The Challenge of Predicting Pressure Ulcers in Critically Ill Patients

A Multicenter Cohort Study

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Abstract

Rationale: Pressure ulcers are preventable events. Critically ill patients are particularly vulnerable. The Braden scale has been used to identify hospitalized patients at high risk for the development of pressure ulcers; however, this predictive tool has not been adequately validated for critically ill patients.

Objectives: We aimed to validate and improve the Braden scale for critically ill patients by adding clinical variables to the original scale.

Methods: We conducted a cohort study in 12 intensive care units (ICUs) within a network of hospitals in Brazil during 2013. We excluded patients who stayed less than 48 hours, patients with one or more pressure ulcers at admission, and those who developed a pressure ulcer within the first 48 hours. We evaluated the Braden scale and clinical variables through a competing risk analysis. Discrimination and calibration were evaluated using the Concordance index (C-index) and a calibration plot, respectively. We used bootstrapping to assess internal validation.

Measurements and Main Results: Our primary outcome was incident pressure ulcer within 30 days of ICU admission. We analyzed 9,605 patients and observed 157 pressure ulcers (rate of 3.33 pressure ulcers/1,000 patient-days). The majority of pressure ulcers were detected at stage I or II (28.7 and 66.2%, respectively). The Braden scale had good discrimination (C-index, 0.753; 95% confidence interval, 0.712–0.795), although its performance decreased for the most severely ill patients. We derived a modified predictive tool by adding eight clinical variables to the Braden scale: age, sex, diabetes mellitus, hematological malignancy, peripheral artery disease, hypotension at ICU admission, and need for mechanical ventilation or renal replacement therapy in the first 24 hours after ICU admission. The derived score had better discrimination and calibration than the original Braden scale. The best score cutoff was at least 6 points, with a sensitivity of 87% and a specificity of 71%.

Conclusions: The original Braden scale measured at ICU admission is a valuable tool for pressure ulcer prediction, although it is not accurate for severely ill patients. To overcome the limitations of the original scale, we derived a modified score with better performance, which may identify high-risk ICU patients and support target interventions. External validation of the proposed clinical prediction score is needed.

Keywords: pressure ulcer; pressure sore; Braden scale; validation; intensive care unit

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Pressure ulcers are preventable events associated with patient suffering and increased costs of care (1, 2). Critically ill patients have a high risk of developing pressure ulcers, because most are frequently bedridden and severely ill (3–5). From nurse maneuvering to special mattresses, interventions to prevent pressure ulcer development are costly and laborious (6–8), and there is no consensus about which patients may benefit from the prevention bundles. Indeed, bundles of care and programs aimed at preventing pressure ulcer development have been described with variable results (4, 6, 9). The correct identification of high-risk groups among intensive care unit (ICU) patients is imperative, allowing target prevention, improving the effectiveness of such interventions, and, possibly, reducing their associated costs (4, 9).

Currently available tools to identify patients at high risk of pressure ulcer development come originally from non–critical care settings, limiting interventions focused on high-risk groups in ICUs (4, 10, 11). Among the available tools to predict pressure ulcer development, the Braden scale has outperformed other scales in hospitalized and nonhospitalized patients (12–14). Although guidelines recommend application of the Braden scale in critically ill patients (2, 12, 15), for this population the scale has been evaluated in small and retrospective studies, with limited methodology and generalizability (4, 15–20). The largest study evaluating the Braden scale in critically ill patients showed that the Braden scale had poor performance prediction for pressure ulcer development in ICU patients, using retrospective data from a center in the United States (17).

We aimed to evaluate the Braden scale in a multicenter cohort study of general critically ill patients. During their ICU stay, patients are more frequently exposed to pressure ulcer risk factors not taken into account by the Braden scale (e.g., severity of illness and the need for artificial organ support). Therefore, we hypothesized that the discriminatory capability of the Braden scale may be diminished for critically ill patients. Thus, our secondary aim was to develop a new score incorporating the Braden scale.

Methods

Setting

This cohort study was conducted in 2013 by the Amil Critical Care Group network, which consists of 12 adult ICUs (188 ICU beds) in a group of 11 associated hospitals that is centrally managed and coordinated in São Paulo, Brazil. Two of the authors (E.S.S. and D.T.N.), a nurse and a physician who are responsible for the group's policy making and for implementation and monitoring of common routines, coordinate this group (21). The group develops customized task forces aiming to produce local guidelines and protocols. After protocol approval, all centers had access to the same training, policy, materials, and recommendations for prevention, evaluation, and treatment. The reporting of this study follows the STROBE (*St*rengthening the *R*eporting of *Ob*servational Studies in *E*pidemiology) guideline.

