Prediction of In-Hospital Pressure Ulcer Development

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Objective: The development of in-hospital acquired pressure ulcers (PUs) is of great concern for both patients and professionals in health care. Based on the hypothesis that identification of patients who are prone to develop PU will enhance preventive measures in this group of patients, we investigated a new tool, Qscale, for in-hospital prediction of PU.

Approach: A total of 383 patients were recruited from three departments. The investigations were performed in two steps: 252 patients were used to train the algorithm, and 131 patients were used in the validation. The new scale combines observational and on-site available information regarding patient mobility.

Results: The validation data yielded an area under the curve (AUC) of 0.82. The Qscale had a significantly higher AUC compared with that of the Braden Scale with an AUC of 0.76 ($p < 0.05$). When comparing the performance at specific thresholds, a sensitivity of 47% and a specificity of 94% were observed. This was significantly ($p < 0.05$) better than the Braden score with a sensitivity of 20% and a specificity of 94%.

Innovation: Our study showed promising results on both the training and validation data of the Qscale in comparison with the Braden Scale.

Conclusion: The new scale has a potential benefit in the prevention of PU in a hospital setting.

Keywords: risk scale, prediction, pressure ulcers

INTRODUCTION

THE DEVELOPMENT OF acquired pressure ulcers (PUs) is of great concern in hospitalized health care today. In the United States, PUs are observed in more than 500,000 annual inpatient hospital stays.¹ Because incidence and prevalence rate of PU depends on patient's characteristics, such as disease and complications, it is hard to predict rates of prevalence and incidence in general. Estimates of prevalence from different studies range from 7% to 25% of hospitalized pa-

tients.^{2–4} PUs are a painful, incapacitating, and potentially fatal complication in routine medical and nursing care. Treatment of PUs is very costly, and the development of PUs can be prevented by integrating dedicated use of evidence-based best nursing practice. In the United Kingdom the cost of treating a PU varies from ~£1,200 to ~£14,000 (~\$1,600–\$18,400).⁵ This treatment cost is likely to increase in the future as the population ages. In addition to the increased cost, the length of hospital

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stay and patient recovery time will be prolonged.¹ PUs normally result from long periods of continuous pressure and shear induced to the skin and underlying soft and muscle tissue and bony prominences. High-risk patients are elderly people, stroke patients, people with diabetes, individuals with dementia, persons who use wheelchairs or are bedbound, and any patient with reduced mobility.¹ The use of appropriate preventive measures is being hampered by the fact that high-risk patients cannot be accurately, reliably, and timely detected, even when routinely using the Braden Scale (the most used risk scale, with the best predictive values).⁶ Treatment options to avoid progression of PU are well established, but the method to detect and avoid them before onset has not evolved in two decades.

CLINICAL PROBLEM ADDRESSED

Often the prevention and treatment of PUs are performed unsystematic and based on clinical experience of the individual health care provider.⁷ Predictive models have the potential to improve the management and prevention of PUs. We have previously shown in a different medical domain how predictive models that fuse information from different modalities could potentially help prevent serious disease.^{8–10} Several risk scores assessing the patient's risk of developing PUs have been proposed and used in medical care, such as the Braden, Waterlow, and Norton scales.^{11–13} However, the predictive value of these scales has shown low to modest accuracy.^{14,15} We hypothesize that PUs can be prevented by dedicated early warning in high-risk patients. The objective of the study was to investigate the potential of using a pattern classification method for individualized development of PUs.

MATERIALS AND METHODS

Study design

The study design was a longitudinal observational cohort study. The study was conducted at Aarhus University Hospital, Denmark. Patients were recruited from an intensive care ward, a medical ward, and a surgical ward from March 2011 to September 2011. The included patients were observed from admission until discharge date. Data were collected by three research nurses, one located in each of the participating wards. The three nurses were all specialized in observing skin conditions indicative of PU development, in scientific data collection, and in preventive care. The study was conducted according to the principles of the "Helsinki Declaration" and approved by the Danish authority, Datatilsynet (No. 2007-58-0010), all patients gave their informed consent.

