Predicting the Risk for Hospital-Acquired Pressure Ulcers in Critical Care Patients

Xiaohong Deng, RN, MSN, ET
Ting Yu, RN, MSN
Ailing Hu, RN, MSN, ET

BACKGROUND Assessments of risk for pressure ulcers in critical care patients may not include important predictors.
OBJECTIVE To construct risk-prediction models of hospital-acquired pressure ulcers in intensive care patients and compare the models' predictive validities with validity of the Braden Scale.
METHODS Data were collected retrospectively on patients admitted to intensive care from October 2011 through October 2013. Logistic regression and decision trees were used to construct the risk-prediction models. Predictive validity was measured by using sensitivity, specificity, positive and negative predictive values, and area under the curve.
RESULTS With logistic regression analysis, 6 factors were significant independent predictors. With the decision tree, 4 types of high-risk populations were identified. Predictive validity of Braden Scale scores was lower than the validities of the logistic regression and the decision tree models.
CONCLUSION Risk for hospital-acquired pressure ulcers is overpredicted with the Braden Scale, with low specificity and low positive predictive value. (*Critical Care Nurse*. 2017;37[4]:e1-e11)

Pressure ulcers (PUs) are a global health problem with complex and multifactorial causes. Internationally, in the 20th century, PUs were considered a debilitating complication with high medical expenses.[1] In 2008, the US Center for Medicare and Medicaid Services declared that the organization would not pay for the additional costs associated with stage III and stage IV hospital-acquired PUs (HAPUs).[2] In critically ill patients, PUs are an additional comorbid threat. In fact, PUs are one of the most underrated medical problems in these patients. Despite the use of evidence-based prevention programs and advances in medical technology, the prevalence of PUs in hospitalized critically ill patients continues to increase. Patients in intensive care units (ICUs) are at high risk for PUs because of characteristics such as sedation, altered consciousness, prolonged bed rest, treatment with mechanical ventilation, special medications, and unstable hemodynamic status.[3] In research by various investigators,[4-7] prevalence rates for PUs ranged from 13.1% in US ICUs with fewer than 100 beds[5] to 45.5% in a study

 doi:https://doi.org/10.4037/ccn2017548

conducted in teaching hospitals in China,[6] and the incidence of facility-acquired rates in ICUs ranged from 3.3% in a sample from 2 German hospitals[7] to 53.4% in Chinese teaching hospitals.[6]

The first step to preventing HAPUs is determining the risk factors and identifying populations of patients at high risk. Many risk factors have been identified, but consensus is lacking on the most important risk factors for HAPUs in critically ill patients. Traditionally, risk assessment scales for PUs have been used to predict level of risk and to screen for patients at high risk.[8] However, no risk assessment scale exclusively for PUs in ICU patients exists. Currently, in the United States the most widely used risk assessment scale is the Braden Scale,[9] which has 6 subscales: sensory perception, moisture, activity, mobility, friction and shear, and nutrition. The total score on the Braden Scale ranges from 6 to 23, and lower scores indicate higher risk. In ICUs, all patients are bedridden, have diminished levels of sensory perception, and are totally dependent on caregivers for both repositioning and transfers, resulting in total scores of 9 to 12, which are significantly lower than the critical score of 18.

Our aim was to understand the prevalence, location, and stage of HAPUs in ICU patients.

The Braden Scale has high sensitivity, but low specificity for determining the risk for PUs in ICU patients. This inaccuracy leads to an overestimation of the incidence of PUs.[10] Consequently, the specificity of the Braden Scale for ICU patients needs to be markedly improved.

In addition to the factors assessed by using the Braden Scale, many other factors are associated with the development of PUs in critically ill patients. In order to quantify the risk for PUs more precisely in critically ill patients, a prediction model should be developed that includes specific risk factors in critical care. Reynolds[11] recommended that a risk assessment scale be combined with some biochemical indexes (eg, serum level of albumin) to improve the ability to predict PUs in ICU patients. However, in recent studies,[12,13] traditional statistical methods, such as univariate analysis and logistic regression analysis, have been used to analyze the data. In these prediction models, the main effects of the independent variables were considered, but interactions and collinearity were not addressed. The results were not always intuitive and were difficult to apply to clinical applications.

A decision tree is a data mining algorithm that uses artificial intelligence and semiautomated processing of data to analytically discover the association of variables with outcomes.[14] The model is a nonparametric statistical method and can be used to quickly and effectively mine the main factors that affect diseases. The basic principle is to classify the data recursively by using a series of rules, and the core technology is the growing and pruning of the tree.[15] Decision trees can lead to a simple, clear, and intuitive tree structure to show the meaningful classification of prediction variables, eliminate the impact of collinearity between variables, and exploit the interaction between the independent variables. In addition, the tree model can be used to generate some rules to guide clinical decision making.[16]

In this study, our aim was to understand the prevalence, location, and stage of HAPUs in ICU patients. The objective was to explore and evaluate the feasibility and accuracy of applying decision-tree methods and logistic regression to predict the risk of HAPUs in ICU patients. Finally, we compared the predictive validity of the 2 risk-prediction models with that of the Braden Scale. We wished to provide a theoretical basis for the prevention of PUs in clinical practice and the rational allocation of nurses.

Methods

A retrospective design and cluster sampling were used to focus on the predictive value of the total Braden Scale score and other factors in determining the risk for PUs in critically ill patients.

Selection Criteria

Data were obtained from the hospital information system of a 3A-grade hospital in Guangzhou, China. All

Authors

Xiaohong Deng is a nurse and enterostomal therapist, Department of Nursing, Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, China.

Ting Yu is the head nurse, Emergency Department, Third Affiliated Hospital of Sun Yat-sen University.

