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Using Pressure Mapping to Optimize Hospital-Acquired Pressure Injury Prevention Strategies in the Burn Intensive Care Unit

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Although prior studies have demonstrated the utility of real-time pressure mapping devices in preventing pressure ulcers, there has been little investigation of their efficacy in burn intensive care unit (BICU) patients, who are at especially high risk for these hospital-acquired injuries. This study retrospectively reviewed clinical records of BICU patients to investigate the utility of pressure mapping data in determining the incidence, predictors, and associated costs of hospital-acquired pressure injuries (HAPIs). Of 122 patients, 57 (47%) were studied prior to implementation of pressure mapping and 65 (53%) were studied after implementation. The HAPI rate was 18% prior to implementation of pressure monitoring, which declined to 8% postimplementation (chi square: $P = .10$). HAPIs were less likely to be stage 3 or worse in the postimplementation cohort ($P < .0001$). On multivariable-adjusted regression accounting for known predictors of HAPIs in burn patients, having had at least 12 hours of sustained pressure loading in one area significantly increased odds of developing a pressure injury in that area (odds ratio 1.3, 95% CI 1.0–1.5, $P = .04$). Patients who developed HAPIs were significantly more likely to have had unsuccessful repositioning efforts in comparison to those who did not ($P = .02$). Finally, implementation of pressure mapping resulted in significant cost savings—$6750 (standard deviation: $1008) for HAPI-related care prior to implementation, vs $3800 (standard deviation: $923) after implementation, $P = .008$. In conclusion, the use of real-time pressure mapping decreased the morbidity and costs associated with HAPIs in BICU patients.

Burn patients in the burn intensive care unit (BICU) are particularly vulnerable to hospital-acquired pressure injuries (HAPIs).[1] To be admitted to the BICU, burn patients typically have substantial partial- or full-thickness burns, which can be further complicated by preexisting medical comorbidities and concomitant injuries. In addition to these complex clinical presentations, BICU patients have a number of risk factors for HAPIs, including increased nutritional needs, decreased tissue perfusion, edema, moisture, and longer lengths of stay than other populations of hospitalized patients.[1] Furthermore, many of the treatments used for burn injury have been found to increase the risk of HAPIs, including large-volume resuscitation, splinting, immobilization, and repeat operations for wound therapy.[2] Prior literature has reported HAPI rates of up to 50%[3] in BICU patients, compared to 30.6% in ICU patients overall and 3 to 14% in all hospitalized patients.[4] This increased rate of HAPIs translates to greater costs of care among BICU patients, with reports of charges up to $70,000 per patient.[5] Deeter et al[6] demonstrated that among adult burn survivors, hospital-acquired complications result in poorer overall longitudinal outcomes. Thus, measures to reduce HAPI rates in this at-risk patient population can have a substantial clinical and economic impact.

Traditional HAPI preventive measures are not always possible in BICU patients. For instance, a common practice to prevent HAPIs involves repositioning the patient at interval time points in order to redistribute the pressure load off of vulnerable areas.[7] In BICU patients, however, burn injuries and skin grafts complicate the process of repositioning. Other preventive interventions that are traditionally used, including support surfaces and splinting devices, are also difficult to implement in the BICU due to the patients' underlying burn injuries and health issues. Thus, not only are these patients at greater baseline risk, they also have limited preventive options available.

In burn patients, devices that allow for full-body, real-time pressure monitoring have two major benefits. First, these devices can help in preventing pressure injuries by alerting patients and providers to high-pressure areas. This is especially important because compromise of the skin due to burn injury results in diminished perceptions of pressure. Second, by specifically pinpointing high-pressure areas, pressure monitoring devices can help to guide repositioning efforts for maximum benefit while preventing further damage to areas compromised by burn injury.

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were considered to be in the postimplementation cohort. Patients with missing inpatient data were excluded from study analyses. Among patients in the postimplementation cohort who underwent real-time pressure monitoring with the Wellsense Vu™ pressure mapping device, those who were missing mapping data during their inpatient stay were excluded.