Participants

Patients aged >20 years were included in the study if they were admitted in one of three participating wards. Patients admitted and discharged within the same date were excluded from the study. Moreover, patients with PUs at admission were excluded.

Data measurements

Data were obtained on the day of admission, the day after the admission, and every fourth day until discharge.

Data were collected from patient medical files and by dedicated observations of each patient. Data included information on outcome, risk factors, and PU prevention activities. An overview of the information used in this analysis is shown in Table 1. Demographic variables are gender, age (years), and admitting unit. Factor variables are up and self-reliant, had surgery, nerve damages, limitation in activity performance, mobility and willingness, consciousness, hospitalization type, and instructed in pressure injury preventive activities.

Model derivation and development. A pattern classification method was developed to predict individualized development of PUs into one of two classes: (1) no PUs during hospitalization or (2) development of PUs during hospitalization.

Logistic regression classification was chosen for foundation of the model due to the possibility of including both nominal and ordinal data types. Logistic regression utilizes a transparent decision model—this makes it attractive in a clinical setting as a decision support system. We used forward selection to include features in the model based on statistical significance. Moreover, we used 10-fold

Table 1. Description of the variables included in the analysis

Variable	Type	Options
Outcome		
Pressure injury	Category	Yes/no
Demographics		
Gender	Category	Male/female
Age (years)	Continuous	20–92
Admitting unit	Category	Intensive, medical, surgical
Factors		
Up and self-reliant	Category	Yes/yes (have diabetes)/no
Had surgery	Category	Yes/no
Nerve damages	Category	Yes/no
Limitation in activity performance	Category	None/mild/moderate/severe/activity cannot be performed
Mobility and willingness	Category	Yes/yes partly/no
Consciousness	Category	Yes/yes partly/no
Hospitalization type	Category	Acute/planned
Instructed in pressure injury preventive activities	Category	Yes/yes partly/no
Braden Scale	Continuous	0–23 (steps)

cross-validation to ensure that the model was not overfitted and that the results were transferrable to a similar cohort. We derived and tested the model on a rotating 9 (of 10) partitions of training data and 1 (of 10) partition of test data. The accepted statistical methods ensure valid testing of the model performance and reduces generalization bias.^{16,17}

Validation and comparison. We evaluated the prediction models through sensitivity and specificity for predetermined cutoff points and receiver operating characteristics based on logistic regression models comparing the area under the curve (AUC) of the new model.

We used another cohort for validation ($n = 131$); these data were obtained in the same manner as the training cohort and also from the Aarhus University Hospital. Validation using patients not used for training is the golden standard in prediction modeling. In the validation cohort, data scoring on the Braden Scale was also obtained in these patients by direct observations. We also compared our results with that of using the Braden Scale for predicting the development of PUs during hospitalization. The PU incidence and distribution of PU severity (category 1–4) for the training and the validation group during hospital admission are shown in Table 2.

RESULTS

A total of 383 patients were included in this study. The training data included 252 patients and the validation data included 131 patients. In the training data the mean age was 63 ($\pm$ standard deviation [SD] 16) years, 36% were women, 30% of the patients were recruited from a medical unit, 51% from a surgical unit, and 19% from an intensive care unit. Furthermore, we observed a pressure injury incidence of 12.7%. In the validation data the mean age was 65 ($\pm$ SD 16) years, 34% were women, 35% of the patients were recruited from a medical unit, 47% from a surgical unit, and 18%

Table 2. Pressure ulcer incidence for training and validation groups during hospital admission

	Training group	Validation group
<i>N</i>	252	131
Women (%)	36	34
Age (years)	63 (16)	65 (16)
PU (%)	12.7	28.1
PU severity (%)		
Category 1	7.8	13.3
Category 2	3.7	10.4
Category 3	0	3.7
Category 4	1.2	0.7

PU, pressure ulcer.

from an intensive care unit. The observed incidence for pressure injuries was 28.1%.

