

ORIGINAL ARTICLE

A nomogram prediction of pressure injury in critical ill patients: A retrospective cohort study

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Abstract

Pressure injury (PI) is still a significant public health problem to be solved. Accurate prediction can lead to timely prophylaxis and therapy. However, the currently used Braden score shows insufficient predictive validity. We aimed to develop a nomogram to predict PI development in critically ill patients. We extracted data from Medical Information Mart for Intensive Care-IV v1.0. Variable selection was based on univariate logistic regression and all-subset regression. The area under the receiver operating characteristic curve (AUC) was used to assess the performance of the nomogram and Braden score. Decision curve analysis (DCA) was performed to identify and compare the clinical usefulness between the nomogram model and Braden score. We have developed a novel and practical nomogram that accurately predicts pressure ulcers. The AUC of the new model was better than that of the Braden score ($P < .001$). DCA showed that the nomogram model had a better net benefit than the Braden score at any given threshold. This finding needs to be confirmed by external validation as well as multicentre prospective studies.

KEYWORDS

database, nomogram, prediction, pressure injury, retrospective studies

Key messages

- the aim of the study was to develop a nomogram to predict pressure injury (PI) development in critically ill patients through a retrospective study
- the nomogram is better than Braden scale in predicting the individualised risk of PI development
- it provides significant guidance for screening high-risk populations and developing intervention strategies

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1 | INTRODUCTION

Pressure injury (PI), defined as localised damage to the skin and/or underlying tissue as a result of pressure or pressure in combination with shear,¹ is still a significant public health problem to be solved. These injuries are associated with adverse health outcomes and increased healthcare costs.² A recent study reported that PI affects 1 to 3 million people in the United States,² and the incidence in the intensive care units (ICUs) is one of the highest among hospitalised individuals.³ Therefore, the prevention of PI is the ultimate goal due to its challenges and the high costs of treatment.⁴ Aggressive prevention measures require a significant amount of medical resources,⁵ but medical resources are in short supply,^{6,7} especially during the COVID-19 pandemic.⁸ Therefore, it is important to accurately assess a patient's risk of developing PI and to reasonably allocate resources to those who truly need them.

The Braden scale for predicting the risk score of PI is currently used in clinical settings worldwide⁹ and includes six subscales (sensory perception, activity, mobility, moisture, nutrition, and friction/shear).¹⁰ However, the Braden score shows insufficient predictive validity.^{11,12} In recent years, although there have been a number of studies using machine learning to try to find better estimates,^{13,14} the complexity of their models makes it difficult to interpret and therefore hinders clinicians from using the models in practice.

The nomogram has been accepted as a reliable tool to create a simple intuitive graph of a statistical predictive model that quantifies the risk of a clinical event.¹⁵ Thus, in this study, we aimed to develop a nomogram that is easy for nurses to understand and perform in the clinics to predict PI development using data from critically ill patients in the first 24 hours after ICU admission.

2 | MATERIALS AND METHODS

2.1 | Database

This study was reported in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement. We extracted data from Medical Information Mart for Intensive Care (MIMIC)-IV v0.4,¹⁶ which is a public database containing hospitalisation information. It is a relational database containing real hospital stays for patients admitted to a tertiary academic medical centre in the United States. It included 76 540 ICU admissions for 53 150 patients from 2008 to 2019.

2.2 | Ethical considerations

This study was in accordance with the ethical standards of the Declaration of Helsinki and was approved by the institutional review boards of MIT and Beth Israel. Author Yu completed the required courses for the use of this database and obtained the corresponding certificate (Record Id 28806891).

2.3 | Study cohort

We used the International Classification of Diseases-(ICD)-9,10 code and nursing records to identify critically ill patients with or without PI (see Part I of Appendix S1). The critically ill patients in this study were defined as organ dysfunction patients whose Sequential Organ Failure Assessment (SOFA) >2.¹⁷ We only included ICU admission data of the first admission and of adult patients who had been in the ICU for at least 1 day. Patients without Braden scores, diagnosis records, and nursing records were excluded.