Clinical Variables of Interest

Patients' demographic and baseline clinical characteristics (comorbidities, tobacco history) for both preimplementation and postimplementation cohorts were abstracted from the medical record. Clinical variables of interest regarding the burn injury included location, percent total body surface area (%TBSA) affected, degree of burn, surgical burn treatments, immobilization, mechanical ventilation status, and ICU length of stay. Clinical variables of interest with regard to pressure injuries among patients who developed HAPIs included Braden scores on admission, Braden scores at the time of HAPI development, HAPI stage, and HAPI location. Only pressure injuries that developed during the inpatient stay and that were not present on admission were considered in study analyses. Costs of HAPI-related care were also tabulated among patients who developed pressure injuries, including costs of surgical debridement, negative pressure wound therapy ($100 per day), and air fluidized therapy beds.

Pressure Mapping Data

Among patients in the postimplementation time period, Wellsense Vu™ pressure mapping data were downloaded in 30-minute intervals across each patient's entire burn ICU admission. Because prior literature has demonstrated that pressure injuries can begin to develop within 6 hours of sustained pressure loading,[8] pressure mapping data were converted into categorical format[9]and analyzed in 6-hour time periods from the time of admission. For each 6-hour period, the proportion of readings in each pressure category (high, medium, and low) was recorded, in four anatomic areas known to be at greatest risk for HAPI that could be monitored using Wellsense outputs (sacrum, occiput, elbows, and heels).[10]

Statistical Analyses

All statistical analyses were performed using Stata version 15.0 (StataCorp, College Station, TX). Cases with missing demographic or clinical data were excluded from analyses. Categorical data were presented as counts and percentages. All continuous variables were evaluated for normality using the Schapiro–Wilk test: Data with a normal distribution were presented as mean and standard deviations (SDs), while non-normal data were presented as medians and interquartile ranges (IQRs). Parametric testing (chi square, analysis of variance) or non-parametric (Fischer's exact, Kruskal–Wallis) testing was used as appropriate to compare demographic and clinical characteristics of HAPIs between pre- and postimplementation cohorts. Multivariable logistic regression with a stepwise forward selection of predictor variables was used to determine risk factors for HAPIs among the available pressure mapping data. A P value of less than .05 was considered significant for all analyses. Post-hoc power analyses were undertaken to evaluate the retrospective findings. All findings were reported in accordance with standards set by the International Committee of Medical Journal Editors.

RESULTS

In total, 136 burn ICU patients met inclusion criteria during the study period, of whom 14 were excluded for missing data. Of the 122 patients included, 57 (47%) were studied prior to implementation of pressure mapping and 65 (53%) were studied after implementation.

Patient Demographics and Clinical Characteristics

Patients in the preimplementation vs postimplementation cohorts were well-matched in terms of demographics (Table 1). Overall, the mean patient age among burn ICU patients across both preimplementation and postimplementation cohorts was 50.3 years (*SD*: 18.2 years). Sex, race, body mass index, presence of comorbidities, and smoking history did not vary between pre- vs postimplementation study cohorts.

Burn injury characteristics were also similar in preimplementation vs postimplementation cohorts (Table 2). Overall, the median %TBSA was 4% (IQR: 2–8%) and the median length of BICU stay across all study patients was 4 days (IQR: 2–10 days). The median length of stay among patients who developed HAPIs was 8 days (IQR: 6–10 days). These metrics did not significantly differ between study cohorts.

Pressure Injury Characteristics and Treatment Costs

The HAPI rate was 18% (n = 10) prior to implementation of pressure monitoring, but declined to 8% (n = 5) after implementation of pressure monitoring (chi square: P = .10). Median Braden scores did not significantly differ between

Table 1. Demographics and baseline patient characteristics

	Preimplementation (n = 57)	Postimplementation (n = 65)	*P*
Age, mean (*SD*)	50.3 ± 1.4	50.3 ± 2.4	.98
Sex, n (%)			.73
Male	25 (44)	31 (48)	
Female	32 (56)	34 (52)	
Race, n (%)			.94
White	33 (58)	34 (52)	
Black	18 (32)	26 (40)	
Hispanic	4 (7)	4 (6)	
Asian	1 (1)	1 (2)	
Other	1 (1)	0 (0)	
Mean BMI (*SD*)	29.7 (8.2)	31.6 (7.0)	.18
Comorbidities, n (%)			
Diabetes	14 (25)	18 (28)	.69
Hypertension	27 (47)	28 (43)	.63
Tobacco history, n (%)	19 (33)	26 (40)	.45

BMI, body mass index; *SD*, standard deviation.

