Using EHR data to predict hospital-acquired pressure ulcers: A prospective study of a Bayesian Network model

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ABSTRACT

Background: Hospital-acquired pressure ulcers (HAPUs) are common among inpatients and create substantial morbidity, mortality, and costs, but prevention strategies have been only variably effective.

Objectives: To develop and assess the impact of a decision support intervention to predict HAPU on the prevalence of ulcers and length of stay in an intensive care unit (ICU), and on the user adoption rate and attitudes.

Methods: We compared the HAPU prevalence before and after introducing the intervention, and surveyed the users. We used a Bayesian Network model that was validated in previous studies and linked to the electronic health record system in an application called Pressure Ulcer (PU) Manager. The intervention group included 866 at-risk patients in the surgical ICUs of a tertiary teaching hospital over a 6-month period in 2009 and 2010; the controls were 348 patients from a 6-month baseline period in 2006 and 2007.

Results: In the intervention group, the overall HAPU prevalence rate fell from 21% to 4.0% and the ICU length of stay shortened from 7.6 to 5.2 days. After adjustment for primary diagnoses and illness severity, the intervention group was significantly less likely than the baseline group to develop HAPU ([odds ratio (OR) = 0.1, p < 0.0001] and had a shorter ICU length of stay (OR = 0.67, p < 0.0001). Data entry regarding ulcer severity and body site increased, and the participants used PU Manager more than once a day for over 80% of eligible cases. Attitudes toward PU Manager were positive.

Conclusions: This decision support approach reduced the prevalence of HAPU tenfold and the ICU length of stay by about one-third. Furthermore, the nurses had favorable attitudes toward using it.

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1. Introduction

In the acute setting, hospital-acquired pressure ulcers (HAPUs) have a serious impact on both patient recovery and the healthcare system [1–4]. They increase the incidence of infection, sepsis, and additional surgical procedures, which increase the hospital costs and length of stay and create a substantial burden to patients. The HAPU incidence ranges widely, from 0.4% to 38% [3,5,6]. These events are costly, with one study estimating that they cost US$ 3.3 billion in the USA in 2008 [7].
While numerous efforts have been made to reduce the incidence of HAPU, it remains unacceptably high. According to the current best evidence, prevention measures should be initiated in a timely manner after identifying at-risk patients in order to enable prevention [5,8]. Identifying such patients remains a significant issue.

Standardized risk assessments, usually using the Braden Scale [9] or the Norton Scale [10], are now part of normal clinical practice. However, the quality and clinical utility of these tools are questionable, since they do not take into account all relevant risk factors, and so fail to identify some patients who may benefit from interventions to prevent pressure ulcers [11], and the scoring is inconsistent between staff members. Consistency can be improved by initial and periodic training, but the inconsistency is partly attributable to educational policies, staff mixes, and staff turnover rates varying between hospitals. Moreover, variations in use of these tools are common and their use is often low despite their availability [12–15].

The use of support surfaces, repositioning the patient, optimizing their nutritional status, and exercise and treatment of incontinence have been explored in comprehensive programs to prevent HAPU in acute-care settings [16]. McInnes et al. [17] concluded that alternatives to the standard hospital foam mattress can reduce the incidence of pressure ulcers in people at risk, based on the Cochran Database of Systemic Review of 53 randomized controlled trials. Iglesias [18] showed that alternative pressure mattresses were associated with lower overall costs due to a shortened length of stay in hospital and a delayed time to ulceration. DeFloor et al. [19] reported that applying various combinations of turning and pressure-reducing devices to at-risk patients decreased the incidence of grade II and higher pressure ulcers by fivefold. de Laat et al. [20] found in a prospective cohort study that implementing a hospital-wide pressure ulcer guideline reduced the incidence from 43% to 28%. Baldelli and Paciella [21] also reported an overall reduction in incidence (7%) and prevalence (15%) after implementing a prevention strategy in an intensive care unit (ICU) setting. These strategies have been embodied in clinical guidelines such as Prevention and Treatment of Pressure Ulcers [22] developed by the National Pressure Ulcer Advisory Panel (NPUAP) and the European Pressure Ulcer Advisory Panel (EPUAP), and Pressure Ulcers in Adults [23] by the Agency for Health Care Policy and Research (AHCPR). These well-known preventive care measures should be applied to appropriately selected patients at the right time.