The following demographic parameters were collected (using data from the first 24 hours of admission, and data with multiple measurements are represented by averages): age, sex, body mass index (BMI), race (Caucasian, American African, Asian and others [Hispanic/Latino, American Indian/Alaska native and patients whose race information were unable to obtain]), complications (congestive heart failure [CHF]), renal disease, peripheral vascular disease, cerebrovascular disease, and diabetes), SOFA score, Simplified Acute Physiology Score (SAPS)-II, Braden score (friction/shear, sensory/perception, moisture, activity, nutrition, and total score), vital signs (temperature [*T*]), heart rate [HR]), mean arterial pressure [MAP], oxygen saturation [SpO₂]), and laboratory values (haemoglobin [Hb], albumin, pO₂, lactate, red blood cell distribution width [RDW], and glucose [Glu]). In addition, significant first-day interventions (mechanical ventilation, sedatives, and vasoactive agents) were also collected as variables.

2.4 | Nomogram construction

The included patients from the MIMIC cohort were divided into training and testing cohorts at a ratio of 3:1 using random-stratified grouping. We used training cohort to develop a nomogram model. All available covariates were included as a priori risk factors in the models.^{1,18} Variable selection was based on univariate logistic regression and all-subset regression.¹⁹ Factors with $P < .05$ on univariate analysis were entered as candidate variables, and all-subset regression analysis was performed.

2.5 | Nomogram validation

We calculated the area under receiver operating characteristic (AUC) and calibration plot for the training and

testing validation cohorts, respectively. AUC was used to assess the performance of the nomogram. Calibration plots were constructed to validate the accuracy and reliability of the nomogram with 1000 bootstrap samples.

Variables	Non-PI cohort n = 8698	PI cohort n = 946	P value
Age (≥ 75 , n [%])	2658 (30.6)	366 (38.7)	<.001
Gender (M, n [%])	5485 (63.1)	551 (58.2)	.004
Race (%)			.013
Asian	259 (3.0)	22 (2.3)	
Caucasian	5788 (66.5)	591 (62.5)	
American African	700 (8.0)	79 (8.4)	
Other	1951 (22.4)	254 (26.8)	
BMI (mean [SD])	28.29 (4.67)	27.68 (5.18)	<.001
T (≥ 36.6 , n (%))	4464 (51.30)	553 (58.5)	<.001
HR (mean [SD])	86.54 (16.82)	90.99 (18.34)	<.001
RR (mean [SD])	18.11 (4.88)	19.74 (5.15)	<.001
MAP (mean [SD])	77.67 (14.71)	75.49 (15.43)	<.001
SpO ₂ (mean [SD])	97.95 (2.57)	97.36 (2.77)	<.001
pH (mean [SD])	7.36 (0.10)	7.33 (0.11)	<.001
pO ₂ (mean [SD])	205.14 (145.61)	144.72 (118.09)	<.001
Lactate (≥ 2 , n (%))	3335 (38.3)	465 (49.2)	<.001
Albumin (mean [SD])	3.03 (0.41)	2.82 (0.51)	<.001
Haemoglobin (mean [SD])	10.20 (2.19)	10.03 (2.10)	.023
RDW (≥ 14.6 , n (%))	4135 (47.5)	671 (70.9)	<.001
Glu (%)	4610 (53.0)	601 (63.5)	<.001
Vasoactive agent use (%)	5604 (64.4)	633 (66.9)	.138
Ventilation use (%)	4717 (54.2)	562 (59.4)	.003
SOFA (≥ 5 , n [%])	3481 (40.0)	430 (45.5)	.001
SAPS-II (≥ 41 , n [%])	4082 (46.9)	668 (70.6)	<.001
Cerebrovascular (%)	996 (11.5)	158 (16.7)	<.001
Peripheral vascular (%)	1139 (13.1)	188 (19.9)	<.001
Diabetes (%)	2839 (32.6)	383 (40.5)	<.001
CHF (%)	2695 (31.0)	381 (40.3)	<.001
Renal disease (%)	2258 (26.0)	338 (35.7)	<.001
Sedative use (%)	6354 (73.1)	659 (69.7)	.029
Activity score (mean [SD])	1.20 (0.58)	1.17 (0.50)	.05
Friction/shear score (mean [SD])	2.24 (0.53)	1.81 (0.59)	<.001
Mobility score (mean [SD])	2.19 (0.86)	2.06 (0.75)	<.001
Moisture score (mean [SD])	3.61 (0.57)	3.34 (0.68)	<.001
Nutrition score (mean [SD])	2.30 (0.65)	2.01 (0.63)	<.001
Sensory/perception score (mean [SD])	2.46 (1.08)	2.35 (0.95)	.002
Braden total score (mean [SD])	14.00 (2.47)	12.75 (2.38)	<.001

TABLE 1 Baseline characteristics between the original cohort

Abbreviations: BMI, body mass index; CHF, congestive heart failure; HR, heart rate; MAP, mean arterial pressure; RDW, red blood cell distribution width; RR, respiratory rate; SAPS-II, Simplified Acute Physiology Score; SOFA, Sequential Organ Failure Assessment.