The ability to assess real-time pressure in areas susceptible to pressure injury has the potential to significantly improve the efficacy of preventing debilitating and costly HAPIs in the BICU. While prior studies have investigated the use of real-time pressure monitoring in medical ICU patients, none have specifically investigated this technology in BICU patients. As previously mentioned, these patients have the potential to uniquely benefit from this technology, given their substantial soft tissue burn injuries. Thus, the purpose of this study was twofold. First, we wanted to understand the utility of real-time, full-body pressure monitoring in preventing HAPIs in the BICU patient population. Second, we aimed to use pressure monitoring data to better understand the development of pressure injury in this vulnerable patient population. By doing so, we hoped to determine metrics by which to risk-stratify burn ICU patients for HAPIs in the context of their pressure monitoring data.

METHODS

This was a Johns Hopkins Medicine Institutional Review Board-approved (IRB Number: IRB00241324) single-institution, retrospective investigation of BICU patients at the Johns Hopkins Bayview Medical Center, a tertiary care hospital. Two patient cohorts were defined: 1) those who were admitted before and 2) those who were admitted after implementation of real-time pressure monitoring in the burn ICU. The Johns Hopkins Bayview BICU began using the Wellsense Vu™ device (Wellsense Inc., Nashville, TN) in fall 2019, in light of relatively high-pressure injury rates among burn ICU patients (~15% of all admitted BICU patients), despite the implementation of standard clinical prevention measures. At the time that Wellsense technology was purchased for use in our BICU, it was the only full-body, continuous pressure mapping system available on the market. We had previously trialed smaller pressure maps to measure pressure over specific anatomic regions (eg, sacrum, occiput), but we found that these non-continuous, localized systems did not provide enough information to effectively allow for pressure redistribution in BICU patients, given their substantial burn injuries. As of February 2021, there are other available full-body pressure maps (eg, Tactilus Bodyfitter System, Tekscan Body Pressure Measurement System, Blue Chip MeasureX Mattress, BodiTrak2), but the Wellsense device is the most widely used/studied device in the medical literature, and not all available full-body systems provide real-time, continuous data.

In the preintervention time period, only standard clinical HAPI prevention measures were used. These included encouraging patients to shift in position at regular 15 minutes intervals or turning patients every 2 hours if they were incapable of shifting position themselves. These repositioning interventions were undertaken as possible in light of patients' burn injuries. In addition, the redistribution of pressure away from bony prominences occurred using pillows, wedges, and air cushions as needed. Appropriate moisture management precautionary measures were undertaken for wound sites. Other preventive interventions included ensuring that patients' metabolic needs were met through regular monitoring of plasma pre-albumin levels and other indicators of nutritional status by a registered dietician.

In the postintervention time period, the aforementioned clinical prevention measures were used in conjunction with the Wellsense Vu™ pressure monitoring system. The Wellsense Vu™ is a pressure visualization system that visually maps pressure recordings using a color-based system, where red indicates high pressure (greater than 75 mm Hg), yellow/green indicates medium pressure (10–75 mm Hg), and blue corresponds to low pressure (less than 10 mm Hg; Figure 1). The Wellsense Vu™ is designated as a class I medical device by the Food and Drug Administration and consists of a pressure sensing mat along with a controller unit that produces the digitized pressure maps. The mat is placed inside the mattress liner and consists of sensors (1 square inch each) that can detect pressure levels between 0 and 180 mm Hg. Pressure readings from each sensor are continuously recorded and transmitted to the controller unit, which then generates and presents a pressure map. All burn center nurses received education related to the use of the pressure mapping system and clinical indications for its use during mandatory clinical in-servicing of the equipment. BICU nurses used the pressure map data to pinpoint specific focal areas for targeted pressure redistribution when completing routine clinical repositioning protocols and to determine whether the clinical position change was effective. BICU nurses were instructed to reposition or offload the patient to minimize pressure readings in high-risk zones (bony prominences, areas with substantial soft tissue loss, etc.) as much as possible without compromising areas of burn injury.

