation, including the type and frequency of skincare, the products used, and wiping pressure.¹⁷ It would be desirable to prioritize evidence-based, “low-irritating” skin care^{5,11} and add comfort care such as a hot towel.³⁵ Low-risk patients can receive standard skincare that prioritizes the maximum patient preferences and requests.

The value of fundamental care, including skincare, can be overlooked due to competing demands on time due to high workload and staff shortages in clinical settings.⁴⁷ Focusing on high-risk patients based on the nomogram could optimize the effort required for nursing care while preserving the quality of skincare. This may motivate busy nurses to recognize the importance of skin assessment. In addition, the evidence-based predicted values provide a basis

for care that can be shared by nurses and patients, allowing informed consent for skincare. Another implication is that our nomogram could help possibly support self-skincare education for high-risk patients. To sum up, our work is beneficial to both nurses and patients.

Limitations

This study has some limitations. First, the nomogram could not be applied to patients with skin diseases because they were excluded. However, most skincare studies exclude patients with skin diseases (e.g., atopic diseases) because these patients require further dermatological treatment. Second, our nomogram excluded factors associated with older patients with chronic kidney disease, such as diabetes mellitus, cognitive impairment, frailty, and sarcopenia,⁴⁸ which may influence skin conditions.^{18,49} Although the selection of predictors based on the literature was justified, these factors must be considered to expand the generalizability of the nomogram to other populations. The systematic review used for variable selection also suggests the need for further examination of factors related to SBD.¹⁸ Future studies should examine whether these factors improve the predictive performance of nomograms in other countries. Third, our study is inherently limited by its finite generalizability because of the relatively small sample size at a single hospital in Japan. Ethnic and regional differences can influence skin barrier function.^{18,42} Therefore, future studies should examine the external validity in multicenter settings with different patient demographics, magnitudes, and countries. Moreover, feedback from clinical nurses and patients using nomograms will contribute to further model improvements.

Conclusions

This study developed a risk prediction nomogram for SBD by mechanical irritation during skincare in Japanese older patients. The model consisted of five important predictors: chronic

kidney disease, purpura, dry skin, BMI, and ADL, all easily accessible to nurses. Furthermore, the nomogram demonstrated satisfactory discrimination, calibration, and clinical usefulness. This nomogram can be a novel skin assessment tool to select tailored skincare methods to prevent skin disorders and incorporate patient preferences. Additional external validations are required in multicenter settings with different patients, magnitudes, and countries.

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