The final model for predicting development of PUs during hospitalization included the following predictors in a logistic model: gender, up and self-reliant, limitation in activity performance, mobility and willingness, and consciousness. The performance of our classifier Qscale is shown in Fig. 1. The training data yielded an AUC of 0.82; the AUC of validation data was also 0.82. The Qscale had a significantly higher AUC compared with that of the Braden Scale with an AUC of 0.76 ($p < 0.05$). When comparing the performance at specific thresholds (Table 3), for the low threshold, a specificity of 94% and a sensitivity of 47% was found (Table 2). This was significantly ($p < 0.05$) better than the Braden score with a specificity of 94% and a sensitivity of 20%.

DISCUSSION

Several risk scores for assessing patients' risk of developing PUs have been proposed and used in medical care, such as the Braden, Waterlow and Norton scales.^{11–13} The accuracy of these scales has not been optimal, and there has been a call for an updated scale that could be used to predict the risk of developing PUs in hospital. We tested a new scale for predicting PUs using only simple observational data and gender of the patient. The new scale, which combines observational and on-site available information regarding patient mobility, willingness, and motivation, could lead to an improved accuracy in predicting PUs compared with a well-established method. The Braden Scale is the most widely used risk scale in Denmark and, therefore, used for comparison in this study. For a

Figure 1. ROC curve of the model and the Braden model from the validation data. ROC, receiver operating characteristic.

Table 3. Performance represented as sensitivity, specificity, area under curve, positive predictive value, negative predictive value

	Sensitivity %	Specificity %	AUC %	PPV %	NPV %
Scale					
Training Qscale	47	94	82	53	92
Validation Qscale	43	94	82	72	92
Braden Scale	20	94	76	55	92

AUC, area under the curve; NPV, negative predictive value; PPV, positive predictive value.

threshold with a high specificity of 94% the new scale could improve the sensitivity significantly from 20% to 43% (Braden Scale vs. Qscale). This means that the Qscale can potentially predict 43% of developing PUs with few false-positives. In clinical use a higher sensitivity could be chosen on the cost of specificity. This calculation of an optimal sensitivity and specificity would require a cost-benefit analysis, which includes the cost of treating patients who are predicted to develop ulcers (true-positives and false-positives), as well as the potential benefits, such as reduced development of ulcers and savings.

Moreover, this sensitivity of 43% would yield a positive predictive value (PPV) of 72% and a negative predictive value of 92%. In other words, this would mean that the clinicians would have to treat 10 patients and 7 of these would develop PUs if no preventive measures were taken. Of course, the PPV is influenced by the incidence of having PUs in a specific cohort. For instance, we observed a difference in PPV between the training and validation results. This was primarily due to the differences in incidence rate between the two samples. In the training data we observed an incidence rate of 12.7% for the development of a PUs—in the validation data we observed an incidence rate of 28.1%. Several studies have shown how the prevalence/incidence is varying between departments^{2–4}; this could explain the difference in incidence between the training and validation data.

The implication of identifying patients prone to develop PUs during a hospital stay is to enable clinicians to target these patients with a personalized prevention plan. Patients with a high risk of PUs could be treated with friction-reducing mattresses and an intensified plan for helping the patient to move or be mobilized during day and night. In contrast, patients with a low risk of developing PUs might not need the same level of attention for preventing PUs, and these patients could be checked less intensively. As described, significant resources are being used on treating PUs each year.¹⁸ If just a small percentage of these iatrogenic

wounds could be avoided, the hospitals would save significant resources. But this would also be of great benefit to the patients, who often suffer severely as a result of these complications. One potential usage of the proposed score could be that patients with a high risk of developing PUs could receive intensive prevention measures. Such measures could include more frequent observations and assistance to change body positions. Another approach could be to use a pressure-relieving mattress.