Study Population

All adults 18 years or older who were admitted to the BICU for burn injuries between May 2019 and May 2020 were considered for study inclusion. Those who were admitted between May 2019 and September 2019 were considered to be in the preimplementation cohort, while those who were admitted between October 2019 and May 2020

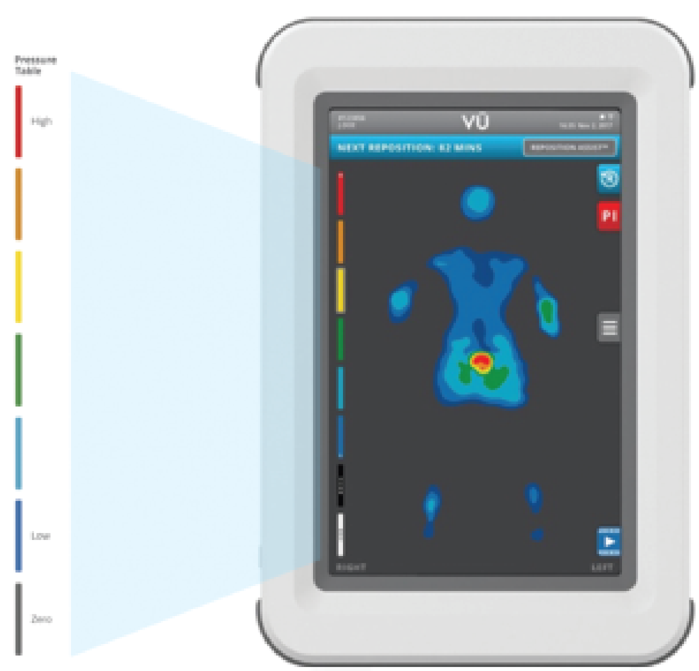

Figure 1. Wellsense Vu™ controller unit and pressure grading color scale.

Table 2. Burn injury details

	Preimplementation (n = 57)	Postimplementation (n = 65)	P
Burn location, n (%)			
Head/neck	16 (28)	15 (23)	.53
Trunk	11 (19)	16 (25)	.48
Upper extremity	14 (25)	18 (28)	.69
Groin/buttocks	5 (9)	5 (8)	.83
Lower extremity	11 (19)	16 (25)	.48
Median %TBSA (IQR)	3.5 (6.5)	4.1 (8.2)	.66
Third-degree burn, n (%)	24 (42)	27 (42)	.95
Surgical treatment, n (%)	25 (44)	30 (46)	.80
Immobility, n (%)	13 (23)	13 (20)	.71
Mechanical ventilation, n (%)	7 (12)	9 (14)	.80
Median length of stay (IQR)	3 (8)	4 (7)	.14

TBSA, total body surface area; *IQR*, interquartile range.

Table 3. Pressure injury details

	Preimplementation (n = 10)	Postimplementation (n = 5)	P
HAPI location, n (%)			1.0
Sacrum	8 (80)	4 (80)	
Occiput	1 (10)	1 (20)	
Elbows	0 (0)	0 (0)	
Heels	1 (10)	0 (0)	
Median Braden score (IQR)			
Admission	15 (6)	14 (7)	.45
Time of HAPI	16 (5)	14 (7)	.73
HAPI stage*, n (%)			**<.0001**
1	1 (10)	3 (60)	
2	7 (70)	2 (40)	
3 or worse (including deep tissue injuries)	2 (20)	0 (0)	
Mean cost, HAPI care (*SD*)	$6750 ($1008)	$3800 ($923)	**.008**
Median length of stay (IQR)	8 (2)	9 (1)	.87

