Background: Hospital-acquired pressure ulcers (HAPUs) are largely preventable yet still common occurrences in hospitals. The current study is to determine how data from the electronic medical record can be used to better understand and predict HAPU formation over the course of a hospital admission. Methods: A case-control study on HAPUs was performed over an 8-month period at Yale New Haven Hospital. A Cox regression analysis model analyzed the impact of multiple factors on HAPU development including friction and shear, among other Braden score components. A receiver operating characteristic curve was calculated to determine the sensitivity and specificity of changes in these factors in predicting HAPU development. Results: On a sample of 8,790 admissions, HAPU incidence was 4.2% over the study period (6.3% per annum). The average hospital day for HAPU development was day 15.6 (± 19.3). The Cox regression analysis demonstrated that the volatility of the friction and shear component of Braden scores had a risk ratio of 28.6 (P < 0.01; CI, 14.5–56.4). Volatility in the friction and shear component was the most predictive factor with a high receiver operating characteristic curve area of 0.865 (CI, 0.847–0.882). Conclusions: Volatility of the friction and shear component of Braden scores appears to be the most significant factor preceding HAPU development at Yale New Haven Hospital. Efforts to place more focus on identifying and reducing volatility of this factor may help decrease HAPU risk for future patients. (Plast Reconstr Surg Glob Open 2019;7:e2099; doi: 10.1097/GOX.0000000000002099; Published online 11 April 2019.)

Significance of Friction and Shear in the Prevention of Contemporary Hospital-acquired Pressure Ulcers

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Background: Hospital-acquired pressure ulcers (HAPUs) are largely preventable yet still common occurrences in hospitals. The purpose of the current study is to determine how data from the electronic medical record can be used to better understand and predict HAPU formation over the course of a hospital admission.

Methods: A case-control study on HAPUs was performed over an 8-month period at Yale New Haven Hospital. A Cox regression analysis model analyzed the impact of multiple factors on HAPU development including friction and shear, among other Braden score components. A receiver operating characteristic curve was calculated to determine the sensitivity and specificity of changes in these factors in predicting HAPU development.

Results: On a sample of 8,790 admissions, HAPU incidence was 4.2% over the study period (6.3% per annum). The average hospital day for HAPU development was day 15.6 (± 19.3). The Cox regression analysis demonstrated that the volatility of the friction and shear component of Braden scores had a risk ratio of 28.6 ($P < 0.01$; CI, 14.5–56.4). Volatility in the friction and shear component was the most predictive factor with a high receiver operating characteristic curve area of 0.865 (CI, 0.847–0.882).

Conclusions: Volatility of the friction and shear component of Braden scores appears to be the most significant factor preceding HAPU development at Yale New Haven Hospital. Efforts to place more focus on identifying and reducing volatility of this factor may help decrease HAPU risk for future patients. (Plast Reconstr Surg Glob Open 2019;7:e2099; doi: 10.1097/GOX.0000000000002099; Published online 11 April 2019.)

INTRODUCTION

Hospital-acquired pressure ulcers (HAPUs) are largely preventable yet still common occurrences in hospitals. Hospitals invest in many techniques to prevent them: specialty dressings, specialty mattresses, mobility protocols, and the Braden score, a risk-stratifying tool. Despite all these attempts, HAPUs still occur, affecting about 2.5 million patients per year with a total cost of $9.1–11.6 billion annually to treat.¹

The Braden score is a nursing tool used to stratify patients at risk of HAPU development upon hospital admission. This score is determined by nurses and is used to risk stratify patients into cohorts who require more attention due to increased pressure sore risk. It is a composite score made up of 6 components: sensory perception, moisture, activity, mobility, nutrition, and friction and shear. The sensory perception component evaluates a patient’s ability to detect and respond to discomfort. Moisture evaluates the degree of dampness on a patient’s skin and includes whether the patient suffers from incontinence. Activity is determined by a patient’s level of physical activity, whereas mobility evaluates the degree to which a patient is able to change body position independently. Nutrition evaluates the adequacy of a patient’s food intake. The friction and shear component evaluates the frequency of surface

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This study was conducted under the approval and in conformance with all guidelines of the local institutional review committee for patient data collection.