Ailing Hu is the deputy director and professor of nursing, Department of Nursing, Third Affiliated Hospital of Sun Yat-sen University.

Corresponding author: Ailing Hu, RN, MSN, ET, Department of Nursing, the Third Affiliated Hospital of Sun Yat-sen University, No. 2693 Kai Chuang Rd, Guangzhou, China (email: h-ailing@163.com).

adult patients admitted to the medical intensive care unit (MICU) and coronary care unit (CCU) during the period October 2011 through October 2013 who met the selection criteria were included in the sample. We collected the patients' information from electronic medical files and nursing records. Patients were included in the sample if they were 18 years or older, had an ICU length of stay of 24 hours or greater, had no PUs at the time of ICU admission, and had any subsequent PUs that met the 2009 definition and staging of PUs of the National Pressure Ulcer Advisory Panel.[17] Patients were excluded if they had skin disease such as systemic lupus erythematosus or psoriasis or had burns or other skin damage.

Independent Variables

We developed 2 data forms to collect the data. Form 1 was used to understand the occurrence of HAPUs and to gather demographic data. Time of occurrence, number, location, and stage of each HAPU were recorded as indicated by the 2009 staging system of the National Pressure Ulcer Advisory Panel.[17] Form 2 was developed by reviewing studies on the risk factors and prediction of HAPUs in ICU patients and was evaluated twice by using a Likert scale among 5 clinical nurse specialists. Each entry was screened on the basis of the content validity index; ultimately all index values should be between 0.8 and 1.0. Form 2 included the following study variables: age,[9,18,19] ICU length of stay,[20] temperature,[18,21] systolic blood pressure,[18] diastolic blood pressure,[18] mean arterial pressure,[18] oxygen saturation by pulse oximetry,[19] hemoglobin level,[22] serum level of albumin,[22] results of arterial blood gas analysis (pH, Pao_2, $Paco_2$),[23] use of mechanical ventilation,[24] diabetes mellitus,[20] infection,[20,25] score on the Braden Scale,[26] scores on the Braden subscales,[26] smoking,[21,27] edema,[9] and fecal incontinence.[28] Temperature, blood pressures, and oxygen saturation were measured and the mean values were determined during the first 24 hours of admission.[29] For hemoglobin level, albumin level, pH, Pao_2, $Paco_2$, scores on the Braden Scale and subscales, the initial values after ICU admission were recorded.[12,30]

Because of the study's retrospective design, most data were collected from electronic medical records. Scores on the Braden Scale were determined by ICU nurses within 8 hours of ICU admission. Vital signs, including blood pressures and oxygen saturation, were recorded every hour via electrocardiographic monitoring. ICU nurses measured patients' temperature every 4 hours after admission.

Outcome Variables

Outcome variables were based on the development of HAPUs in ICU patients; a value of 1 indicated a yes (developed), and 0 indicated a no (did not develop). HAPUs were staged according to the classification system as follows: 1, stage I; 2, stage II; 3, stage III; 4, stage IV; 5, unstageable; and 6, suspected deep tissue injury.

Statistical Analysis

SPSS, version 20.0 for Windows, software (SPSS Inc) was used for data analysis. Descriptive statistics included the frequency distribution of study variables and demographic data. Stepwise logistic regression analysis and decision-tree analysis were used to construct the risk-prediction models.

The principle of a decision tree is to use information theory to find the fields with the most information in the database, establish a node of the tree, and then establish a branch of the tree depending on the value of the field. Then, this process is repeated to establish the lower nodes and branches of the tree in each branch subset to finally obtain a complete decision tree. The structure is similar to that of an inverted tree composed of a trunk and many branches. A decision tree consists of classification trees and regression trees. Regression trees are applied to the data analysis of numerical dependent variables, whereas classification trees are applied to categorical dependent variables. The principle of a decision tree model is similar to variation decomposition in analysis of variance. The basic purpose of the tree is to divide the study population into several relatively homogenous subpopulations on the basis of certain characteristics (the values of the independent variables) in which the values of the dependent variables inside each subpopulation are highly consistent (homogenous) and the values of dependent variables among different subpopulations have large differences. All of the algorithms for decision tree models follow this basic principle.[15] In this study, we used the classification and regression tree algorithm to construct the decision tree model.

In this study, we used the classification and regression tree algorithm to construct the decision tree model.

In addition, we used a 10-fold crossvalidation method to create the decision tree. The dataset was split into 10 equal subsets of data (folds). A training dataset representing 9 folds was used to create the model, which was then tested on the tenth fold. This procedure was repeated until each of the folds had been used as a testing set, and the mean of the results of the 10 iterations was determined. The goal was to create a parsimonious decision tree with the highest accuracy.

We used 6 measurements to compare the predictive validity between the 2 risk prediction models (logistic regression model and decision tree model) and scores on the Braden Scale. The 6 measurements were sensitivity, specificity, positive predictive value, negative predictive value, the Youden index (sensitivity + specificity - 1), and the area under the curve on the receiver operating characteristic curve.

Results

Description of the Sample

Of the 529 patients admitted to the ICUs during the study period, 468 met the inclusion criteria and were included in the sample: 253 from the MICU and 215 from the CCU. The patients' ages ranged from 19 to 93 years (mean, 58; SD, 17). The ICU length of stay was 1 to 98 days (mean, 12; SD, 14). The most common diseases requiring admission to the ICU were circulatory system diseases (47.6%) and respiratory diseases (27.4%). The basic characteristics of the study sample are summarized in Table 1.