HAPI, hospital-acquired pressure injury; *SD*, standard deviation; *IQR*, interquartile range.
Bold values are statistically significant ($P < .05$).
*Highest stage to which the wound progressed.

cohorts, Most HAPIs were noted in the sacral region (80%). However, in the preimplementation cohort, most patients (70%) had stage 2 HAPIs, while in the postimplementation cohort, most patients (60%) had stage 1 HAPIs. In fact, the distribution across HAPI stages differed significantly between pre- vs postimplementation timepoints ($P < .0001$; Table 3). Additionally, implementation of real-time pressure monitoring in the BICU resulted in significant HAPI-related cost savings (mean cost of $6,750, *SD*: $1008, for HAPI-related care prior to implementation, vs $3800, *SD*: $923, after implementation; $P = .008$). Across patients with HAPIs in both study cohorts, time from admission to pressure injury was shorter in the preimplementation time period than in the postimplementation time period, though this association only achieved borderline statistical significance (4.5 ± 1.7 days to HAPI development vs 6.5 ± 2.0 days to HAPI development, respectively, $P = .06$).

Pressure Mapping Results

Pressure mapping results were analyzed in the postimplementation cohort. When comparing patients who developed HAPIs to those who did not, pressure mapping demonstrated that patients who developed HAPIs were significantly more likely to have had unsuccessful repositioning efforts prior to HAPI development, defined as persistent high pressure in at-risk areas despite repositioning (60 vs 17%, respectively; $P = .02$; Figure 2). Furthermore, on multivariable-adjusted regression with stepwise inclusion of known predictors for HAPIs in burn patients (BMI, length of stay, comorbidities, age, %TBSA burned, mobility),[11,12] having had at least 12 hours of sustained pressure loading in one area significantly increased odds of developing a pressure injury in that area (adjusted odds ratio 1.3, 95% confidence interval 1.0–1.5, $P = .04$; Figure 3). It should be noted that patients who developed HAPIs in the postimplementation cohort were significantly more likely to have a higher BMI and more serious burn injuries than those who did not (Table 4).

Post-Hoc Power Analyses

Given the retrospective nature of the investigation, post-hoc power analyses were undertaken for the two primary study objectives. When comparing HAPI incidence in pre- vs