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friction experienced by a patient’s skin when moving and also takes into account the amount of assistance required to move a patient. Each component score is arrived at through a combination of subjective and objective assessments. For example, a score of “1” for activity is applied to a patient who is “confined to bed,” which is a relatively objective determination. However, a score of “3” is applied to a patient who “walks occasionally... spends majority of shift in bed or chair,” a determination that is more prone to subjective assessment. Nonetheless, inter-rater reliability for the Braden score between nurses has been measured at 0.84 (95% CI, 0.72–0.92). The cut-off score used to stratify patients is 18 based on previous work using receiver operating characteristic (ROC) curves to analyze the relationship between Braden scores and actual development of pressure ulcers. Braden scoring has been extensively investigated, and there have been multiple published studies in a variety of different hospital settings validating its predictive abilities. When the Braden score is ≤18, nursing protocols are employed to ensure assisted movement and allow for more focused attention on a patient to reduce HAPU development. The Braden score is reassessed every 8 hours by nurses and, therefore, may vary constantly throughout an admission for a given individual patient, but a patient is only deemed high risk when the score is ≤18.

Per hospital protocol, patients who have a Braden score of ≤18 are deemed to be at high risk and result in the implementation of pressure ulcer prevention measures. Nursing protocol at Yale New Haven Hospital includes multiple parts: moisture, repositioning, nutrition/hydration, and devices. Moisture is addressed by utilizing special 1-step cleanser, barrier creams, soft wipes, incontinence pads, and fecal management. Repositioning is addressed with specialty beds, heels being floated, wedges for positioning, flat sheets, pressure ulcer dressings, cushions, and physical repositioning of the patient. Nutrition is addressed by making sure that fluids are available and the patient is receiving adequate nutrition. Devices are addressed by placing padding and anchoring tubes.

Overall, health of patients and their mortality can affect pressure ulcer formation. There are methodologies that allow one to utilize data in the electronic medical record (EMR), such as laboratory values and vital signs, to track trends in the patient’s overall condition independent of diagnosis. One of them is the Rothman index: it uses 26 variables including diastolic and systolic blood pressure, temperature, respiration, heart rate, pulse oximetry, creatinine, blood urea nitrogen, serum chloride, serum potassium, serum sodium, hemoglobin, white blood cell count, Braden score, and review of systems nursing assessments. Risk calculations based on these variables are integrated together to calculate an overall risk of hospital mortality, including the likelihood of mortality within 24 hours, and an estimated risk of hospital readmission within 30 days if the patient were to be discharged. Additionally, Rothman index scores for a given patient are recalculated during a hospital stay based on new information; therefore, it can also track patients’ health changes throughout a hospital admission.

The purpose of the current study was to understand how data from the EMR can be used to better understand and predict HAPU formation throughout the course of a hospital admission and determine if there are any changes reflected in the EMR data that can be identified as sentinel markers of future pressure ulcer acquisition, thereby allowing the potential to further reduce the incidence of pressure ulcer formation within a hospital setting.

METHODS

Data Collection

A case-control study design was employed under a protocol that had been reviewed and approved by the local institutional review board. All admissions during the period of December 1, 2014, to July 29, 2015, to Yale New Haven Hospital were included in this study that fulfilled the following criteria: patient 18 years old or older, length of stay longer than 2 days, patient had not opted to exclude medical records from research, and no documented code status of “Do Not Resuscitate” during the first 2 days of the admission. Patients also had to have Braden scores recorded and Rothman index scores calculated within the EMR.

Patients were included for this study if the nursing flow-sheet variable “HAPU” indicated “yes” for the patient’s admission. The HAPU had to have been first reported on or after hospital day 3. Previous history of pressure ulcers was determined by the presence of the following International Classification of Diseases, Ninth Revision (ICD-9) codes: 707.02, 707.03, 707.04, 707.05, 707.06, 707.07, 707.09, 707.20, 707.21, 707.22, 707.24, and 707.25.