Bedside nursing staffs need access to the right information at the right time in order to improve outcomes. As part of a research project intended to provide predictive risk information to point-of-care nurses by employing technology to rapidly synthesize and analyze electronic health record (EHR) data, we developed a predictive decision model that can be embedded in a clinical decision support (CDS) system. Computerized decision support can be embedded within electronic records to enhance clinical decision making and can improve patient safety and quality of care. The decision model was constructed using the Bayesian network (BN) technique and was designed and validated for patients of surgical ICUs (SICUs) at two tertiary teaching hospitals with complete EHR systems [24–28]. The model was implemented as a CDS intervention and evaluated in November 2009 at two inpatient SICUs at Seoul National University Hospital (SNUH). This article reports on the impact of the CDS intervention on the prevalence of HAPU, ICU length of stay, and user adoption and attitudes toward the CDS.

2. Methods

2.1. Setting

The study site was a large, urban, not-for-profit, university-affiliated teaching hospital in Seoul with approximately 2000 operational beds. In the 2004 fiscal year, the hospital installed a locally developed complete EHR system for inpatient and outpatient units. All clinicians at the hospital used the EHR, which at the time of the study included computerized physician order entry, nursing records, and laboratory and radiology results. In 2008 the hospital increased the number of beds in the SICU from 24 to 32, and divided it into 2 units (1 with 18 beds and 1 with 14 beds), as a result of an increasing need for SICU capacity that was partly driven by large increases in the number of patients with high-severity and cancer diagnoses. The hospital assigned more clinicians to participate in the care of SICU patients to maintain the same staff mix and patient–nurse ratio relative to the increase in SICU size. Additional beds with the same specifications as the existing ones were purchased. No additional equipment for HAPU was introduced, but special mattresses had already been used for all patients.

2.2. Study design

The design of this evaluation was a before and after comparison. Data were collected retrospectively before the intervention began in November 2009 (from November 1, 2006 to April 30, 2007; baseline period) and then after 6 months of implementation in April 2010 (from November 1, 2009 to April 30, 2010; intervention period). Fig. 1 shows the outline of the study.

2.3. Patients

Patients admitted to the SICUs during the two periods who met the following eligibility criteria were selected: SICU stay of 2 days or longer, older than 18 years, no ulcers at ICU admission, and the first admission to an ICU during the study period. During the 6-month intervention period, 866 patients were identified. They received the usual nursing assessment and interventions from 64 nurses who were blinded to the eligibility criteria. For the baseline period, 348 patients meeting the eligibility criteria were selected retrospectively.

2.4. Outcomes

The main end points for the study analyses were the prevalence of HAPU and the ICU length of stay. The prevalence was measured by dividing the number of new patients with HAPU within 6 months by the total number of at-risk patients. We used the nursing assessment data retrieved from the EHR or intervention database as a reference standard. The ICU length
of stay, which was from the ICU admission date to the ICU discharge date, was also measured. The prevalence and ICU length of stay during the intervention period were compared with those of the baseline period.

Two secondary outcomes were also compared. User adoption, which refers to how frequently the system was used by target users, was measured as the rate of system use and the rate of recording ulcer data in the system. The rate of system use was the usage percentage self-reported by the study participants during three shifts a day. The rate of recording ulcer data was the input percentage of ulcer severity and body sites for cases. The ulcer severity was recorded from stage II and above according to the NPUAP Pressure Ulcer Staging System [29]. User attitudes toward the system were also measured, using the United Theory of Acceptance and Use of Technology (UTAUT) model questionnaire [30], which was developed to explain user intentions to use an information system and subsequent usage behavior. It consolidated previous Technology-Acceptance-Model-related studies and consisted of five main constructs (performance expectancy, effort expectancy, social influence, facilitating conditions, and behavioral intention) and four mediating variables (gender, age, experience, and voluntariness of use). Fifteen items from the questionnaire were used with mediate variables after replacing the social influence construct with the attitude toward using technology. Since the CDS intervention was provided on a voluntary basis, we decided that social influence was not appropriate for this study. All items were translated into Korean so they would be clearly understood.