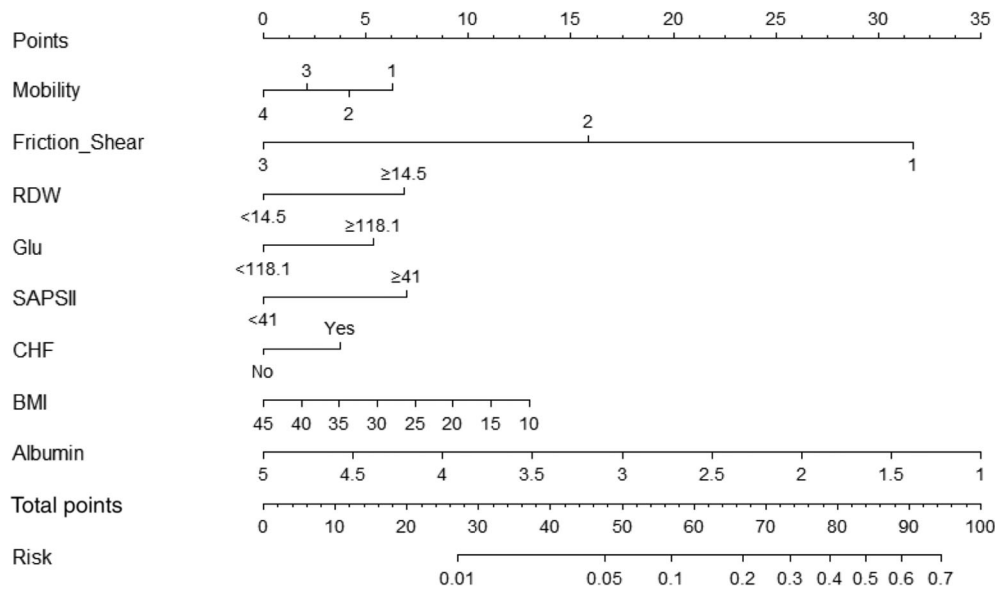


FIGURE 1 Nomogram to calculate the risk score and predict the probability of pressure injury in critically ill patients. Scores were assigned for albumin, red blood cell distribution width (RDW), Simplified Acute Physiology Score-II (SAPS-II), body mass index (BMI), congestive heart failure (CHF), glucose (Glu), friction/shear, and mobility by drawing a line upward from the corresponding values to the “points” line. The sum of all these scores, plotted on the “Total points” line, corresponds to the predictions of pressure injury probability in critically ill patients

2.6 | Clinical application and value assessment

Decision curve analysis (DCA) was performed to identify and compare the clinical usefulness between the nomogram model and Braden score by quantifying the net benefits at different threshold probabilities.²⁰

2.7 | Statistical methods

We used the K-nearest neighbor to impute missing data (Figure S1).²¹ Continuous variables are shown as the mean and standard deviation, and categorical variables are represented as the total and proportion. For continuous variables, we used a nonparametric test or the Wilcoxon rank-sum test. For the categorical variables, we used a chi-square test or Fisher’s exact test.

Statistical significance was determined by a two-sided $P < .05$. All statistical analyses mentioned earlier were performed using R version 4.0.4.

3 | RESULTS

3.1 | Basic Information

After reviewing 69 619 admissions from MIMIC-IV, we identified 9644 critically ill patients. The exclusion criteria

TABLE 2 Multivariate analysis of risk factors for pressure injury

Variables	Adjusted OR	95% CI	P value
Albumin	0.49	0.41–0.59	<.01
RDW	1.74	1.45–2.09	<.01
SAPS-II	1.76	1.47–2.11	<.01
CHF	1.36	1.14–1.61	<.01
BMI	0.97	0.95–0.99	<.01
Glu	1.54	1.30–1.83	<.01
Friction/shear score	0.28	0.24–0.33	<.01
Mobility score	0.84	0.76–0.94	<.01

Abbreviations: BMI, body mass index; CI, confidence interval; CHF, congestive heart failure; Glu, glucose; OR, odds ratio; RDW, red blood cell distribution width; SAPS-II, Simplified Acute Physiology Score.

were readmission, age <18 years, sofa <2, ICU stay <1 day, missing Braden score, missing diagnosis records, and missing nursing records (Figure S2). In total, the incidence of PI in critically ill patients was 9.81% (Table 1). Patients who succumbed to PI were those with older age, worse microcirculation perfusion (lower pH, higher lactate), higher SOFA and SAPS-II scores, and more comorbidities.