Table 1 Basic characteristics of the study sample (n = 468)

Characteristic	No. of cases (%)[a]	Mean (SD)
Sex		
Male	349 (74.6)	
Female	119 (25.4)	
Age, y		57.81 (16.72)
≤40	68 (14.5)	
41-60	148 (31.6)	
>60	252 (53.8)	
Department		
MICU	253 (54.1)	
CCU	215 (45.9)	
Length of ICU stay, d		11.57 (14.36)
1-14	381 (81.4)	
15-28	52 (11.1)	
29-42	17 (3.6)	
≥43	18 (3.8)	
Diagnoses		
Circulatory system	223 (47.6)	
Respiratory system	128 (27.4)	
Digestive system	45 (9.6)	
Nervous system	30 (6.4)	
Urinary system	12 (2.6)	
Other	30 (6.4)	

Abbreviations: CCU, coronary care unit; ICU, intensive care unit; MICU, medical intensive care unit.

[a] Because of rounding, not all percentages total 100.

Occurrence of HAPUs

As shown in Table 2, HAPUs developed in 94 of the 468 patients (20.1%) in the sample; the ulcers were stage II or greater in 43 patients (9.2%). The prevalence was 32.8% in the MICU (13.8% when stage I ulcers were excluded) and 5.1% in the CCU (3.7% when stage I ulcers were excluded). A total of 140 HAPUs developed; of these, 81 were stage I (57.9%), 58 were stage II (41.4%), and 1 was a suspected deep issue injury (0.7%). The top 3 locations were the sacrum (45.7%), heels (11.4%), and back (7.9%). In addition, HAPUs occurred in a number of nonapophysis sites, including the nostrils and auricles.

Table 2 Occurrence of HAPUs in different departments

Department	No. of patients with cases of HAPUs	No. of HAPUs	No. of cases in hospital	Prevalence, %
MICU	83	128	253	32.81
CCU	11	12	215	5.12
Total	94	140	468	20.09

Abbreviations: CCU, coronary care unit; HAPU, hospital-acquired pressure ulcer; MICU, medical intensive care unit.

Descriptive Statistics of the Study Variables

Descriptive statistics of the numerical variables are summarized in Table 3. The differences between patients with and without HAPUs in age, ICU length of stay, diastolic blood pressure, mean blood pressure, hemoglobin level, albumin level, $Paco_2$, total Braden score, and scores on the mobility and nutrition Braden subscales were significant (all $P < .05$). The mean Braden scores were 11.30 (SD, 1.37) for patients in whom HAPUs developed (when stage I ulcers are excluded), and 13.47 (SD, 1.80) in patients who remained ulcer-free. Of the 94 patients in whom HAPUs developed, 6 were classified as at risk (6%), 35 as at moderate risk (37%), 47 as at high risk (50%), and 6 as at very high risk (6%) (Figure 1). Descriptive statistics of the categorical variables are

Table 3 Descriptive statistics of the numerical variables and comparison of patients with and without HAPUs[a]

Independent variables	Mean (SD)		*t*	*P*
	No HAPU (n = 374)	HAPU[a] (n = 43)		
Age, y	56.14 (14.70)	68.70 (14.45)	-5.31	<.01[b]
ICU length of stay, d	9.19 (10.16)	25.74 (25.17)	-4.27	<.01[b]
Pulse rate, beats/min	95.64 (18.13)	96.37 (10.78)	-0.39	.70
Respiration, breaths/min	23.83 (4.91)	23.95 (5.44)	-0.15	.88
SBP, mm Hg	121.64 (12.93)	118.79 (14.57)	1.35	.18
DBP, mm Hg	70.84 (6.18)	66.67 (7.80)	3.38	<.01[b]
MAP, mm Hg	87.77 (6.68)	84.05 (8.43)	2.80	<.01[b]
Spo_2, %	96.70 (2.34)	96.28 (2.57)	1.12	.26
Hemoglobin, g/L	109.14 (28.34)	99.70 (27.78)	2.08	.04[c]
Albumin, g/L	33.37 (5.37)	30.70 (5.11)	3.10	<.01[b]
pH	7.36 (0.11)	7.34 (0.15)	0.54	.59
Pao_2, mm Hg	91.52 (38.78)	80.81 (35.62)	1.73	.09
$Paco_2$, mm Hg	48.56 (22.33)	42.90 (14.64)	2.25	.03[c]
Braden subscale scores	13.47 (1.80)	11.30 (1.37)	7.67	<.01[b]
Sensory perception	2.79 (0.62)	2.90 (1.10)	-3.13	.76
Moisture	2.86 (0.44)	2.50 (0.53)	2.10	.06
Activity	1.00 (0.00)	1.02 (0.24)	-1.10	.36
Mobility	2.47 (0.63)	1.70 (0.82)	3.71	<.01[b]
Nutrition	2.03 (0.27)	1.50 (0.53)	3.14	.01[c]
Friction/shear	1.85 (0.44)	1.90 (0.57)	-0.34	.74

Abbreviations: DBP, diastolic blood pressure; HAPU, hospital-acquired pressure ulcer; ICU, intensive care unit; MAP, mean arterial pressure; SBP, systolic blood pressure; Spo_2, oxygen saturation as measured by pulse oximetry.
[a] Excludes stage I ulcers.
[b] Significant at $P < .01$.
[c] Significant at $P < .05$.