Approval for the study was obtained from the SNUH Institutional Review Board for acquiring retrospective data and prospective studies involving patients and nurses (IRB No. 0907-032-286). Written consent to participate was obtained from the nurses, patients themselves or their legal family members.

2.5. Implementing the CDS intervention

This implementation was based on four previous studies [24–28]. The network structure of the BN model for HAPU was based on a literature review of published risk-assessment tools [24,25], which revealed eight unique studies on the development or modification and validation of risk-assessment tools. We extracted 30 relevant unique concepts with definitions from these studies, and examined the coded data in the electronic nursing record system of Bundang Hospital and cross-matched them with 37 data items semantically. More than 90% of the concepts were matched successfully. We also evaluated the data quality of the EHR system with regard to syntactics and semantics [26], and found that 88.7% of the data were meaningful and appropriate for direct computational use. The remaining 11.3% of the data had system-constraint and user problems; we provided the hospital with feedback so that these problems could be resolved.

The values for link weights in the model were assigned by the retrospective data of Bundang Hospital [28]. We used 21,114 hospital-day records of 3348 discharges over 3 years from 2005 to 2007. Testing of the model disclosed sensitivity, specificity, and positive and negative predictive values of 82%, 76%, 36% and 96%, respectively. The area under the receiver operating characteristics curve exceeded 85%. We also found that the BN model exhibited better prediction and case coverage than other modeling methods such as decision tree and regression models.

For a prospective evaluation of the BN model, we conducted a model validation study at SNUH, which uses an EHR system developed by the same vendor [27]. We used over 2800 hospital-day records of 3393 discharges that were eligible for the same selection criteria as the previous research. Since the SNUH had richer data items, the BN model was extended to 39 nodes, 54 links, and 26,659 conditional probabilities, which yielded similar results to the original model. Table 1 lists the data elements used in the final model.

Two of the authors (I.C. and I.P.) defined a succinct statement of needs and objectives, the required database, the major program modules, screen displays, and inputs and outputs for an EHR data interface. The health information technology (HIT) staff of the hospital determined the physical and logical definitions of the system. The main program module and database used Java technology, Netica version 3.24 Application Programmer Interface (Norsys Software, Vancouver, Canada), and MySQL version 5.5; we called this CDS intervention “PU Manager”.

After implementation, we provided a 40-min education session to the participating nurses, which included the importance of the HAPU in SICU settings, an explanation of the
study background, an introduction on how to access and use PU Manager, how to interpret the risk information, and the care they should provide to a high-risk patient. The hospital already had its own pressure ulcer prevention protocols that were developed based on NPUAP–EPUAP and AHCPR guidelines. We briefly reminded the nurses about these protocols.

2.6. Data collection

Baseline data were collected from the clinical data repository of the hospital, which provided a detailed, flexible, and rapid retrospective view of clinical and financial data including complete nursing records. We retrieved the ‘Nursing Assessment Checklist’ template, which is a structured data input form for physical assessment in ICUs; every shift nurse is required to complete this record. This template had a skin-assessment section to establish whether the patient has a pressure ulcer and, if so, its site and severity. These data were used to calculate the prevalence and percentage of recording ulcer-relevant data.

All 64 full-time nurses participated voluntarily in the study during the intervention period. They used PU Manager after logging into the hospital information system. To ensure that they reviewed the data generated by the system, we asked them to click the checkbox located in the PU Manager screen every day. We also asked the participants to put skin-assessment data into the PU Manager screen and linked the data with the Nursing Assessment Checklist. User survey data were collected on-line for 2 weeks in May, 2010. All of the 64 nurses (aged 23–30 years), who were all female registered nurses engaged in patient care with three shifts, responded.