Pressure Ulcer Protocol

Work by the pressure ulcer task force occurred between August and December 2012. After a literature review and with guidance from a major international guideline for pressure ulcer management (2), we chose the Braden scale as our risk assessment tool and used the classic pressure ulcer diagnostic and staging classification (*see* Tables E1 and E2 in the online supplement) (2, 10). The Braden scale consists of six domains (sensory perception, skin moisture, activity, mobility, nutritional status, and friction/shear), attributing 6–23 points, with lower scores associated with higher risk of pressure ulcer development.

We organized meetings with ICU nurse coordinators and individual training sections in each ICU, involving all nurse staff. The coordinating nurse was responsible for all trainings, and the local education nurse at each hospital applied an objective examination before and after the training. The training program focused on how to calculate the Braden scale score, how to monitor pressure ulcer occurrence, and on preventive and treatment measures. We also implemented equal material supplies and equipment at all ICUs, such as protective cushions, translucent films, timely decubitus changes (every 2 h), and pneumatic mattresses for every ICU bed. During 2013, the ICU nurse coordinator monitored and checked data reports and provided continuous feedback weekly, with monthly ICU visits dedicated to the pressure ulcer project, covering all three shifts (morning, afternoon, and night). Further information is available in Table E3.

Data Collection

The data were prospectively collected simultaneously in two dedicated databases: one for general clinical data and the other for pressure ulcer data. The clinical data were audited by a specialized private company (Epimed Solutions, Rio de Janeiro, Brazil) and maintained by dedicated staff from the Amil Critical Care Group (22). Each hospital had a case manager (nurse), who was committed exclusively to inputting data daily into a case report form, using Epimed Monitor software. Each record was tagged with a unique identifier for each patient, without releasing personal data to maintain patient anonymity. The database maintains multiple controls to guarantee the quality of the recorded data (22). Only the first ICU admission within the same hospitalization was analyzed.

The pressure ulcer database was developed and implemented between August and December 2012. It contains the Braden scale score calculated at ICU admission, daily inputs regarding patient skin conditions, and the characteristics of pressure ulcers that occurred. The attending ICU nurse was responsible for inputting the data. We created a linkage between the clinical and pressure ulcer databases. We used the software Link Plus (Centers for Disease Control and Prevention, Atlanta, GA) to conduct a deterministic ("exact") linkage based on the hospital registry (unique identifier). To select only the Braden scale score calculated within the first 24 hours of ICU admission, we compared date and time of ICU admission from both data sets. Further information on linkage is available in Figure E1.

Outcome Definition

Our primary outcome was incident pressure ulcer, defined as a pressure ulcer at any stage and anatomic site, which appeared after 48 hours of ICU admission up to 30 days of ICU stay (23). We excluded patients with a pressure ulcer at admission or that developed within 48 hours of admission. We used this time frame to have a homogeneous population for which we could develop a useful risk prediction. Indeed, patients who had a pressure ulcer at ICU admission are at very high risk of developing new pressure ulcers and deserve specific care. Patients who develop a new

pressure ulcer within the first hours of ICU admission have a mix of "acute stressors" that could have happened before or after ICU admission, hindering preventive measures in the ICU setting. Therefore, our choice to exclude patients whose ICU stay was less than 48 hours and those who developed a pressure ulcer during the first 48 hours of ICU admission was designed to exclude very low-risk patients and to avoid processes that started before ICU admission, respectively.

Statistical Analysis

Continuous data are presented as means ± standard deviation or as medians and interquartile range, as appropriate. Categorical variables are shown as percentages. For categorical variables, Fisher's exact test or a χ^2 test was used; for continuous variables, an unpaired *t* test was used if the data were normally distributed, or the Mann–Whitney *U* test was used if they were nonnormally distributed.

We developed a clinical prediction model to support clinical decision-making (24). In the dynamic setting of critically ill patients, for some events of interest, a competing event can occur first (25, 26), in which case it would not be possible to observe the occurrence of the event of interest. Indeed, a patient at high risk for pressure ulcer development shares risk factors associated with mortality. Thus, if a patient died early, we were unable to evaluate the occurrence of a pressure ulcer, although that patient had been at high risk of pressure ulcer development. By using the competing risk analysis, patients who died early were taken account of in the model, as they were at risk to develop a pressure ulcer in the future whether or not they were dying.