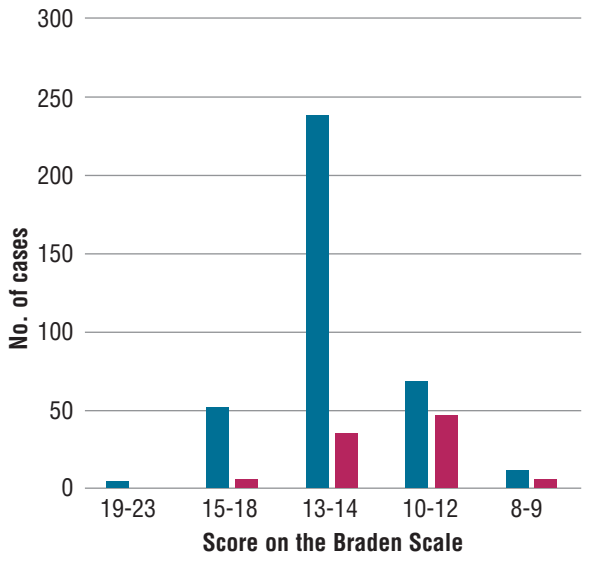

Figure 1 Risk stratification of intensive care unit patients with hospital-acquired pressure ulcers.

summarized in Table 4. The 2 groups of patients differed significantly for mechanical ventilation and fecal incontinence ($P < .01$).

Logistic Regression Analysis

Independent variables significant at $P < .05$ in patients with HAPUs compared with patients without HAPUs were included in the logistic regression analysis. The independent variables were recoded and classified on the basis of the reference value in the clinical practice, excluding age, ICU length of stay, and scores on the Braden Scale and subscales, which were recorded by the measured value directly. The variable values in the normal range were considered the referent level when 3 or more were in the group (Table 5). The following risk factors were significant predictors of HAPUs in ICU patients: age, ICU length of stay, diastolic blood pressure, albumin level, total Braden score, use of mechanical ventilation, and fecal incontinence (Table 6).

Table 4 Descriptive statistics of the categorical variables and comparison of patients with and without HAPUs[a]

Independent variables	No. of cases		χ^2	*P*
	No HAPU (n=374)	HAPU (n=43)		
Sex			1.5	.70
Male	286	34		
Female	88	9		
Temperature, °C			0.7	.72
>37	134	14		
36-37	214	27		
<36	26	2		
Mechanical ventilation			13.2	<.01[b]
No	245	16		
Yes	129	27		
Diabetes			6.4	.01[c]
No	291	26		
Yes	83	17		
Infection			3.2	.08
No	66	3		
Yes	308	40		
Smoking			2.3	.31
No	139	19		
Yes	145	11		
Quit	90	13		
Edema			2.2	.51
No	278	35		
Mild	55	3		
Moderate	27	4		
Severe	14	1		
Fecal incontinence			43.5	<.01[b]
No	366	32		
Yes	8	11		

Abbreviation: HAPU, hospital-acquired pressure ulcer.
[a] Excludes stage I ulcers.
[b] Significant at $P<.01$.
[c] Significant at $P<.05$.

Decision Tree Results

Independent variables significant at $P<.05$ in patients with HAPUs compared with patients without HAPUs were used to create prediction models via decision tree analyses. Figure 2 shows the results of the decision trees. Decision trees are like upside down trees with the roots on the top and the leaves on the bottom. The lines are links that point to another node that is the terminal node, the end point for development or no development of a HAPU. The link from one node to the next is important in classifications because the links represent the order of decision; traversing the various branches of the tree, one can construe rules in the development of HAPUs (when stage I ulcers are excluded).

The 7 classification rules in the risk of HAPUs (when stage I ulcers are excluded) extracted by using decision tree models are summarized in Table 7. Four types of high-risk populations were identified. One rule that can be inferred from this tree is as follows: if a patient is more than 81 years old, then the risk for HAPUs is 90.9%. The second high-risk population can be represented by the following rule: if a patient is more than 71 years old, not more than 81 years old, and if the total Braden score is not more than 12, then the risk for HAPUs is 87.5%. The rule for the third high-risk population is as follows: if a patient is not more than 71 years old and if the total Braden score is not more than 12 and if the patient's diastolic blood pressure is not more than 60 mm Hg, then the risk for HAPUs is 63.6%. The rule for the fourth high-risk population is the following: if a patient is not more than 71 years old, and if the total Braden score is not more than 12, and if the patient's

Table 5 Variables for logistic regression analysis

Independent variables	Code and group
Age, y	Observed value
ICU length of stay, d	Observed value
DBP, mm Hg	60-90 = 0 <60 = 1 >90 = 2
MAP, mm Hg	70-105 = 0 <70 = 1 >105 = 2
Hemoglobin, g/L	
Male	120-160 = 0 <120 = 1 >160 = 2
Female	110-150 = 0 <110 = 1 >150 = 2
Albumin, g/L	36-51 = 0 <36 = 1 >51 = 2
$Paco_2$, mm Hg	35-45 = 0 <35 = 1 >45 = 2
Total Braden scores	Observed value
Mobility subscale	Observed value
Nutrition subscale	Observed value
Mechanical ventilation	No=0 Yes=1
Fecal incontinence	No=0 Yes=1

Abbreviations: DBP, diastolic blood pressure; ICU, intensive care unit; MAP, mean arterial pressure; SBP, systolic blood pressure.

diastolic blood pressure is normal, and if the patients has fecal incontinence, then the risk is 57.1%.

Evaluation of the Braden Scale and Risk-Prediction Models

The results comparing the predictive validity between the 2 risk prediction models and the Braden Scale are summarized in Table 8. In this study, the best cutoff score of the Braden Scale was 12. The areas under the curve of logistic regression and decision tree models were significantly greater than the area for the Braden Scale.