2.7. Statistical analysis

The unit of analysis for prevalence and ICU length of stay was the ICU discharge date. It was the same number of patients because we included the first admission to the ICUs. Continuous variables were compared between the two periods using Fisher’s exact test or the $\chi^2$ test. For prevalence and ICU length of stay, logistic linear regression and a Poisson regression model were used to adjust for primary diagnosis and Acute Physiology and Chronic Health Evaluation (APACHE) II score. Data were analyzed with the SAS v.9.1 statistical software package (SAS Institute, Cary, NC, USA).

3. Results

3.1. Development of PU Manager

The developed PU Manager provided decision support in three distinct ways:

1. Probabilistic risk information, driven by the BN model from EHR data, guides the user in developing a patient-specific prevention plan.
2. The data entry form provides focused ulcer recording for case assessments.
3. The user can click on individual patients on the screen for definitions of variables of the BN model and values of mapped EHR data.

The system was designed to create prediction results on a daily basis in ICUs, as with the Braden Scale. When nurses input a Braden Scale score, the results can be referenced by nurses in the three shifts on the day. Each prediction was considered to be independent from the previous ones. Early every morning, at around 1.00 am, PU Manager receives relevant EHR data captured during the previous 24 h. It processes each data item along with the converting rules predefined in the system. The CDS database maintains an EHR data feed and transformed, which are mapped into the variables of the BN model; the inference engine returns probability values into the CDS database (Fig. 2).
3.2. Evaluation

3.2.1. Comparison of patient demographics

Comparison of the patient demographics between the two periods revealed insignificant trends toward more women and older patients in the intervention period (Table 2). For both periods, over 45% of patients were older than 60 years. Evaluation of the primary diagnoses showed that the frequency of malignant neoplasm increased between the baseline and intervention periods (from 24% to 43%), and those of circulatory and digestive diseases halved. The mean APACHE II score was also significantly higher in the intervention period. The mean body mass index was slightly higher in the intervention period, while there were no significant differences in serum hemoglobin and albumin between the two periods.

3.2.2. Comparison of ulcer prevalence and length of stay

The ulcer prevalence rate decreased significantly from the baseline period (21.3%, 74/348) to the intervention period (4.0%, 35/866; $\chi^2 = 64.07$, $p < 0.0001$), including after adjusting

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline period (N = 348)</th>
<th>Intervention period (N = 866)</th>
<th>$\chi^2$ or t</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, frequency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>220 (63.2)</td>
<td>501 (57.8)</td>
<td>2.96</td>
<td>0.0851</td>
</tr>
<tr>
<td>Female</td>
<td>128 (36.8)</td>
<td>365 (42.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age in years, mean (SD)</td>
<td>55.87 (15.71)</td>
<td>56.88 (15.66)</td>
<td>1.01</td>
<td>0.3128</td>
</tr>
<tr>
<td>Diagnosis, frequency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neoplasm: malignancy</td>
<td>85 (24.4)</td>
<td>368 (42.5)</td>
<td>63.83</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Neoplasm: benign</td>
<td>41 (11.8)</td>
<td>125 (14.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circulatory disease</td>
<td>82 (23.6)</td>
<td>117 (13.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nervous system disease</td>
<td>18 (5.2)</td>
<td>29 (3.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestive disorder</td>
<td>39 (11.2)</td>
<td>50 (5.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>31 (8.9)</td>
<td>31 (3.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other a</td>
<td>52 (14.9)</td>
<td>144 (16.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APACHE score (ranging 0–58), mean (SD)</td>
<td>11.10 (6.19)</td>
<td>18.67 (9.05)</td>
<td>10.00</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Body mass index, mean (SD)</td>
<td>22.73 (3.71)</td>
<td>23.23 (3.34)</td>
<td>−1.98</td>
<td>0.0482</td>
</tr>
<tr>
<td>Hemoglobin, mean (SD)</td>
<td>11.08 (2.10)</td>
<td>11.05 (1.60)</td>
<td>0.21</td>
<td>0.8370</td>
</tr>
<tr>
<td>Albumin, mean (SD)</td>
<td>2.98 (0.55)</td>
<td>2.96 (0.47)</td>
<td>0.53</td>
<td>0.5936</td>
</tr>
</tbody>
</table>