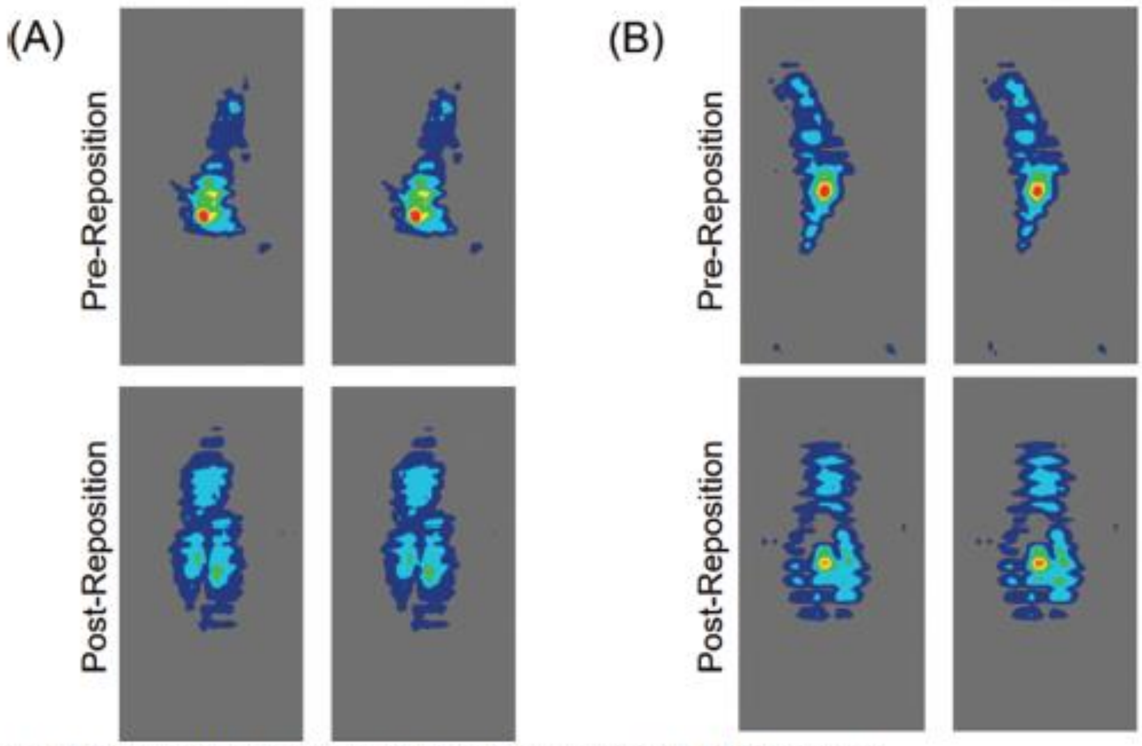

Figure 2. Example of (A) a successful unloading procedure vs (B) an unsuccessful unloading procedure.