Statistical Analysis

The Braden score and Rothman index values on the day of admission and on the day of ulcer formation were compared using a paired t test to study the overall trend of the volatility. Further data analysis was performed on patients who were categorized into the high-risk group (Braden score ≤18 both at admission and on the day of ulcer formation) and low-risk group (Braden score >18 both at admission and on the day of ulcer formation). Patients with Braden scores at admission that were >18 but ≤18 on the day of ulcer formation (or vice versa) were excluded from this analysis. There was no comparison to non-HAPU patients because these patients do not have a day of HAPU formation; therefore, these results represent overall trends.

A Cox regression analysis model was created using SPSS Statistics 24.0 (IBM, Armonk, N.Y.) to analyze and quantify the extent of the effect on the development of HAPUs. The Cox regression analysis included the following variables: age, history of previous pressure ulcers, Braden score on admission, Rothman index on admission, and SD values for each of the Braden score subcomponents (sensory, nutrition, moisture, mobility, friction and shear, activity) and for the Rothman index. Clinically, the SD was interpreted as the volatility of the Braden subcomponent scores and Rothman index. The Cox regression analysis allows for the multivariate analysis of various covariates and their specific effects while holding others constant, and it
reduces the impact of wide variability in lengths of hospital stay among patients. The Cox regression analysis was performed in repeated fashion with the unified data set, and the data set was divided into high risk (Braden score on admission $\leq 18$) and low risk (Braden score on admission $>18$). Using the same computer-assisted approach, ROC curve analysis was also performed for the admission Braden score and its subcomponent scores.

**RESULTS**

Based on the criteria outlined in the Methods section, our study included 8,790 separate admissions and 7,514 individual patients. The incidence of HAPUs in our cohort was 371, 4.2% over a period of 8 months (approximately 6.3% per annum). The average Braden score on admission was 20.1 ± 2.3 and the Rothman index was 79.7 ± 17.0. On admission, 83.2% of patients were deemed low risk (Braden score $>18$) and 15.8% were deemed high risk (Braden score $\leq 18$). Patients who developed HAPUs were older, predominantly male, and white, and had a length of stay that was longer by 28 days (Table 1). The Braden score and the Rothman index were lower on admission for patients who developed HAPU compared with non-HAPU patients.

Compared with the cohort that developed HAPUs, the average Braden score on admission was 16.3 ± 3.5 and average Rothman index was 52.1 ± 22.7 (Table 2). The average day of admission in which the pressure ulcer was acquired was hospital day 15.6 ± 19.3, and the most common location was in the sacrum/coccyx/ischial (52%) (Table 3).

**Table 1. Demographics of Both Cohorts (HAPU and Non-HAPU Patients)**

|                      | Non-HAPU Patients | HAPU Patients |
|----------------------|-------------------|---------------|
| Age, mean (SD)       | 50.3 (19.3)       | 63.2 (15.2)   |
| Length of stay, mean (SD) | 6.5 (7.1)       | 35.2 (37.4)   |
| Gender, frequency (%)|                   |               |
| Male                 | 5,548 (42.1)      | 210 (56.6)    |
| Female               | 4,871 (57.9)      | 161 (43.4)    |
| Race, frequency (%)  |                   |               |
| Asian                | 171 (2)           | 5 (1.3)       |
| African American     | 1,618 (19.2)      | 55 (14.8)     |
| White                | 5,487 (65.2)      | 275 (74.1)    |
| Native American      | 15 (0.2)          | 0 (0)         |
| Unknown/refused      | 1,128 (13.4)      | 36 (9.7)      |

The most common location was the coccxyx.

Overall, the admission Braden score ROC area under the curve was 0.163 (CI, 0.141–0.185) (Fig. 1).