All patients were monitored after ICU admission until death or ICU discharge. Our event of interest was the first pressure ulcer diagnosed, the competing event was death, and patients at ICU discharge or after 30 days of ICU stay were censored. We used the Fine–Gray model to perform the competing risk analysis (26), because we were aiming to build a prediction model (27). First, we ran a univariate analysis and selected variables associated with pressure ulcer development ($P < 0.250$). We aimed to not categorize the continuous variable in the final model when the fit with the nonlinear effect was similar to the linear effect, evaluated by the Akaike information criterion (AIC) (24, 28, 29). Second, we used the AIC to choose the final model, looking for parsimonious models with the lowest AIC values in a backward–forward stepwise selection.

For the Braden scale, we also compared the prediction ability of various prespecified cutoff values. We did not prespecify any interaction in our analysis and we assessed collinearity in the final model. We ran a complete case analysis, because we expected few missing values. Finally, we derived a predictive additive scoring tool based on the final multivariate model. We first ran an internal model validation generating 1,000 data sets of the same sample size, using bootstrap with replacement (24, 30). The difference between the coefficients in the original sample and bootstrap samples is a surrogate for the "optimism" of the model. Subsequently, we multiplied the original coefficients by the slope index generated from the bootstrapping to correct for optimism. Finally, the coefficients were rounded and converted to integers. Further information is provided in the online supplement.

We assessed the performance of the Braden scale, final model, and derived score to predict incident pressure ulcers at 30 days. We conducted sensitivity analysis for the predictive ability of the Braden scale in prespecified subgroups of patients (i.e., those receiving mechanical ventilation, vasoactive drugs, or renal replacement therapy and in surgical patients). We measured discrimination with the concordance index (C-index) and calibration with a calibration plot, adapted for the competing risk framework (26). For the C-index, the 95% confidence interval (CI) was derived using a bootstrapping method (1,000 replications). To better evaluate the discrimination over time, we also estimated the C-index daily for 30 days (time-dependent area under the receiver operating characteristic curve [AUROC]) (31). For the calibration plot, we plotted the actual observed risk from the cumulative incidence function estimate within percentiles of the predicted risk at 30 days.

As our aim was to provide easy and interpretable information for clinical practice, we additionally presented the performance of the Braden scale, final model, and derived score considering the pressure ulcer events within 30 days of ICU stay as a binary event.

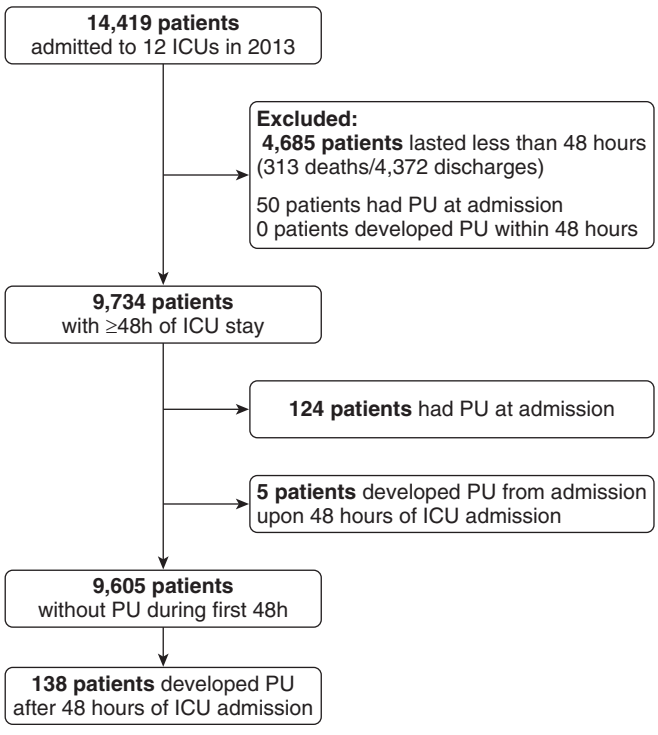

Figure 1. Study flowchart. ICU = intensive care unit; PU = pressure ulcer.

We estimated a standard AUROC and its 95% CI with bootstrapping (1,000 replications) and a calibration plot. We used the negative of the Braden scale to obtain higher values of the scale predicting higher risk of pressure ulcer development in the discrimination assessments.

Statistical analysis was performed with R statistical software (R Foundation for Statistical Computing) (32).

The Research and Ethics Committee of Hospital Pró-Cardíaco (Rio de Janeiro, Brazil) approved the current study and publication of the data on behalf of the entire network under number 772.962 and waived the need for informed consent.