3.2 | Nomogram construction

We randomly divided the subjects into a training cohort and a test cohort at a ratio of 3:1 (Table S1). To make the

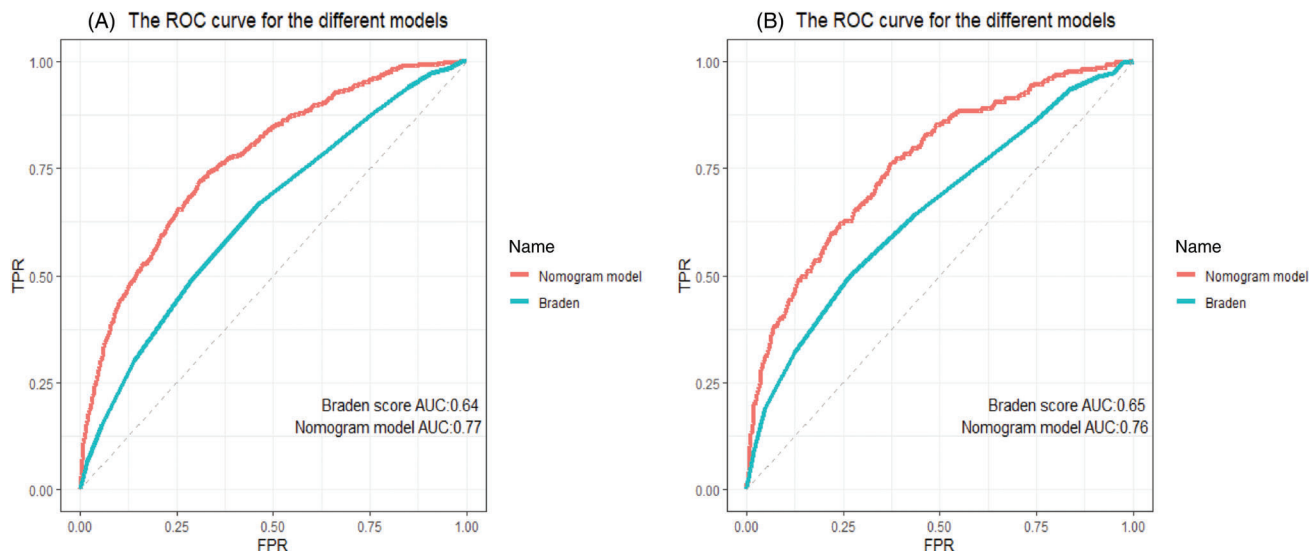


FIGURE 2 Performance evaluation of the nomogram in the training and testing cohorts. A, In the training cohort, the area under the receiver operating characteristic curve (AUC) of the nomogram was 0.77, and the AUC of the Braden score was 0.64. B, In the test cohort, the AUC of the nomogram was 0.76, and the AUC of the Braden score was 0.65