**Table 2. Admission Braden Scores and Rothman Index for Both Cohorts (HAPU and Non-HAPU Patients)**

|                | Non-HAPU Patients | HAPU Patients |
|----------------|-------------------|---------------|
|                | Average | SD   | Average | SD   | $P$    |
| Braden score   | 20.3    | 2.1  | 16.3    | 3.5  | <0.01  |
| Sensory and    | 3.9     | 0.4  | 3.2     | 0.8  | <0.01  |
| perception     |         |      |         |      |        |
| Nutrition      | 3       | 0.4  | 2.5     | 0.6  | <0.01  |
| Moisture       | 3.8     | 0.4  | 3.5     | 0.6  | <0.01  |
| Mobility       | 3.5     | 0.5  | 2.7     | 0.8  | <0.01  |
| Friction and   | 2.9     | 0.3  | 2.3     | 0.6  | <0.01  |
| shear          |         |      |         |      |        |
| Activity       | 3.2     | 0.8  | 2       | 1    | <0.01  |
| Rothman index  | 79.7    | 17   | 52.1    | 22.7 | <0.01  |

**Table 3. Location of Hospital-acquired Pressure Ulcers**

| Location                     | Frequency (%) |
|------------------------------|---------------|
| Abdomen                      | 9 (2.4)       |
| Coccyx/sacrum/ischial        | 192 (51.8)    |
| Arms                         | 5 (1.3)       |
| Legs                         | 36 (9.7)      |
| Head                         | 75 (20.2)     |
| Genitals                     | 6 (1.6)       |
| Other/unknown                | 48 (12.9)     |

**Rothman Index and Braden Score Decrease over the Course of the Admission for HAPU Patients**

Among the patients who eventually developed HAPUs (n = 371) during their admission, the Braden score components and the Rothman index values decreased from the day of admission to the day of ulcer formation ($P < 0.01$) (Table 4). For patients who were classified as low risk (n = 46), the only statistically significant difference found between the admission and the day of ulcer formation Braden scores component and Rothman index values were the nutrition and mobility score ($P = 0.01$) [see table, Supplemental Digital Content 1, which displays the paired t tests between the admission and the day of ulcer formation Braden score (and subparts) for patients deemed lower risk (Braden score $>18$), http://links.lww.com/PRS-GO/A982]. For patients who were classified as high risk (n = 224), sensory perception, moisture, mobility, friction and shear, and the Rothman index ($P < 0.01$) decreased from the day of admission to the day of ulcer formation [see table, Supplemental Digital Content 2, which displays the paired t tests between the admission and the day of ulcer formation]

**Fig. 1. ROC of the Braden score on admission. The admission Braden score is not predictive of HAPU development as the area under the ROC curve is 0.163 (CI, 0.141–0.185).**
Volatility in Friction and Shear Is Predictive of HAPU Development

A ROC curve was calculated for the Braden score upon admission with the area under the curve being 0.865 (CI, 0.847–0.882) (Fig. 1). Using the standard cut-off for the Braden score for high risk of pressure ulcer development of 18, the sensitivity was 0.35 and the specificity was 0.10. The ROC curve was also calculated for the volatility of the friction and shear component, and the area under the curve was 0.865 (CI, 0.847–0.882) (Fig. 2). An SD of friction and shear component >0.16 units predicts pressure ulcer development with a sensitivity of 0.922 and a specificity of 0.241.

Utilizing survival analysis, like the Cox regression analysis, prevents bias from differences in lengths of stay between HAPU and non-HAPU patients (about 28 days longer for HAPU patients than non-HAPU patients).