Results

Characteristics of Pressure Ulcers

In 2013, there were 14,419 first admissions in the 12 ICUs. We excluded 4,685 admissions that lasted less than 48 hours (313 deaths and 4,372 discharges), 124 who presented with a pressure ulcer at admission, and 5 who developed a pressure sore within the first 48 hours. Finally, 9,605 patients were included in the cohort (Figure 1). Of these, 138 developed at least one incident pressure ulcer (1.4%) during ICU stay. The total number of incident ulcers was 157, corresponding to a rate of 3.33 incident pressure ulcers/1,000 patient-days during ICU stay (Table 1).

The cumulative incidence of pressure ulcers increased steadily after 5 days of ICU stay, and the probability of developing a pressure ulcer was approximately 10% after 30 days of ICU stay. The importance of considering competing events analysis is shown in Figure 2, indicating the impact of mechanical ventilation on the occurrence of both death and pressure ulcers. The baseline hazard rate of pressure ulcer development increased until the second week of ICU stay and achieved its maximum at approximately 15 days (Figures E2 and E3).

Most of the ulcers were detected at stage I or II (28.7 and 66.2%, respectively). The time to first diagnosis of a pressure ulcer was 9 ± 8 (mean ± SD) days after ICU admission; half of the ulcers occurred after 1 week of stay (median, 7 d). The pressure ulcer locations included the following: coccyx/sacrum (58%), gluteus/buttocks (10.2%), heel (8.9%), intergluteal cleft (6.4%), auricle (5.7%), trochanter (3.8%), occiput (3.2%), dorsum (1.9%), and other location (1.9%) (Table 1).

Table 1. Characteristics of incident pressure ulcers in 138 patients among 9,605 patients admitted to the intensive care unit

Number	138 Patients	157 PUs
Incidence	138/9,605 (1.4%)	3.33/1,000 patient-days
Stage, n (%)	Stage for the first PU	Stage for all PUs
I	38 (27.5)	45 (28.7)
II	94 (68.0)	104 (66.2)
III	3 (2.2)	5 (3.2)
IV	1 (0.7)	1 (0.7)
Unclassified/suspected deep tissue injury	2 (1.4)	2 (1.2)
Time to first PU diagnosis, d		
Mean ± SD	9 ± 8	
Median (IQR)	7 (4–11)	
Location, n (%)	Location for the first PU	Location for all PUs
Coccyx/sacrum	84 (60.9)	91 (58)
Gluteus/buttocks	14 (10.1)	16 (10.2)
Heel	10 (7.2)	14 (8.9)
Intergluteal cleft	10 (7.2)	10 (6.4)
Auricle	6 (4.3)	9 (5.7)
Trochanter	4 (2.9)	6 (3.8)
Occiput	4 (2.9)	5 (3.2)
Dorsum	3 (2.2)	3 (1.9)
Other	3 (2.2)	3 (1.9)

Definition of abbreviations: IQR = interquartile range; PU = pressure ulcer.

General Differences among Those with and without Pressure Ulcers

The general characteristics of patients with and without pressure ulcers are described in Table 2. Patients with pressure ulcers were

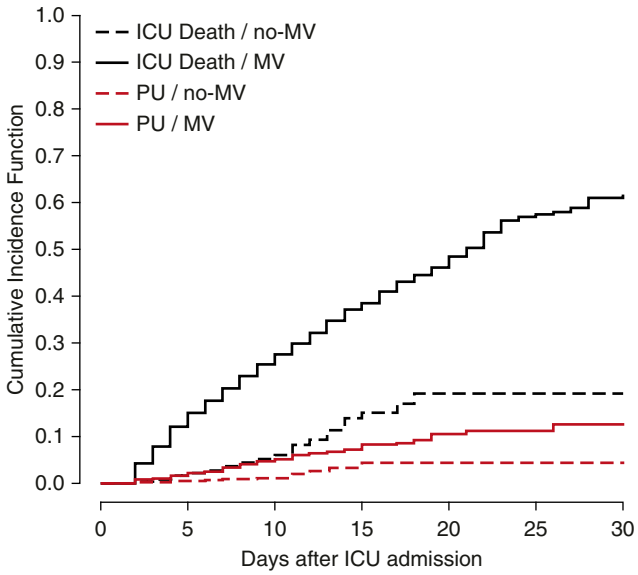

Figure 2. Cumulative incidence function for intensive care unit (ICU) mortality and pressure ulcer occurrence. The data shown indicate how the competing risk analysis is important in this scenario. Mechanical ventilation during the first 24 hours of ICU admission had a strong impact on ICU mortality (sHR, 6.20; 95% CI, 4.96–7.73) and on pressure ulcer occurrence (sHR, 3.71; 95% CI, 2.37–5.81). CI = confidence interval; MV = mechanical ventilation; PU = pressure ulcer; sHR = subdistribution hazard ratio from the Fine–Gray model.