a Includes infection, respiratory and musculoskeletal diseases, congenital malformations, surgical procedures, and skin and subcutaneous diseases.
Table 3 – Comparison of outcome measurements.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline period (N = 348)</th>
<th>Intervention period (N = 866)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevalence of ulcers (%)</td>
<td>21.26</td>
<td>4.04</td>
<td></td>
</tr>
<tr>
<td>Unadjusted odds (95% CI)</td>
<td>0.16 (0.10–0.24)</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Adjusted odds &lt;sup&gt;a&lt;/sup&gt; (95% CI)</td>
<td>0.08 (0.05–0.15)</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Length of stay in intensive care unit in days, mean, (SD)</td>
<td>7.63 (13.45)</td>
<td>5.17 (8.13)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Unadjusted odds (95% CI)</td>
<td>0.39 (0.34–0.44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted odds &lt;sup&gt;a&lt;/sup&gt; (95% CI)</td>
<td>0.67 (0.61–0.73)</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Abbreviation: CI, confidence interval.
<sup>a</sup> Adjusted for diagnosis and APACHE score.

3.2.3. User adoption and user attitudes toward the system

Over 80% of the participants used the system more than once a day. Day-shift nurses reviewed the information of the system more frequently than those on the other shifts, with the proportion being about half as great in the evening-shift, and half as great again for the night-shift. Detailed ulcer data entries regarding ulcer severity and body site were more likely during the intervention period; these detail items were almost missed in the baseline period. However, the frequency with which nurses entered data items rose to 81% during the intervention period (Table 4).

The average values of all five of the UTAUT concepts for user attitudes toward PU Manager exceeded the midpoint of 3 on the 5-point Likert scale: 3.46 (SD 0.55) for performance expectancy, 3.67 (SD 0.50) for effort expectancy, 3.26 (SD 0.60) for attitude toward using PU Manager, 3.33 (SD 0.55) for the facilitating condition and 3.23 (SD 0.67) for behavioral intention (Fig. 3). As key moderators, the scores for voluntariness and experience were 3.69 (SD 1.02) and 3.55 (SD 0.92), respectively.

4. Discussion

Using a predictive model we found that a CDS intervention reduced HAPU rates by over tenfold, significantly shortened the ICU length of stay, and increased data entries regarding ulcer severity and body site, while being well-accepted by nurses. These findings suggest that the PU Manager approach is a useful and effective way of preventing HAPU in ICUs.

HIT has been applied previously to improving patient HAPU outcomes, but few studies have focused on a computerized predictive model using EHR data in risk assessment. Willson et al. [31] developed a computerized support of pressure ulcer prevention and treatment protocols by implementing reminders to nurses to perform Braden assessments and stage appropriate treatment recommendations at the LDS Hospital, Salt Lake City, USA. This improved adherence to both the prevention and treatment protocols, and reduced the incidence of pressure ulcers from 7% to 2%. Dowding et al. [32] evaluated the impact of an integrated EHR including nursing documentation, risk assessment tools, and documentation tools at 29 hospitals in California. The EHR introduced a computerized version of the Braden Scale, which increased documentation rates for HAPU risk (coefficient = 2.21, 95% CI = 0.67–3.75) and decreased HAPU rates (by 13%; coefficient = −0.76, 95% CI = −1.37 to −0.16). Another approach provided a daily electronic feedback report that consisted of the patients’ demographics, Braden Scale scores, and the number of days the patient was at risk for HAPU.