Table 4. Multivariable Cox Regression Analysis Model for Pressure Ulcer Risk Factors

| Risk Factor          | Admission | Ulcer | Δ   | P   | 95% Confidence Interval |
|----------------------|-----------|-------|-----|-----|-------------------------|
| Sensory perception   | 3.24      | 3.60  | 0.24| <0.01| 0.14–0.33               |
| Nutrition            | 2.49      | 2.56  | 0.07| <0.01| 0.04–0.21               |
| Moisture             | 3.47      | 3.12  | 0.35| <0.01| 0.20–0.42               |
| Mobility             | 2.71      | 2.43  | 0.28| <0.01| 0.20–0.36               |
| Friction and shear   | 2.54      | 2.03  | 0.51| <0.01| 0.24–0.38               |
| Activity             | 2.02      | 1.74  | 0.27| <0.01| 0.16–0.38               |
| Rothman index        | 52.1      | 41.7  | 10.46| <0.01| 7.93–12.99              |

The Cox regression analysis demonstrated that the friction and shear component of Braden scores had a risk ratio of 28.596 ($P < 0.01$; CI, 14.49–56.42), meaning an increase of 1.0 in the SD of the friction and shear component was associated with 28.6-fold increase in HAPU risk. $\Delta =$ Total decrease from day of admission to day of ulcer formation.

DISCUSSION

It is common practice for Braden scores to be assessed by nurses and certified nursing assistants. Despite high-quality training, the documentation of HAPU risk remains inherently subjective; however, to our knowledge, this study is one of the first that looks at how these assessments are used in actual clinical practice over a large number of admissions and their relationship to actual HAPU development.

The admission Braden score is not predictive of HAPU development as the Cox regression analysis does not indicate the Braden score on admission to be a statistically significant variable ($P = 0.17$; CI, 0.924–1.014) and the area under the ROC curve was low at 0.163 (CI, 0.141–0.185) (Fig. 1). This is probably due to proper risk stratification and appropriate nurse intervention in response to the initial Braden score calculated at the time of admission. At the cut-off score of 18, the sensitivity and specificity of the
Braden score upon admission are relatively low with the sensitivity and specificity being 0.35 and 0.10, respectively. In comparison, an initial clinical trial of the Braden score (using a cut-off score 18) had a reported sensitivity and specificity of 0.92 and 0.39, respectively.6

The SD, as a measure of volatility, was used to track changes in a given patient’s status over the course of a given hospital stay. Metrics indicating the SD, or volatility, have been commonly used in other settings to track overall status of stocks and investment portfolios over time and assist with decision-making, so we applied a similar data analysis approach for this study. Increased volatility in the friction and shear component on admission was not very predictive of HAPUs with a risk ratio of 28.6 for all patients in the study. This signifies that a change of 1 point in the SD of friction and shear component increased the association of the development of HAPUs by almost 294-fold. The predictive ability of the volatility of friction and shear applied to both high- and low-risk patients as shown by the risk ratio of 62.5 and 6.4, respectively (P < 0.01). Previous studies have demonstrated how predictive the admission Braden score can be and that admission friction and shear has a similar predictive ability with a similar ROC curve. However, these previous studies did not account for the impact of clinical intervention to prevent HAPUs. The current study is the first to do so and address the impact of volatility in HAPU metrics for the course of a hospital admission.

The Cox regression analysis is a multivariate analysis which allows for the analysis of an effect while taking into account other variables compared with the ROC analysis, a common method for analyzing Braden scores but which includes only 1 variable. The ROC curve for the friction and shear component on admission was not very predictive (0.245; CI, 0.214–0.275), probably reflecting the impact of nursing interventions. In contrast, the SD of friction and shear throughout admission was predictive of the development of HAPU as shown in the ROC curve area of 0.865 (CI, 0.847–0.882), which is similar to ROC curves from previous studies on Braden score analyses. Using the ROC curve calculated from our data in the current study, the sensitivity and specificity were optimized at 0.922 and 0.241, respectively when the SD of the friction and shear component was >0.16 units.

The Cox regression and ROC curve analyses demonstrate that increases in volatility within the friction and shear component increase risk of HAPU formation and are also predictive of HAPU formation. The trends of the changes of the friction and shear components of the Braden score were studied in the HAPU patients. Therefore, the admission friction and shear scores were compared to the friction and shear scores on the day of HAPU formation. This demonstrated a trend to overall decline in patients according to paired t tests (Table 4).