Table 2. General characteristics and differences among patients who developed/did not develop pressure ulcers during their stay in the intensive care unit

Variable	No PU (*n = 9,467*)	PU (*n = 138*)	*P* Value*
Age, mean ± SD	59.6 ± 20	65.7 ± 18	<0.001
Sex, male, n (%)	4,622 (49)	83 (60)	0.008
SAPS 3, mean ± SD	44.6 ± 14	57.1 ± 16	<0.001
Admission type, n (%)			
Elective surgery	1,483 (16)	14 (10)	0.076
Emergency surgery	440 (4)	13 (9)	0.009
Medical	7,544 (80)	111 (81)	0.83
Comorbidities			
Charlson score			
Mean ± SD	1.47 ± 1.8	2.16 ± 2	<0.001
Median (IQR)	1 (1–2)	2 (0–3)	<0.001
Diabetes	2,768 (29)	55 (40)	0.007
Chronic kidney disease	1,061 (11)	26 (19)	0.005
Chronic heart disease	1,024 (11)	25 (18)	0.006
Chronic liver disease	120 (1.3)	3 (2.2)	0.26
COPD	641 (7)	18 (13)	0.004
Coronary artery disease	835 (9)	17 (12)	0.151
Chronic arterial disease	102 (1.1)	5 (3.6)	0.019
Solid tumor	1,105 (12)	13 (9)	0.41
Hematological malignancy	121 (1.3)	7 (5.1)	0.002
Functional status, n (%)			
Independent	7,065 (75)	67 (49)	<0.001
Partially dependent	1,717 (18)	47 (34)	
Fully dependent	685 (7)	24 (17)	
Admission reason, n (%)			
Cardiovascular	2,493 (26)	16 (11.6)	<0.001
Neurologic	1,287 (13.6)	12 (8.7)	0.095
Sepsis	2,272 (24)	79 (57)	<0.001
Orthopedic surgery	278 (3)	2 (1.4)	0.44
Respiratory	557 (6)	13 (9)	0.081
Post–cardiac arrest	89 (1)	2 (1.4)	0.38
Support during first 24 h, n (%)			
Mechanical ventilation, 24 h	2,288 (24)	107 (78)	<0.001
Vasoactive drugs	1,801 (19)	84 (61)	<0.001
Renal replacement therapy	597 (6)	47 (34)	<0.001
Mortality, n (%)			
ICU mortality	716 (7.6)	43 (31.2)	<0.001
In-hospital mortality	1,303 (13.8)	70 (50.7)	<0.001

Definition of abbreviations: COPD = chronic obstructive pulmonary disease; ICU = intensive care unit; IQR = interquartile range; PU = pressure ulcer; SAPS = Simplified Acute Physiology score.
**P* values refer to comparisons between no-PU and PU groups.

older, predominantly male, had more severe illness, and a higher Charlson score than patients who did not develop pressure ulcers. They also had a different distribution among the case-mix of causes of admission and needed more organ support during their ICU stay. Length of stay before ICU admission (5.7 ± 9.5 vs. 2.8 ± 10.9 d; $P < 0.001$) and ICU and hospital stay (17.5 ± 13 vs. 4.7 ± 4.6 d and 34.6 ± 24.7 vs. 14.5 ± 20 d, respectively; $P < 0.001$) were more prolonged for patients with a pressure ulcer than those without a pressure ulcer. ICU and hospital mortality were higher in the pressure ulcer group (31.2 vs. 7.6 and 50.7 vs. 13.8%, respectively; $P < 0.001$).

Predictive Factors for Pressure Ulcer Development within 30 Days of ICU Admission

We achieved 99% of matching between the two databases. After applying the time window criteria (i.e., considering only the Braden scale scores calculated within the first 24 h of ICU admission), we had 8,175 cases to be analyzed. The Braden scale score was lower for patients with a pressure ulcer (11.2 ± 2.7 vs. 15.1 ± 3.5 points; $P < 0.001$) (Table 3).