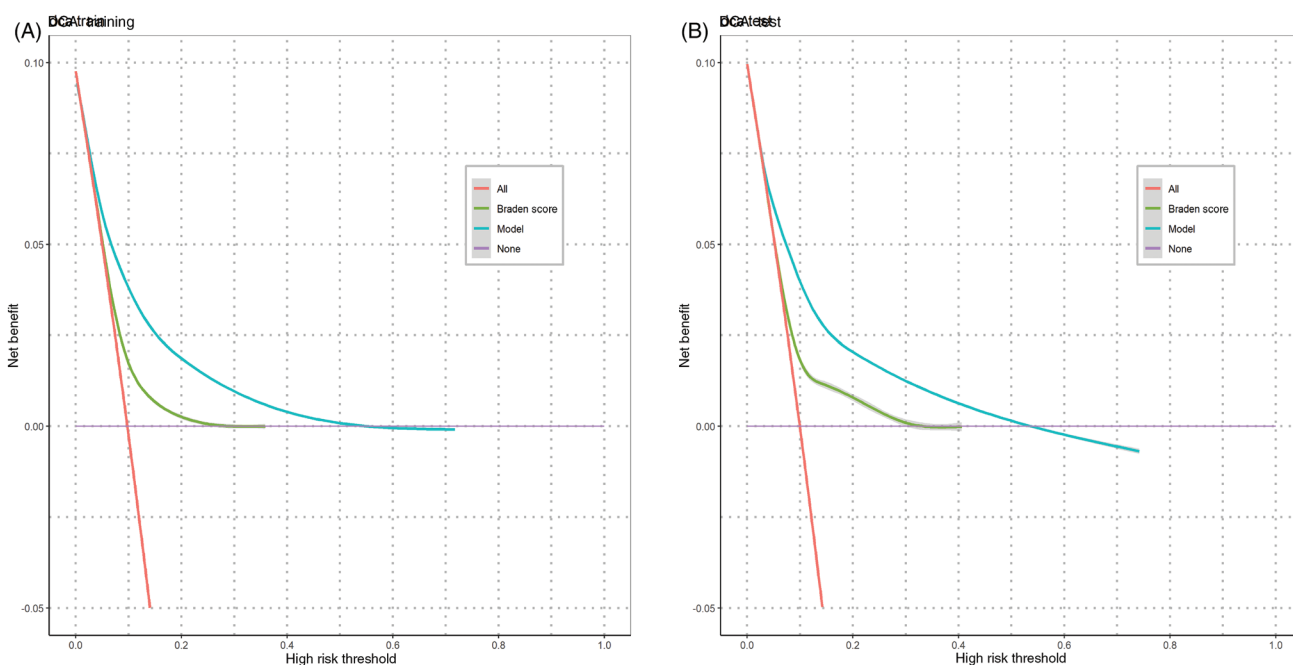


FIGURE 3 Decision curve analysis. A, In the training cohort, the nomogram had a better net benefit than the Braden scale at any given threshold. B, In the test cohort, the nomogram had a better net benefit than the Braden scale at any given threshold

model easier to understand and use, we transformed some continuous variables (age, T , lactate, RDW, SOFA, SAPS-II, and Glu) into classification variables according to the best Youden index. We used logistic regression as univariate analysis to evaluate the risk factors for PI in the training set (Table S2). Age, SpO_2 , T , pH, pO_2 , lactate, albumin, Hb, Glu, RDW, ventilation and sedative use, SOFA, SAPS-II, BMI, HR, MAP, peripheral vascular disease, diabetes,

cerebrovascular disease, CHF, renal disease, friction/shear score, activity score, moisture score, nutrition score, sensory/perception score, and mobility score were statistically significant. Then, through all-subset regressions, albumin, RDW, SAPS-II, BMI, CHF, Glu, friction/shear score, and mobility score were finally incorporated into the model (Figure 1). Multivariate logistic regression analysis results are shown in Table 2.

3.3 | Evaluation of the model

The performance of the nomogram model was measured by receiver operating characteristic curves, and the AUC was 0.77 (95% CI 0.75–0.79), with a sensitivity of 0.69 and a specificity of 0.72 (Figure 2) in the model from the training cohort. The AUC of the Braden score was 0.64 with a sensitivity of 0.54 and a specificity of 0.67. The AUC of this new model was better than that of the Braden scale ($P < .001$).

The model fits the data according to the Hosmer-Lemeshow goodness-of-fit test ($X^2 = 5.70$, $P = .68$). Calibration was considered acceptable (Figure S3). Similar results were found in the test cohort (Hosmer-Lemeshow goodness-of-fit test: $X^2 = 10.29$, $P = .25$, and calibration was also considered acceptable; Figure S3).

3.4 | Decision curve analysis

The DCA results are shown in Figure 3. The nomogram model was found to have a better net benefit than the Braden scale at any given threshold.

4 | DISCUSSION

In the present study, the incidence of PI was 9.8%, which was lower than that of previous studies²² and similar to a recent study.²³ This may be attributed to the growing international health policy focused on PI prevention.

Although many scales (Norton scale, Waterlow scale, and Jackson Cubbin scale) have been developed since the Braden scale, the Braden scale is still the most widely used scale in the world.⁹ Our cohort showed that almost all patients were evaluated by Braden score on the first day of admission to the ICU (Braden score was missing in only 107 patients). However, the Braden scale did not accurately predict the occurrence of PI.¹² More reliable assessment methods are urgently needed to accurately predict the occurrence of PI and reduce the waste resources in today's circumstances with tight medical resources.