Discussion

One purpose of this study was to describe the occurrence of HAPUs in ICUs. According to our results, prevalence of HAPUs in ICU patients was 20.1% overall (9.2% when stage I ulcers were excluded), significantly higher than the rate of 0.6% in the general units in 12 hospitals in China.[31] However, this prevalence was less than the medium level in a previous study.[32] The high prevalence of HAPUs in ICUs may be associated with patients' severe illness and limits in activity. In our study, HAPUs in ICUs were mainly stages I and II, similar to findings in a study by Suriadi et al.[21] ICU patients receive 1-on-1 care, and HAPUs can be detected and treated in a timely manner. In our study, the most common anatomical locations of HAPUs in ICU patients were the sacrum, the heel, and the back, in that order; these findings were consistent with those of Cox.[12] Burk and Grap[33] found that raising

Table 6 Logistic regression analyses for predictors of hospital-aquired pressure ulcers[a]

Variables	β	SE	Wald χ^2	*P*	Odds ratio	95% CI
Age	0.09	0.02	12.6	<.01[b]	1.09	1.04-1.14
ICU length of stay	0.07	0.02	21.2	<.01[b]	1.07	1.04-1.10
Diastolic blood pressure[c]	2.52	0.66	14.7	<.01[b]	12.44	3.43-45.10
Albumin level[d]	1.54	0.61	6.4	.01[e]	4.66	1.42-15.32
Mechanical ventilation	1.03	0.47	4.7	.03[e]	2.79	1.11-7.01
Total Braden score	-0.40	0.12	11.5	<.01[b]	0.67	0.53-0.85
Fecal incontinence	1.83	0.69	7.2	<.01[b]	6.25	1.63-23.98

Abbreviation: SE, standard error.
[a] Stage 1 ulcers are excluded. Data were missing for 8 cases (n = 409). Cox and Snell $R^2 = 0.26$; Nagelkerke $R^2 = 0.53$; Hosmer-Lemeshow test $\chi^2 = 10.4$, $df = 8$, $P = .24$.
[b] Significant at $P < .01$.
[c] <60 mm Hg.
[d] <36 g/L.
[e] Significant at $P < .05$.

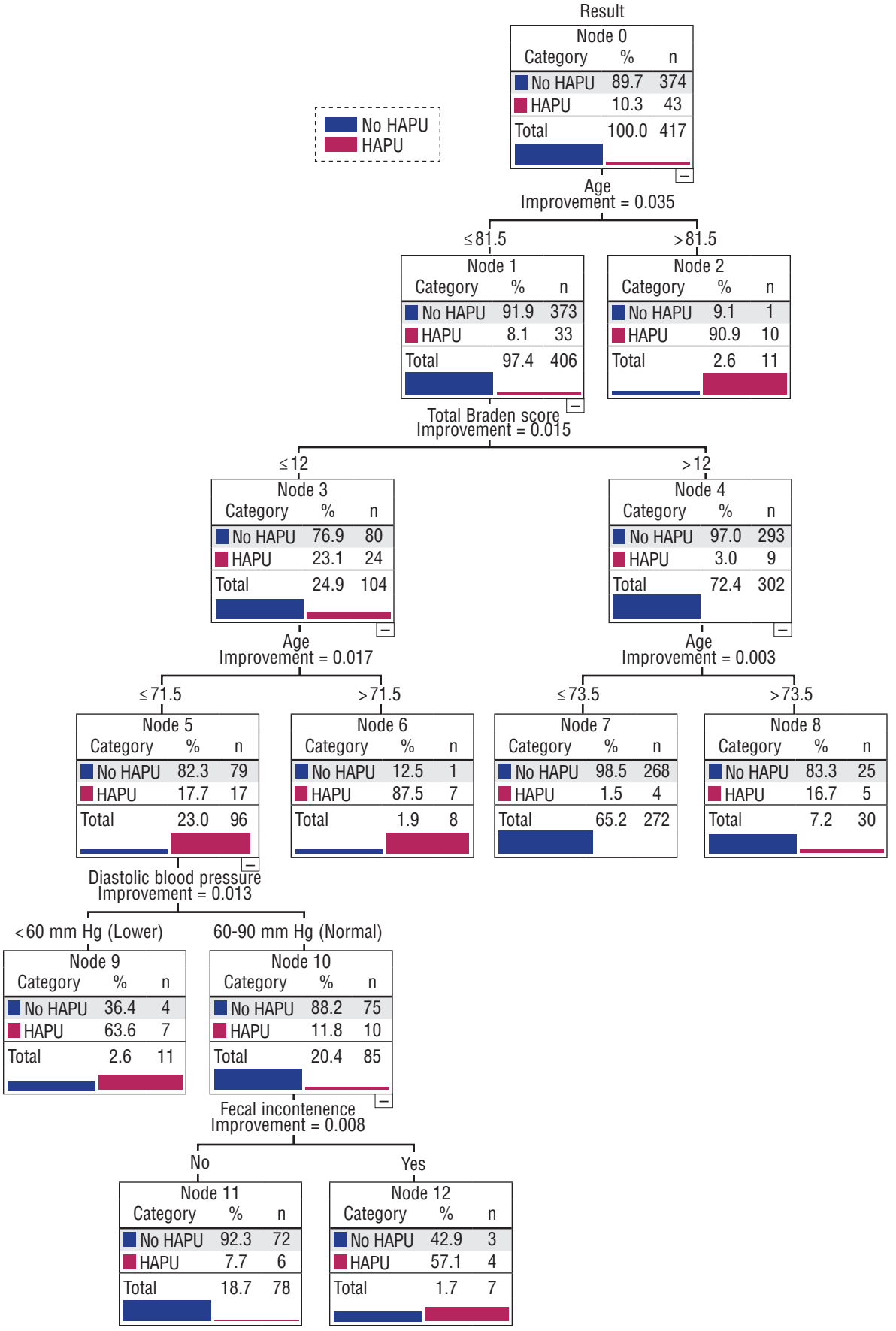

Figure 2 Decision tree for development or no development of hospital-acquired pressure ulcers (HAPUs).