The discrimination of the Braden scale evaluated through the C-index was 0.753 (95% CI, 0.712–0.795) for the overall cohort. However, it performed less well for those who needed mechanical ventilation (C-index, 0.642; 95% CI, 0.591–0.689), renal replacement therapy (C-index, 0.650; 95% CI, 0.557–0.730), or vasoactive drugs (C-index, 0.634; 95% CI, 0.584–0.689) and for surgical patients (C-index, 0.697; 95% CI, 0.558–0.842) (Table E4). When considering pressure ulcer development as a binary event within 30 days, the AUROC was 0.801 (95% CI, 0.768–0.834) for the overall cohort and we equally observed lower values for the subgroups (Table E4). The best cutoff for the Braden scale was not more than 13 points for the overall cohort (Table E4).

Several variables were associated with pressure ulcer development in the univariate analysis (Table E5). Nine variables were retained in the final model (Table 4): age, sex, diabetes mellitus, hematological malignancy, peripheral artery disease, Braden scale score not more than 13, mean arterial pressure less than 60 mm Hg at admission, and need for renal replacement therapy and mechanical ventilation within the first 24 hours of admission. From this model we derived an additive score for clinical practice (Table E6).

The performances of the Braden scale, final model, and derived score are shown in Figure 3 and Figure E4. Our score varied from 0 to 14 points, with a median of 3 (1–6) points (Figure E5). The discrimination of the final model and derived score was higher than that of the Braden scale (C-index, 0.787; 95% CI, 0.745–0.834 and C-index, 0.788; 95% CI, 0.744–0.836, respectively). The final model and derived score also had higher discrimination over time than the Braden scale, as well as better calibration. Considering an incident pressure ulcer as a binary event within 30 days of ICU stay, the final model ($P < 0.001$ vs. Braden scale alone) and derived score ($P < 0.001$ vs. Braden scale alone) had better performance than the original Braden scale (Table 5). The best cutoff for the derived score was at least 6 points, with a sensitivity of 87% and a specificity of 71%. Higher score points (≥6) and lower Braden scale points (≤13) were associated with earlier pressure ulcer occurrence (Figure E6) and presented a trend to most severe stages on occurrence of the first ulcer (Figure E7).

We evaluated the pressure ulcer incidence and the Braden scale and derived score performances in each center. The incidence of pressure ulcer

Table 3. Braden score distribution among patients who developed/did not develop pressure ulcers during their stay in the intensive care unit

Braden Scale	No PU (*n = 8,037*)	PU (*n = 138*)	*P* Value*
Braden scale score (n = 8,175)†			
Mean ± SD	15.1 ± 3.5	11.2 ± 2.7	<0.001
Median (IQR)	15 (12–18)	11 (9–13)	<0.001
Braden scale categories			
⩽9	478 (5.9)	35 (25.4)	<0.001
10–12	1,562 (19.4)	66 (47.8)	
13–14	1,450 (18)	20 (14.5)	
15–18	3,170 (39.4)	15 (10.9)	
⩾19	1,377 (17)	2 (1.4)	

Definition of abbreviations: ICU = intensive care unit; IQR = interquartile range; PU = pressure ulcer.
**P* values refer to comparisons between no-PU and PU groups.
†Braden scale scores calculated for the first 24 hours after ICU admission. Lower values indicate higher risk for developing a pressure ulcer.

ranged from 1.04 to 5.68 incident pressure ulcers/1,000 patient-days. The performances of the Braden scale and derived score in each center were fair to excellent, except for one center. The derived score outperformed the Braden scale in the majority of centers (Table E7, Figure E8).

Discussion

In a large multicenter cohort of critically ill patients, we demonstrated that the Braden scale presents reasonable accuracy and a high negative predictive value. However, the Braden scale performance decreased substantially in subgroups such as mechanically ventilated patients. To overcome this limitation, we derived a new score by adding clinical variables to the original Braden scale, improving its discrimination and calibration.

We observed two phenomena when applying the Braden scale in general, critically ill patients. First, the best cutoff value was lower than for patients evaluated outside the ICU; and second, the scale had poor performance for the most severely ill patients. Lower cutoff values of the Braden scale have been described for critically ill patients (16, 17, 33, 34), with reported values of approximately 13 points, as we described. Furthermore, the Braden scale does not account for several pressure ulcer risk factors described in critical ill patients (35, 36), potentially explaining its lower performance in some subgroups (14, 16, 17, 37, 38).

Our study showed contrasting results to the previous largest study evaluating the Braden scale in critically ill patients (17), which reported an AUROC of 0.672 (95% CI, 0.663–0.683) for the Braden scale. Although recommended in international guidelines (2, 12, 15), a systematic review evaluating the Braden scale in adult critically ill patients concluded that there is limited evidence of its clinical applicability (15, 39). We believe our study contributes to the literature by showing that the Braden scale is a reliable tool and that a lower cutoff value than previously recommended may decrease the "false positive" rates in ICU patients (15).