Among the limitations of this study are its retrospective nature. To better account for the variability among patient factors (age, length of stay, etc.), the study includes both an ROC curve analysis and Cox regression analysis. The ROC curve allows us to compare our analysis to previously published reports, but it does not allow for analysis of multiple effects; therefore, it can overestimate the predictability of a test. We addressed this by including the Cox regression analysis to study the different parameters. Utilizing survival analysis, like the Cox regression analysis, also prevents bias from the differences in lengths of stay between HAPU and non-HAPU patients (about 28 days longer for HAPU patients than non-HAPU patients).

This study demonstrates that across all patients, whether high or low risk for HAPU formation, the volatility of friction and shear component is the most predictive of HAPU formation. It is the first study, to our knowledge, to statistically evaluate the Braden score, in its current practice, and the friction and shear subcomponent in predicting HAPU formation. The friction and shear component had a greater predictive value than overall health as measured by the Rothman index. Therefore, it may benefit patients if clinical protocols were developed that paid more attention to the volatility in the friction and shear component, thereby achieving further reductions in HAPU incidence. For example, the EMR can be configured to allow real-time tracking of friction and shear score volatility for specific patients with an alert triggered when the volatility exceeded a predetermined evidence-based threshold, which in turn would lead to focused attention and mitigating interventions by hospital staff.

**CONCLUSIONS**

The admission Braden score was not predictive of HAPU development as the area under the ROC curve is 0.163 (CI, 0.141–0.185) reflecting the effectiveness of cur-

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### Table 5. Braden Score (and Subparts) at the Day of Admission and Day of Ulcer Formation

| Variable                        | B    | SE   | Wald  | df | P     | Exp(B) | 95% CI for Exp(B) Lower | Upper |
|---------------------------------|------|------|-------|----|-------|--------|-------------------------|-------|
| Age                             | 0.012| 0.003| 14.423| 1  | <0.001| 1.012 | 1.006                   | 1.019 |
| History of previous pressure ulcers | 0.273| 0.159| 2.951 | 1  | 0.087 | 1.314 | 0.961                   | 1.795 |
| Braden score on admission       | -0.015| 0.003| 21.904| 1  | <0.001| 0.985 | 0.978                   | 0.991 |
| Rothman index on admission      | 0.743| 0.267| 7.741 | 1  | 0.005 | 2.103 | 1.246                   | 3.55  |
| Sensory SD                      | 0.354| 0.316| 1.253 | 1  | 0.263 | 1.424 | 0.767                   | 2.646 |
| Nutrition SD                    | 0.399| 0.31| 1.652 | 1  | 0.199 | 1.49  | 0.811                   | 2.738 |
| Mobility SD                     | -0.661| 0.293| 5.085 | 1  | 0.024 | 0.516 | 0.291                   | 0.917 |
| Friction and shear SD           | 3.555| 0.347| 95.55 | 1  | <0.001| 28.396| 14.494                  | 56.417|
| Activity SD                     | -0.542| 0.206| 6.905 | 1  | 0.009 | 0.582 | 0.388                   | 0.871 |
| Rothman index SD                | 0.004| 0.011| 0.165 | 1  | 0.685 | 1.094 | 0.984                   | 1.025 |

P values calculated from paired t tests. B, coefficient value; SE, standard error; df, degrees of freedom; and Exp(B), exponentiation of B coefficient, or risk ratio.
rent clinical protocols to prevent HAPU formation. Overall, the score of friction and shear declines from the day of admission to the day of ulcer formation. The volatility of friction and shear during admission with an ROC curve area of 0.865 (CI, 0.847–0.882) was the most predictive for the development of HAPU. An increase in the SD of friction and shear of 1.0 is associated with 28.60-fold increase in the risk of developing pressure ulcers, with the same trends seen in both high- and low-risk patients. More effective protocols can be developed through EMR capabilities using evidence-based criteria to allow detection of increased volatility in friction and shear scores, thereby allowing a timely and appropriate corrective response.

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