Thus, a nomogram prognostic model was developed and compared with the Braden scale in this study. The results showed that this model had acceptable goodness of fit and calibration. In this new nomogram, albumin, RDW, SAPS-II, CHF, BMI, Glu, friction/shear score (one item of Braden score), and mobility score (one item of Braden score) were still reserved after all-subset regression analysis. Albumin, RDW, SAPS-II, CHF, BMI, and Glu were added to the Braden score. Friction/Shear score and mobility score were retained. The activity score, moisture score, and nutrition score were removed. SAPS-

II,²⁴ albumin,²⁵ and Glu²⁶ have previously been shown to be relevant to PI. Our model retained the friction/shear score and mobility score in the Braden score, suggesting that the friction/shear and mobility were more closely related to PI, which was consistent with the results of Cox's study.²⁷

In addition, this proposed nomogram illustrates the prognostic implications of oxidative stress. To the best of our knowledge, this study evaluated the relation between RDW (as the difference in red blood cell volume) and PI. Our nomogram showed that RDW was an independent risk factor for PI (OR: 1.74, $P < .01$). A high RDW ($\geq 14.6\%$) was strongly associated with high-risk PI. The inflammatory response and oxidative stress probably help to explain why high RDW is an independent risk factor for PI.

RDW reflects the degree of oxidative stress to some extent and has been shown to be associated with the prognosis of many inflammatory and oxidative stress-related diseases.²⁸ The reason for this may be that the inflammatory response inhibits the production of erythropoietin by affecting iron metabolism, thus affecting the survival time of red blood cells and increasing the RDW value.²⁹ At the same time, recent studies have shown that oxidative stress is associated with PI and suggest that antioxidant therapy plays an important role in the prevention of PI.^{30,31} Thus, RDW was confirmed as an independent risk factor for PI in this study, suggesting that it is important to limit the oxidative and inflammatory responses of critically ill patients in the prevention of PI.

Taken together, the occurrence of PI is related to movement limitations, oxidative stress, nutrition, and perfusion. The nomogram included not only the friction/shear score and mobility score (the factors most closely related to the occurrence of PI in Braden²⁷) but also the parameters of oxidative stress, perfusion, and nutrition, which may be the reasons why our model was better than Braden.

The advantage of our study is that the variables in the model are indicators of routine clinical evaluation and are easily accessible. The parameters applied in this study to construct predictive models are relatively common in the ICU and are easy for nurses to obtain, such as RDW, which was included in routine blood examination. In addition, as a simple and intuitive risk scoring tool, the main advantage of nomographs is that they can assess the risk of an individual according to the relevant influencing factors of the disease. Finally, the AUC and DCA of the new model were both better than Braden, indicating better accuracy and clinical value.

There are some limitations in this research. First, our study is a single-centre retrospective observational study with inherent bias in the analysis. Data from different

centres might have different results. Therefore, a large multicentre sample of prospective studies is required to further validate the results of this study. Second, our goal was to assess the incidence of PI accurately and early to allocate appropriate medical resources. For this reason, our laboratory index is the first-day laboratory result in the ICU. However, it must be acknowledged that the quality of care and changes in patient condition after admission to the ICU may have an impact on the outcome. Third, although the Braden scale is most widely used currently in clinical settings worldwide, there are other PI assessment scales, such as the Norton scale, Waterlow scale, and Jackson Cubbin scale. However, since only Braden scores are recorded in the MIMIC-IV database, our nomogram model was merely compared to the Braden scale. Finally, further exploration of the database was not performed, and some key variables might not be included. Although our study has considered many possible risk factors, there is a lack of external validation. The result may be different if other variables are added.

5 | CONCLUSION

We have developed a novel and practical nomogram that accurately predicts PI. The new model has better specificity and sensitivity than the Braden score. Limiting oxidative stress may be beneficial to the prevention of PI. However, these findings need to be confirmed by external validation as well as multicentre prospective studies.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Wen Xu designed this study, collected and analysed data, and drafted the manuscript; **Xueshu Yu** designed this study, collected data, drafted, and revised the manuscript; **Hao Jiang** collected, compiled, and analysed the data; **Yumin Wang** analysed the data, interpreted the results, and reviewed the manuscript; **Yincai Ye** designed and supervised this study. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Xu W, Yu X, Jiang H, Wang Y, Ye Y. A nomogram prediction of pressure injury in critical ill patients: A retrospective cohort study. *Int Wound J*. 2022;19(4):826-833. doi: 10.1111/iwj.13680