Strengths and Limitations

The literature shows that the use of standard analysis overestimates the risk attributed to some predictors in scenarios where competing events are important (25, 26, 40). Therefore, one of the strengths of this study is that we overcome this limitation by using a competing risk analysis to evaluate the Braden scale and to model and derive a new score (26, 41).

Although our modified score had good overall performance, with sensitivity and specificity values appropriate for clinical usefulness, we observed a low incidence of pressure ulcer development in our cohort. This low incidence is likely to be the reason for the low positive predictive value of our

Table 4. Final multivariate model to predict pressure ulcer development 30 days after intensive care unit admission, considering death as a competing event (Fine–Gray model) and derived score

Model	sHR (95% CI)	*P* Value	Score	Description	Points
Age	1.20 (1.03–1.39)	0.022	Age*	⩽55 yr	0
				56–75 yr	1
				⩾76 yr	2
Sex, male/female	1.45 (1.02–2.06)	0.039	Sex	Male	1
Diabetes mellitus, yes/no	1.48 (1.03–2.11)	0.033	Diabetes mellitus	Previous comorbidity	1
Hematological malignancy, yes/no	2.63 (1.24–5.60)	0.012	Hematological malignancy	Previous comorbidity	3
Peripheral artery disease, yes/no	3.21 (1.02–10.04)	0.046	Peripheral artery disease	Previous comorbidity	3
Braden scale score, ⩽13	3.89 (2.46–6.13)	<0.001	Braden scale score†	⩽13 points	4
MAP < 60 mm Hg at admission	1.50 (0.94–2.40)	0.089	MAP at admission	⩽60 mm Hg	1
MV, 24 h	2.14 (1.37–3.34)	0.001	MV	Admission–24 h	2
RRT, 24 h	2.16 (1.48–3.15)	<0.001	RRT	Admission–24 h	2

Definition of abbreviations: CI = confidence interval; MAP = mean arterial pressure (lowest value during the first hour after admission); MV = mechanical ventilation on admission or during the first 24 hours; RRT = renal replacement therapy on admission or during the first 24 hours; sHR = subdistribution hazard ratio from Fine–Gray model.
*Age was modeled as having a linear effect in the model because of better fitting and then categorized to have a meaningful clinical score.
†Braden scores were calculated for the first 24 hours of ICU admission. Lower values indicate low risk to develop pressure ulcer.