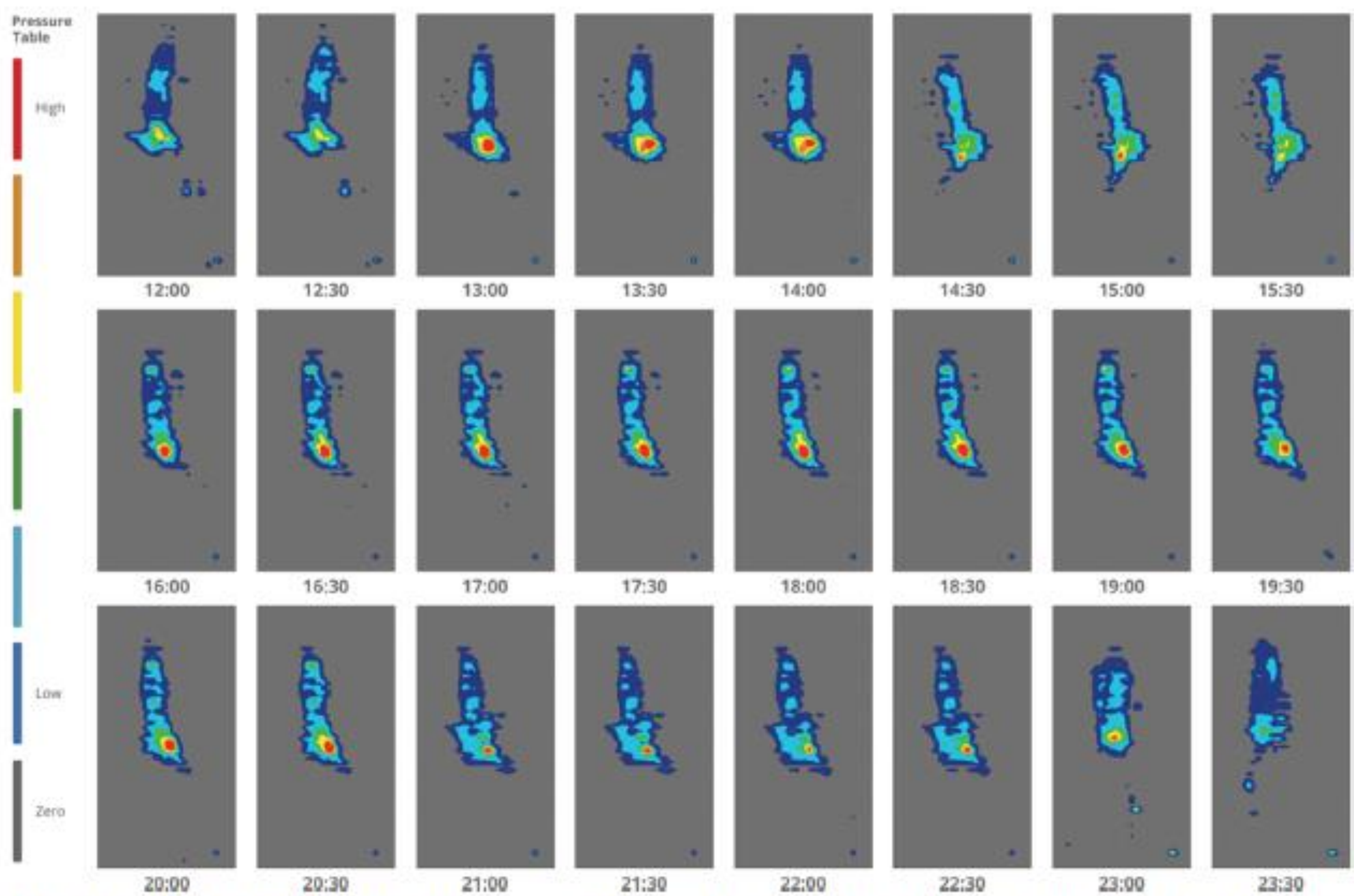

Figure 3. Example of 12 hours of continuous pressure loading in the sacral area, in a patient who developed a stage 2 hospital-acquired pressure injury in this region.

postimplementation patient cohorts, the effect size (15.8% preimplementation vs 4.6% postimplementation) and the available retrospective sample size (n = 57 preimplementation and n = 65 postimplementation) provided a study power of 0.52 for chi-square analyses. When comparing pressure distributions between patients who developed pressure injuries

Table 4. Patient risk factors for HAPI in postimplementation cohort

	No HAPI (n = 60)	HAPI (n = 5)	*P*
Mean BMI (*SD*)	29.1 (2.1)	31.2 (2.9)	**.04**
Median %TBSA (IQR)	3.2 (4.9)	4.9 (5.7)	.46
Third-degree burn, n (%)	24 (35)	4 (80)	**.05**
Surgical treatment, n (%)	27 (45)	3 (60)	.52
Comorbidities, n (%)			
Diabetes	16 (27)	2 (40)	.52
Hypertension	25 (42)	2 (40)	.94
Tobacco history, n (%)	24 (40)	2 (40)	1.0

HAPI, hospital-acquired pressure injury; *SD*, standard deviation; *IQR*, interquartile range.
Bold values are statistically significant ($P < .05$).

(n = 5) vs those who did not (n = 60), the available retrospective sample provided a study power of 0.8 for adjusted multivariable logistic regression.

DISCUSSION

BICU patients are more susceptible to HAPIs than other inpatient populations. This is due to a combination of multiple clinical risk factors secondary to the burn injury itself, including poor perfusion, immobility, and soft tissue edema, as well as due to clinical risk factors as a result of treatment for the burn injury, such as high-volume resuscitation (which can worsen edema) and need for frequent surgical debridement. In such patients, standard precautions for HAPIs, such as periodic clinical repositioning, may not be sufficient or clinically feasible, especially in those with more extensive burn injuries. Therefore, this patient population requires careful, specific consideration for HAPI prevention and may uniquely benefit from the implementation of additional technologies designed to avoid HAPIs, such as real-time pressure monitoring.

Our results demonstrated that implementation of real-time pressure monitoring in the BICU may reduce the incidence of HAPIs, though this finding did not reach statistical significance due to our underpowered retrospective study sample. However, we did find that costs of HAPI-related care in the BICU decreased significantly in the postimplementation timepoint and that HAPIs in the postimplementation cohort were significantly less likely to be as severe as in the preimplementation timepoint. These trends were similar to those reported in prior literature investigating real-time pressure monitoring in the medical ICU and may reflect improved repositioning efforts as a result of real-time pressure monitoring. In fact, in a 2013 survey of ICU providers, a majority agreed that real-time pressure monitoring increased the efficiency of repositioning[13] and prior literature has also demonstrated that the visual feedback provided by these pressure monitoring devices improved proficiency in preventative repositioning.[14] Similarly, in our study, the implementation of pressure monitoring may have helped to reduce both morbidity and costs of HAPIs in the BICU by helping to optimize repositioning efforts in BICU patients. Furthermore, our data demonstrated that real-time pressure monitoring had a clinical benefit even in patients who developed HAPIs, given that on average patients who developed HAPIs in the postimplementation cohort had longer times to HAPI development than in the preimplementation cohort. This suggests that real-time pressure monitoring helped to slow the HAPI development/progression by minimizing pressure as clinically feasible.