Table 7 Classification rules extracted by using the decision tree model (n = 417)[a]

Classification rules	Condition 1, age, y	Condition 2, total Braden score	Condition 3, age, y	Condition 4, DBP, mm Hg	Condition 5	Risk, %	No.
1	>81					90.9	11
2	≤81	≤12	>71			87.5	8
3	≤81	≤12	≤71	<60		63.6	11
4	≤81	≤12	≤71	≥60-≤90	Fecal incontinence	57.1	7
5	≤81	≤12	≤71	≥60-≤90	Without fecal incontinence	7.7	78
6	≤81	>12	>73			16.7	30
7	≤81	>12	≤73			1.5	272

Abbreviation: DBP, diastolic blood pressure.
[a] Stage 1 ulcers are excluded.

Table 8 Comparison of predictive validity between the 2 risk prediction models and the Braden Scale[a] for prediction of HAPUs

Method	SEN	SPE	Youden index	PPV	NPV	AUC	95% CI
Braden Scale	0.744	0.786	0.530	0.286	0.964	0.793	0.709-0.877
Logistic regression	0.836	0.805	0.641	0.769	0.942	0.913	0.867-0.959
Decision tree	0.859	0.822	0.681	0.757	0.976	0.925	0.883-0.966

Abbreviations: AUC, area under the curve on the receiver operating characteristic curve; HAPU, hospital-aquired pressure ulcer; NPV, negative predictive value; PPV, positive predictive value; SEN, sensitivity; SPE, specificity.

the head of the bed 30° or more to prevent ventilator-associated pneumonia in patients treated with mechanical ventilation resulted in greater pressure on the sacrum and heel. These patients tend to slide down from the Trendelenburg position used for mechanical ventilation and turn over and move frequently, changes that increase the risk for exposure of the back to the forces of friction and shear.[33]

In our study, stepwise logistic regression analysis indicated that the following factors were significant independent predictors of HAPUs in ICU patients: diastolic blood pressure, albumin levels, use of mechanical ventilation, fecal incontinence, and the total score on the Braden Scale.

We found that HAPUs were more likely in patients with lower diastolic blood pressure. This finding is consistent with the results of a previous study.[21] In our study, mean diastolic pressure was 66.67 mm Hg in patients in whom HAPUs developed and 70.84 mm Hg in patients who remained free of HAPUs. In our study, an albumin level less than 36 g/L was an independent predictor of HAPUs. According to a review[34] on the relationship between PUs and nutrition, 7 of 13 studies indicated a statistically significant association. A systematic review and meta-analysis[35] provided stronger evidence, indicating that albumin level was a significant predictor of PUs.

In our study, use of mechanical ventilation was a significant predictor of HAPUs, a finding consistent with the results of a study by Pender and Frazier.[19] In our sample, the prevalence of HAPUs was 17.3% (27 of 156 patients) in patients treated with mechanical ventilation and 6.1% (16 of 261) in patients not treated with mechanical ventilation. Our results indicate that development of HAPUs was more likely in patients with fecal incontinence than in patients without fecal incontinence. This finding is consistent with the findings of a study by Shahin et al.[36] In our study, the incidence in patients with fecal incontinence was 57.9% (11 of 19), significantly higher than the incidence of 8.0% (32 of 398 patients) for patients without fecal incontinence.

We found that the total score on the Braden Scale was a significant predictor of HAPUs, consistent with findings of Cox.[12] In our sample, 79.7% of patients (370 of 464) were classified as at risk for HAPUs (total score on the Braden Scale ≤18) but remained ulcer-free (Figure 1). When the Braden Scale was used, the risk for

HAPUs was overpredicted, as indicated by the low specificity and low positive predictive value. An analysis of ICU patients revealed that virtually all had a total score of 18 or less on the Braden Scale, but the majority did not experience a HAPU. Overprediction of HAPUs is often criticized as a limitation shared by all validated HAPU risk assessment instruments. Because of this overprediction, drawing any important conclusions about the capability of the score in predicting HAPUs in ICU patients is difficult. Use of the Braden Scale either led to successful identification of patients at risk, subsequently mobilizing clinicians to implement appropriate strategies to prevent HAPUs and thus averting the occurrence of HAPUs, or led to the implementation of potentially unnecessary strategies to prevent HAPUs, resulting in excessive health care costs and potential inefficient use of caregivers' time. Specific care requirements for patients at mild and moderate risk would be minimal, but greater preventive measures would be required for patients at high risk. The result should be more intensive care for patients at higher risk and less care for those at lower risk, thus conserving resources. Searching for additional risk factors is valid to refine preventive measures.

The results of the decision tree model are more intuitive and user-friendly for clinical nurses and enterostomal therapists.

Because of the characteristics of decision trees, such as high accuracy in classification, the extraction rules can be quantified and are easy to understand; thus, decision tree analysis can be applied in clinical and preventive medicine.[37] In our study, 7 classification rules of the risk for HAPUs were extracted by using the decision tree model, and 4 high-risk populations were identified by using the HAPU risk prediction model. A total of 4 variables were entered in the final model: age, fecal incontinence, total score on the Braden Scale, and diastolic blood pressure. These findings are consistent with previous results of logistic regression analysis.[12,13,38,39] Generally, the focus in logistic regression tends to be on the independent effect of the variables, and this method is more suitable for research on risk factors. However, the focus of decision tree analysis is the predictive effect of the overall model. Clinical nurses and enterostomal therapists can establish a screening strategy or path for assessing the risk for HAPUs by using the decision tree model (Figure 2). The 1-level factor assessed is age; if a patient is more than 81 years old, then he or she is at high risk (90.9%) for HAPUs (when stage I ulcers are excluded). If a patient is more than 71 years old but is 81 years or younger, then a 2-level factor is considered, such as total score on the Braden Scale; if the total Braden score 12 or less, then the patient is at high risk (87.5%). If a patient is 71 years or younger and the total Braden score is 12 or less, then a 3-level factor should be considered, such as diastolic blood pressure. The ultimate result is that nurses' and enterostomal therapists use different intervention strategies according to the risk for HAPUs.