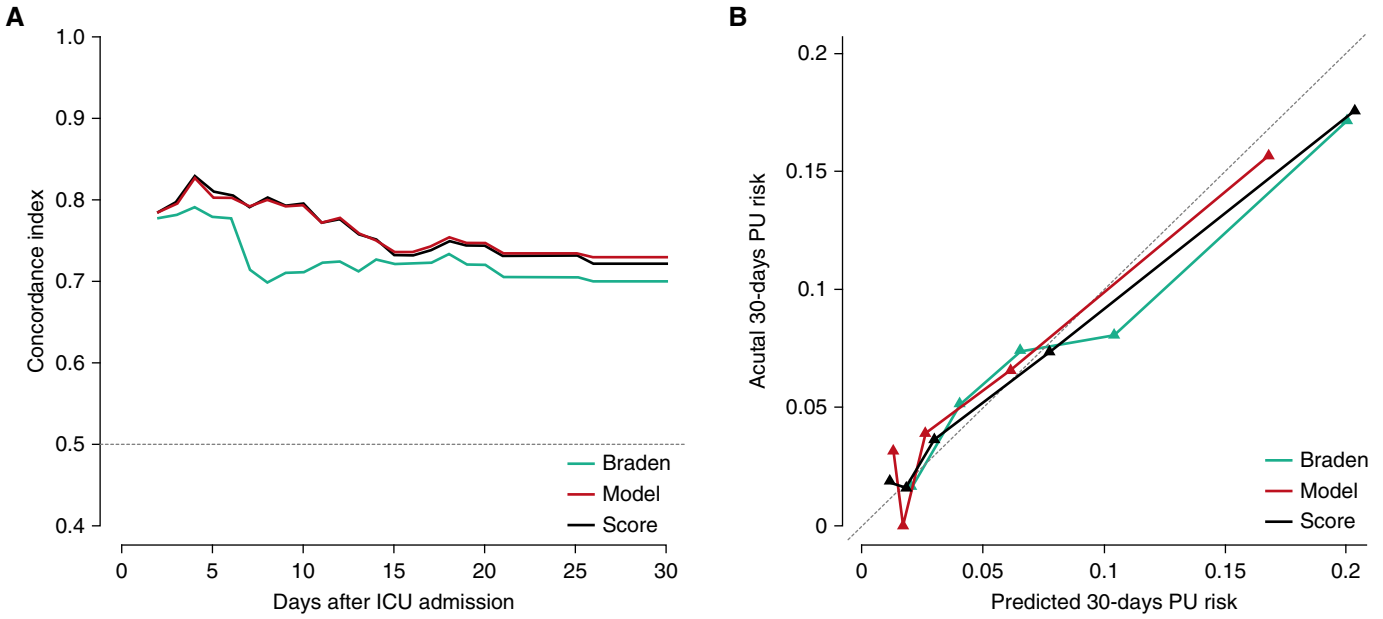

Figure 3. Discrimination and calibration of Braden scale, final model, and derived score for pressure ulcer prediction using competing risk analysis. (*A*) Time-dependent receiver operating characteristic (ROC) curve and the improvement observed for the final model and derived score in comparison with the Braden scale. (*B*) Calibration plot showing similar calibration among Braden, final model, and derived score for lower risks and an improvement for the final model and derived score for higher risks, when the calibration line is closer to the identity line. ICU = intensive care unit; PU = pressure ulcer.

score, the measure expected to better support clinical decision-making (42). In contrast, the negative predictive value was extremely high, helping to rule out patients at low risk. We collected data from 11 hospitals in a centrally coordinated network, which is another strength of this study. However, local staff compliance for pressure ulcer prevention and unmeasured case-mix differences could have influenced our results. Considering that we provided similar training, materials, and protocols, we speculate that these differences did not introduce important bias in our analysis.

We observed a lower incidence of pressure ulcer than the average in other ICU studies (4, 8, 17, 18, 43), decreasing our generalizability. Moreover, the definition of an event (pressure ulcer) was at the discretion of the ICU clinical staff, who were trained and audited, but were not individually adjudicated by dedicated researchers. Although this could lead to misclassification in some cases, we believe this was minimal, because all the hospitals have experience in dealing with process indicators. We also excluded patients who stayed less than 48 hours in the ICU and those who developed a new pressure ulcer within the first 48 hours of ICU stay. The lack of standard care in this brief period can be catastrophic (44), which was not evaluated in our analysis.

Importantly, we did not perform an external validation of our modified score. To partly overcome this limitation, we used bootstrapping to assess internal validation and decrease optimism (24). We did not update the Braden scale or the derived score during the ICU stay. It is possible that the performance of the predictive tool can be improved by updating the score daily.

Finally, we did not evaluate the additional workload that the proposed score could have for staff at the bedside (11, 13, 45). Nevertheless, the clinical variables added to the Braden scale are objective and usually available in the ICU. Because of the potential benefits of better identifying patients at risk, we believe this new derived score could have

Table 5. Performance of Braden scale on admission, final model, and derived score to predict pressure ulcer occurrence (yes/no) during 30 days in the intensive care unit

Variable	No. of Patients	Best Cutoff	AUROC (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	LR+	LR–
Braden	8,175	13	0.801 (0.768–0.834)	81	66	3.9	99.5	2.40	0.28
Original model*	8,175	2	0.864 (0.833–0.895)	86	76	5.5	99.7	3.50	0.19
Score	8,175	6	0.862 (0.831–0.892)	87	71	4.8	99.7	2.99	0.18

Definition of abbreviations: AUROC = area under the ROC (receiver operating characteristic) curve; CI = confidence interval; LR+ = positive likelihood ratio; LR– = negative likelihood ratio; NPV = negative predictive value; PPV = positive predictive value.
*Applied the linear predictor from the model to evaluate its performance. AUROC comparisons: Braden versus original model, $P < 0.001$; Braden versus score, $P < 0.001$; original model versus score, $P = 0.432$.

clinical applicability after an external validation.

Conclusions

To our knowledge, ours is the largest validation of the Braden scale in critically ill patients (16, 17), the most recommended (2, 12) and reproducible (46) tool for pressure ulcer stratification. We found that the Braden scale is a useful tool for pressure ulcer prediction during ICU admissions of adults. However, lower cutoff values of the Braden scale seem more suitable for application to critically ill patients.

To overcome the limitations of the Braden scale, we propose a modified score that includes simple clinical variables and has greater accuracy. The potential use of this new score is to predict the occurrence of pressure ulcer development precisely in the ICU scenario, where ulcers occur most frequently, and to help reduce patient suffering. ■

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