Among patients in our study who developed HAPIs, even after the implementation of real-time pressure monitoring, we found that repositioning efforts were significantly more likely to have been unsuccessful. Even though the pressure maps for these patients demonstrated a change in position, patients continued to experience high loading pressures in the location where they eventually developed a pressure injury. It is possible that these patients had greater limitations restricting adequate repositioning due to their more serious burn injuries. These patients tended to have higher BMIs, thereby increasing their baseline risk for pressure injury. Though implementation of pressure mapping was not able to prevent pressure injury in these patients, the fact that these patients continued to have sustained pressure loading in areas at risk for pressure injury, despite repositioning efforts, may help providers to use such pressure mapping results to risk-stratify BICU patients even prior to HAPI development. In such patients, more intensive HAPI prevention regimens may be necessary and cost-effective, such as the use of therapeutic bed systems prior to HAPI development.

Our results hold multiple clinical and economic implications. As previously mentioned, hospital-acquired complications affect long-term outcomes in BICU patients.[6] Thus, real-time pressure monitoring has the potential to reduce longitudinal morbidity in this patient population. The use of real-time pressure monitoring to avoid HAPIs and reduce associated costs of care is especially important in the current cost-conscious healthcare climate. In fact, in Maryland, hospitals with high rates of hospital-acquired conditions are monetarily penalized. Thus, the costs of implementing such preventive technologies, in addition to standard clinical interventions, especially in high-risk BICU populations, may be economically beneficial to hospital systems overall. Further investigation of the specific cost-utility of real-time pressure monitoring in BICU patients is necessary, especially given that more full-body, real-time pressure mapping devices are now available on the market.

This study was not without limitations. First, its retrospective design limited external validity and the retrospective sample size was underpowered to detect significance for our primary study outcome. However, the study sample was still powered to detect certain HAPI-related differences as a result of the implementation of pressure monitoring. Furthermore, this is one of the largest investigations of real-time pressure monitoring in BICU patients, a particularly vulnerable population for HAPIs. This study was also limited by the availability of study data. Given that data were retrospectively collected, we could not specifically determine whether unsuccessful repositioning efforts in HAPI patients in the postimplementation cohort were due to clinical factors such as the extent of burn injury or due to external factors such as patient noncompliance. Future prospective, randomized investigations would help to better characterize the specific risk profile of BICU patients who do not respond to standard clinical repositioning efforts based on pressure monitoring data.

Overall, this study demonstrated that real-time pressure monitoring can have important implications for HAPI prevention in BICU patients. Based on the results of our study, providers should take extra precautions in BICU patients who do not respond to repositioning efforts based on pressure monitoring, as these patients may be at higher risk for HAPIs. Our study results also highlighted multiple areas for further investigation. For instance, there is debate in prior literature regarding optimal repositioning strategies in patients at risk for HAPIs, including the ideal frequency of repositioning. Less frequent repositioning has been demonstrated to improve the quality of life of patients as it decreases the interruption of activities of daily living and provides for uninterrupted sleep time. Less frequent positioning is also associated with decreased risk of staff injury secondary to a reduction in the lessened physical burden associated with turning patients.[15,16] In the high-risk BICU population, future multi-site, prospective investigations of real-time pressure monitoring can help to optimize the use of this technology with regard to repositioning efficacy and frequency. Such data could be used to generate patient-specific repositioning protocols through live feedback pressure monitoring.

CONCLUSION

Real-time pressure mapping helped to reduce HAPI-related morbidity and costs of HAPI-related care among BICU patients. By correlating pressure mapping data with the development pressure injury, we used the results of our study to determine specific metrics that confer risk for HAPIs over time. By doing so, we hoped to help providers risk-stratify BICU patients for HAPIs using pressure mapping data, in order to help generate a series of best practices with regard to the use of real-time pressure monitoring to prevent HAPIs in the BICU population.

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