In our study, on the basis of the Youden index, the optimal cutoff score on the Braden Scale for prediction of HAPUs in ICU patients was 12. The area under the curve on the receiver operating curve, sensitivity, specificity, positive predictive value, and negative predictive value were 0.793, 0.744, 0.786, 0.286, and 0.964, respectively. When scores on the Braden Scale were combined with other predictive factors, the area under the curve, specificity and positive predictive value of the logistic regression and decision tree risk-prediction models were significantly increased, to 0.913, 0.805, 0.769, and to 0.925, 0.822, 0.757, respectively. Generally, in our study, the 2 different risk-prediction models had similar predictive validity and were superior to the Braden Scale. Clearly, the results of the decision tree model are more intuitive and user-friendly for clinical nurses and enterostomal therapists.

Limitations

Our study has several limitations. Because of the retrospective design, HAPUs were staged and recorded in the health records by staff nurses who are educated annually on the assessment of PUs, and some bias may occur. Because the study was conducted at a single study site, the generalizability of the findings is diminished. In addition, the stability and generalizability of the findings would be improved with more samples. In clinical practice, staff should take preventive measures based on the intensity of the risk and note that not all patients are treated equally.

Conclusions

We found a low to medium incidence of HAPUs in ICU patients, higher than the incidence found in patients in general units. Most HAPUs were stages I and II, and the sacrum, heels, and back were the most common anatomical locations. Logistic regression analysis indicated the following factors were associated with the development of

HAPUs in ICU patients (when stage I ulcers were excluded): age, ICU length of stay, diastolic blood pressure, albumin level, use of mechanical ventilation, fecal incontinence, and total score on the Braden Scale. According to the Youden index, the best cutoff score on the Braden Scale for prediction of HAPUs in ICU patients was 12. Using the HAPU decision tree model, we extracted 7 classification rules and identified 4 types of high-risk populations.

As one of the most commonly used risk assessment scales for PUs, the Braden Scale may not include important predictors in ICU patients. In our study, the comprehensive predictive validities of the 2 different risk-prediction models were better than the predictive validity of the Braden Scale. Development of prediction models including other specific predictors can help in estimating the risk for HAPUs in ICU patients and can be useful for making decisions on prevention of PUs in clinical practice. Furthermore, prediction models can provide a basis for creating guidelines about PU prevention. CCN

Acknowledgment
The authors thank Tiehua Li for assistance with the data collection and Siyu Jiang for assistance with the statistical analysis.

Financial Disclosures
None reported.

eLetters

Now that you've read the article, create or contribute to an online discussion about this topic using eLetters. Just visit www.ccnonline.org and select the article you want to comment on. In the full-text or PDF view of the article, click "Responses" in the middle column and then "Submit a response."