Table 4 – User adoption: system usage rate and documentation rate of ulcer details.

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall use of PU Manager</td>
<td>2561</td>
<td>81.35</td>
</tr>
<tr>
<td>Day-shift use</td>
<td>2490</td>
<td>79.10</td>
</tr>
<tr>
<td>Evening-shift use</td>
<td>1697</td>
<td>53.91</td>
</tr>
<tr>
<td>Night-shift use</td>
<td>1227</td>
<td>38.89</td>
</tr>
<tr>
<td>Total number of records</td>
<td>3148</td>
<td>100.00</td>
</tr>
<tr>
<td>Documentation of ulcer details</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severity</td>
<td>309</td>
<td>81.75</td>
</tr>
<tr>
<td>Body of site</td>
<td>256</td>
<td>67.72</td>
</tr>
<tr>
<td>Total eligible records with ulcers</td>
<td>378</td>
<td>100.00</td>
</tr>
</tbody>
</table>
scores, and pressure ulcer status [35], which significantly decreased the incidence ($t = 2.91$) and severity ($t = 3.52$) of pressure ulcers. However, these previous approaches were limited to providing a computerized version of an existing risk-assessment tool or summary EHR data to support nurses’ decision making.

Few computerized approaches have used EHR data for the prediction or risk assessment of pressure ulcers. Although Zielstorff et al. [33,34] implemented a computerized system for the AHCPR guidelines on the prediction, prevention, and treatment of pressure ulcers, at that time an electronic nursing record system was not available at the Massachusetts General Hospital, so the system had to capture coded data from assessment entry screens separated from nursing documentation. Furthermore, the system had no effect on knowledge about pressure ulcers or on clinical decision-making skills, although there were positive responses for instructional adequacy and user satisfaction. Kim et al. [11] developed a predictive model for the prevention of HAPU using logistic regression, but used a preexisting data set created for quality-improvement purposes that was not linked directly with EHR data.

Bayesian Networks based on probabilistic reasoning were introduced for medical diagnosis decision support. As EHRs are becoming increasingly adopted and have been widely heralded for their potential to improve patient care, Bayesian model applications of EHR data are also increasing. Himes et al. [35] identified clinical factors that modulate the risk of progression to chronic obstructive pulmonary disease among asthma patients. They used 12 data items extracted from electronic medical records and constructed a predictive model with an accuracy of 83.3%. Crump et al. [36] successfully used a Bayesian Network model in conjunction with rule-based time-series statistics to explore the possibility of prediction of patient outcome in the ICU. However, very few studies have implemented approaches and evaluated them prospectively in practice, even though the BN model is used widely in informatics fields such as public health surveillance, monitoring devices, medical subject heading assignment, and for predicting the pathogenicity of uncertain gene variants [37–39].

Our approach was a unique and exploratory trial to connect the existing nursing knowledge with daily practice. The PU Manager intervention focused on providing point-of-care nurses the probabilistic risk information driven from nursing observation data in an EHR system. We hypothesized that more objective and synthesized probability information than Braden Scale scores would be accepted and used by nurses in planning nursing activities along with the nursing protocol, ultimately affecting patient outcomes. PU Manager was accepted well and used by most of the participants. However, it is possible that other factors may also have contributed to the outcomes. For example, this study covered 4 years from the beginning of the baseline interval to the end of the intervention, during which there may have been educational programs, increased pressure from hospital accreditation requirements, patient profile differences, workforce differences, or other differences beyond the intervention. We were able to exclude the possibility of patient profile differences by implementing statistical adjustments. Furthermore, the possibility of workforce differences would affect the outcomes negatively in the intervention period, since more young and novice nurses were introduced during the intervention period due to the increased number of ICU beds. Moreover, it is implausible that these factors would have decreased the overall prevalence of HAPU by nearly tenfold.