Our proposed model did show a high AUC of 0.82, and this was also observed in the validation sample. However, we know that the conditions for these patients vary from hospital to hospital and from unit to unit. We did include different types of units and validated the model on new data. Even though our results are promising, further studies are required to test the generalizability of the model on data from other hospitals. The next step would be to conduct a large, prospective, randomized clinical trial. An alternative strategy would be to test if such a model could be used outside the hospital in the primary sector. A lot of these PUs also develop in nursing facilities or in the patient's own home. A limitation in this study is, of course, the use observational data from medical wards where ongoing preventive care is being delivered.

Another perspective to improve the performance of these models could be to include additional hospital-obtained data on the patient status. This could include results of blood samples, temperature measurements, or skin pressure measurement (if the patients are using a pressure-sensitive mattress). These data could be merged with the observed state of the patient to enhance the overall representation of the patient's ability to move and hereby also reduce the risk of developing PUs.

It is estimated that 70% of PUs occurs in people aged over 70 years, with a relevant share of permanently bedridden elderly due to prevalence of physical disabilities.⁶ Given the extensive consequences of PUs on patient's quality of life, health care safety, and use of medical resources, it is urgent to significantly decrease the incidence and prevalence of such skin lesions. The most effective and efficient way to achieve that goal is through prevention rather than treatment. At early stages, PU prognosis is excellent because most injuries heal by themselves if the risk source is properly handled (*e.g.*, lowering the friction, redistributing the pressure, improving the blood flow). Nurses and doctors surveyed during phase 1 expressed a great focus on treatment routines rather than prevention due to lack of tools to identify high-risk patients, which hampers the prioritization of PU preventive strategies. Annual costs

associated with PUs are very significant worldwide. In the United States, 15% of the patients suffer from PUs. This translates into 2.5 million patients every year, carrying costs related to PU treatment around \$9.1–11.6 billion annually, with an average of \$43,000 per individual. European PU prevalence in hospital in-patients is above 18%, with <10% of patients receiving adequate preventive care.¹⁹

For example, in United Kingdom, PUs cost to National Health Service around €1.6–2.4 billion per year, which is 4% of total expenditure; in Germany, the same costs are between €1 billion and €2.3 billion; and in the Netherlands and Spain they are ~€400 million per year. Based on these data, it is imperative that improved PU prevention systems are developed to reduce the incidence, prevalence, and associated complications and even deaths. Therefore, new technologies to enable early PU detection are needed, since these can bring favorable outcomes in both clinical (shorter hospitalizations) and economic indicators (costs saved per PU episode avoided) and improved quality of life of our patients.²⁰

Some limitations should be mentioned: first, even though the results of the validation showed good generalizability, both data sets were collected from the same hospital and so transferability outside these facilities should be done with caution. Second, our inclusion criteria were broad, which means that we potentially collected a representative sample from the wards; however, extrapolating our results to another group of patients should also be done with caution. Future studies will explore the potentiality of this scale in different settings and in well-defined clinical cohorts. A difference in PU incidence were observed between the training and validation cohort studied. This difference could be attributed to which department the patient came from. This is in line with previous findings showing that the incidence is varying between medical departments. Future studies should investigate the performance in different departments.

KEY FINDINGS

- Validation of a new risk scale for prediction of persons prone to develop pressure ulcers.
- A total of 383 hospitalized patients were investigated.
- Results show that the new risk scale significantly improves accuracy in predicting PUs as compared with a well-established method.

INNOVATION

We have developed and investigated a new screening tool to identify patients at risk of developing PUs during hospital admission. Our study showed promising results on both training and validation data and in comparison with the Braden Scale. The new Qscale could potentially be used in the prevention of PUs in a hospital setting.

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ABBREVIATIONS AND ACRONYMS

AUC = area under the curve
 PPV = positive predictive value
 PU = pressure ulcer
 SD = standard deviation