References

1. Burdette-Taylor SR, Kass J. Heel ulcers in critical care units: a major pressure problem. *Crit Care Nurs Q.* 2002;25(2):41-53.
2. VanGilder C, Amlung S, Harrison P, Meyer S. Results of the 2008-2009 International Pressure Ulcer Prevalence Survey and a 3-year, acute care, unit-specific analysis. *Ostomy Wound Manage.* 2009;55(11):39-45.
3. Keller BP, Wille J, van Ramshorst B, van der Werken C. Pressure ulcers in intensive care patients: a review of risks and prevention. *Intensive Care Med.* 2002;28(10):1379-1388.
4. Cuddigan JE. Critical care. In: Pieper B, National Pressure Ulcer Advisory Panel, eds. *Pressure Ulcers: Prevalence, Incidence, and Implications for the Future.* Washington, DC: National Pressure Ulcer Advisory Panel; 2012.
5. Langemo DK, Anderson J, Volden C. Uncovering pressure ulcer incidence. *Nurs Manage.* 2003;34(10):54-57.
6. Zhao G, Hiltabidel E, Liu Y, Chen L, Liao Y. A cross-sectional descriptive study of pressure ulcer prevalence in a teaching hospital in China. *Ostomy Wound Manage.* 2010;56(2):38-42.
7. Shahin ES, Dassen T, Halfens RJ. Incidence, prevention and treatment of pressure ulcers in intensive care patients: a longitudinal study [published correction appears in *Int J Nurs Stud.* 2014;51(3):522]. *Int J Nurs Stud.* 2009;46(4):413-421.
8. Anthony D, Parboteeah S, Saleh M, Papanikolaou P. Norton, Waterlow and Braden scores: a review of the literature and a comparison between the scores and clinical judgement. *J Clin Nurs.* 2008;17(5):646-653.
9. Compton F, Hoffmann F, Hortig T, et al. Pressure ulcer predictors in ICU patients: nursing skin assessment versus objective parameters [published correction appears in *J Wound Care.* 2008;17(11):493]. *J Wound Care.* 2008;17(10):417-420, 422-424.
10. Duan Zhengzheng, Liu Yilan. Risk factors of pressure ulcers in ICU patients: a case-control study [in Chinese]. *J Nurs Sci.* 2012;27(11):42-44.
11. Reynolds TM. Risk assessment for prevention of morbidity and mortality: lessons for pressure ulcer prevention. *J Tissue Viability.* 2008;17(4):115-120.
12. Cox J. Predictors of pressure ulcers in adult critical care patients. *Am J Crit Care.* 2011;20(5):364-375.
13. Terekeci H, Kucukardali Y, Top C, Onem Y, Celik S, Oktenli C. Risk assessment study of the pressure ulcers in intensive care unit patients. *Eur J Intern Med.* 2009;20(4):394-397.
14. Westra BL, Savik K, Oancea C, Choromanski L, Holmes JH, Bliss D. Predicting improvement in urinary and bowel incontinence for home health patients using electronic health record data. *J Wound Ostomy Continence Nurs.* 2011;38(1):77-87.
15. Han J, Kamber M, Pei J. *Data Mining: Concepts and Techniques.* 3rd ed. Waltham, MA: Morgan Kaufmann Publishing; 2012.
16. Henly SJ. Mother lodes and mining tools: big data for nursing science. *Nurs Res.* 2014;63(3):155.
17. National Pressure Ulcer Advisory Panel. *Prevention of Pressure Ulcers: Quick Reference Guide.* Washington DC: National Pressure Ulcer Advisory Panel; 2009.
18. Bergstrom N, Braden B. A prospective study of pressure sore risk among institutionalized elderly. *J Am Geriatr Soc.* 1992;40(8):747-758.
19. Pender LR, Frazier SK. The relationship between dermal pressure ulcers, oxygenation and perfusion in mechanically ventilated patients. *Intensive Crit Care Nurs.* 2005;21(1):29-38.
20. Rademakers LM, Vainas T, van Zutphen SW, Brink PR, van Helden SH. Pressure ulcers and prolonged hospital stay in hip fracture patients affected by time-to-surgery. *Eur J Trauma Emerg Surg.* 2007;33(3):238-244.
21. Suriadi, Sanada H, Sugama J, et al. Risk factors in the development of pressure ulcers in an intensive care unit in Pontianak, Indonesia. *Int Wound J.* 2007;4(3):208-215.
22. Nixon J, Nelson EA, Cranny G, et al; PRESSURE Trial Group. Pressure relieving support surfaces: a randomised evaluation. *Health Technol Assess.* 2006;10(22):iii-iv, ix-x, 1-163.
23. Nanjo Y, Nakagami G, Kaitani T, et al. Relationship between morphological characteristics and etiology of pressure ulcers in intensive care unit patients. *J Wound Ostomy Continence Nurs.* 2011;38(4):404-412.
24. Manzano F, Pérez-Pérez AM, Martinez-Ruiz S, et al. Hospital-acquired pressure ulcers and risk of hospital mortality in intensive care patients on mechanical ventilation. *J Eval Clin Pract.* 2014;20(4):362-368.
25. Mcgahan M, Kucharski G, Coyer F. Nurse staffing levels and the incidence of mortality and morbidity in the adult intensive care unit: a literature review. *Aust Crit Care.* 2012;25(2):64-77.
26. Tescher AN, Branda ME, Byrne TJ, Naessens JM. All at-risk patients are not created equal: analysis of Braden pressure ulcer risk scores to identify specific risks. *J Wound Ostomy Continence Nurs.* 2012;39(3):282-291.
27. Suriadi, Sanada H, Sugama J, Thigpen B, Subuh M. Development of a new risk assessment scale for predicting pressure ulcers in an intensive care unit. *Nurs Crit Care.* 2008;13(1):34-43.
28. Bergquist-Beringer S, Gajewski BJ. Outcome and assessment information set data that predict pressure ulcer development in older adult home health patients. *Adv Skin Wound Care.* 2011;24(9):404-414.
29. Qian Tu, Yan Sun, Chunyu Zhang. Monitoring of oxygenation and perfusion index to predict pressure ulcers in intensive care units. *Zhonghua Hu Li Zu Zhi.* 2011;46(3):285-287.
30. Tume LN, Siner S, Scott E, et al. The prognostic ability of early Braden Q Scores in critically ill children. *Nurs Crit Care.* 2014;19(2):98-103.
31. XU Ling, Jiang Qi-Xia. Research of prevalence of pressure ulcer and hospital-acquired pressure ulcer [in Chinese]. *J Nurs.* 2012;19(9):9-13.
32. Tayyib N, Coyer F, Lewis PA. A two-arm cluster randomized control trial to determine the effectiveness of a pressure ulcer prevention bundle for critically ill patients. *J Nurs Scholarsh.* 2015;47(3):237-247.
33. Burk RS, Grap MJ. Backrest position in prevention of pressure ulcers and ventilator-associated pneumonia: conflicting recommendations. *Heart Lung.* 2012;41(6):536-545.
34. Finucane TE. Malnutrition, tube feeding and pressure sores: data are incomplete. *J Am Geriatr Soc.* 1995;43(4):447-451.
35. Wang Li-Qi, Jiang Li-Ping. Evidence-based evaluation of the correlation of serum albumin to pressure ulcer [in Chinese]. *Health Res.* 2014;(4):391-394.
36. Shahin ES, Dassen T, Halfens RJ. Pressure ulcer prevalence in intensive care patients: a cross-sectional study. *J Eval Clin Pract.* 2008;14(4):563-568.
37. Shi Xiao-Jing. Data mining and its application in medical information [in Chinese]. *J Med Intell.* 2013;34(5):2-6.
38. Ülker Efteli E, Yapucu Günes Ü. A prospective, descriptive study of risk factors related to pressure ulcer development among patients in intensive care units. *Ostomy Wound Manage.* 2013;59(7):22-27.
39. Shahin ES, Dassen T, Halfens RJ. Pressure ulcer prevalence and incidence in intensive care patients: a literature review. *Nurs Crit Care.* 2008;13(2):71-79.