Several factors might have contributed to the successful introduction and use of our intervention. The first is the hospital characteristics. The site is a leading academic hospital in Korea whose leadership is greatly interested in quality improvement. The nursing department focused on inviting and engaging the unit managers and experienced nurses throughout the study. Randell and Dowding [40] pointed out that organization features represented one of five key elements for the successful use of CDS features, and the nurses’ perceptions and attitudes are strongly affected by a desire to continually improve the quality of patient care.

The second factor was the target domain. The HAPU could be a niche CDS area that will be adopted and used by the focused nurses for whom they are intended. Moreover, the knowledge on HAPU risk factors is well established and most nursing observation data are captured in a structured format in an ICU. These circumstances made it easier to perform semantic matches, and since the present authors had participated in designing and developing the electronic nursing record system, it was straightforward to ensure that the ICU nurses used each data item with the same semantics.

The third factor was our approach toward workflow considerations. We analyzed the current use of the well-established Braden Scale before developing the system. We adopted the following workflow for use with PU Manager: every night-shift nurse assessed a patient and scored the six items of the Braden Scale; if the total score was equal or greater than 13, the patient was assigned to the high-risk group. The classification result was then referenced by nurses in the following three shifts. The adoption of this workflow was regarded as being clinically adequate and understood well by the participants.

Another factor that might have contributed negatively to the outcomes was the PU Manager user interface, which was implemented separately from that of the EHR system. This meant that the nurses had to open new windows to access PU Manager; the participants complained about this. It is well known that the user interface is a key aspect of a system’s acceptability, and the hospital is planning to integrate it into the hospital’s next-generation EHR system that is currently under development.

This study had two main limitations, the most important being that it was not a randomized controlled trial. We used a “before and after” design, and hence temporal effects could have influenced the results. To minimize the influence of the increased number of ICU beds, we chose to separate the periods, which might have introduced uncontrolled covariates. However, it is implausible that these covariates would have decreased the overall HAPU prevalence by over tenfold. The other limitation is that the study was performed at only one institution. We believe that PU Manager will be generalizable to other sites, and multi-institutional evaluations should attempt to confirm this.
Summary points

What was already known on the topic?

- In acute setting, hospital-acquired pressure ulcers (HAPU) are common and have a serious impact on both patient recovery and the healthcare system.
- Despite numerous efforts to decrease HAPU development was witnessed over the past decades, including use of standardized risk assessment tools, the incidence is unacceptably high.
- According to the current best evidence, prevention measures should be initiated in a timely manner after identifying at-risk patients in order to enable prevention.
- The electronic health record (EHR) are becoming an integral component of many healthcare facilities and are perceived to have potential to contribute to reducing healthcare cost and improve the health care quality through clinical decision support (CDS) features.

What this study added to our knowledge?

- The CDS approach to predict high-risk HAPU patients using EHR data and Bayesian Network model is feasible and accepted well by nurses in surgical intensive care practice.
- The CDS approach can be an effective and efficient strategy for preventing HAPU.
- The study shows an example how a CDS intervention can be used meaningfully in practice using EHR infrastructure.
- For the successful implementation of CDS approach, we could witness the importance of users’ engagement and commitment throughout the whole processes as well as CDS features.

5. Conclusion

We have developed and evaluated an EHR-data-driven CDS intervention for predicting the risk of HAPU in ICUs. We found that HAPU prevalence decreased by over tenfold and the ICU length of stay shortened significantly during the intervention period, and user adoption rates and attitudes were generally acceptable. This suggests that such a CDS intervention is an effective and sustainable strategy for preventing HAPU in acute-care settings. Moreover, the data in EHR systems should be reused to create meaningful information for nurses at the point of care.

Author contributions

I.C. and I.P designed the study. I.P., E.K., and E.L. contributed in data collection. The data was analyzed and interpreted by I.C. and D.B. The other co-authors had the opportunity to comment on the statistical methods and analysis. I.C. and D.B. prepared the manuscript. I.C., I.P., E.K., and D.B. contributed in revising and improving the manuscript.

Competing interest

None.

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