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A Continuous Bedside Pressure Mapping System for Prevention of Pressure Ulcer Development in the Medical ICU: A Retrospective Analysis

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this study.*

Abstract: *Objective.* Patient repositioning to offload high-pressure areas is an essential component of pressure ulcer prevention for bed-bound patients. In most settings, the quantity and quality of offloading and repositioning are difficult to measure. Real-time continuous bedside pressure mapping (CBPM) offers an opportunity to do so. *Material and Methods.* Data was collected on 627 patients being treated in a medical intensive care unit (MICU): 307 patients placed on beds with a CBPM system and 320 historical controls placed on the same beds without the CBPM system 1 year prior to the study participants. A pressure ulcer prevention bundle was enhanced by the addition of a CBPM system that provides real-time digital imaging of the patient on the support surface to National Pressure Ulcer Advisory Panel guidelines. *Results.* During the 2-month study period, 1 (0.3%) patient in the CBPM cohort developed a pressure ulcer compared with 16 (5%) patients in the historical cohort ($P=0.001$). In a survey of the MICU care providers, 90% of respondents reported that the CBPM contributed to improved pressure detection and relief, 88% indicated the CBPM assisted them with repositioning protocols, and 84% reported the pressure map provided for more efficient and effective patient repositioning. *Conclusion.* Real-time, ongoing pressure measurement using a pressure-sensing mat may be a useful tool to help care providers effectively reposition patients within the context of existing standardized protocols for the prevention and minimization of pressure ulcers.

Key words: pressure ulcer, decubitus ulcer, prevention, pressure mapping

The International Pressure Ulcer Prevalence Survey has estimated the prevalence of hospital-acquired pressure ulcers at 5% annually.¹ In that survey, hospital-acquired pressure ulcer prevalence was highest in adult intensive care units (ICUs), ranging from 9.2% in cardiac ICUs to 12.1% in medical ICUs (MICUs). It is estimated that pressure ulcer care accounts for \$2.41 billion in excess health care costs in the United States.² The additional care required for pressure ulcers and associated

KEYPOINTS

- The authors' hospital reintroduced a NPUAP-based pressure ulcer prevention bundle in January 2011.
- As part of this effort, the authors' hospital piloted a program specifically for the MICU because of the higher rate of hospital-acquired pressure ulcers.
- A continuous bedside pressure mapping system was chosen to provide real-time imaging of the patient on the support surface.

complications (such as infection) also contributes to increased length of hospital stay and mortality.^{3,4}

Preventing the development of pressure ulcers in health care settings has become increasingly important. Research and innovation presently focuses on pressure ulcer pathophysiology and factors contributing to their development. Furthermore, as of October 2008, acute care hospitals in the United States have financial incentives to prevent hospital-acquired pressure ulcers. The Center for Medicare and Medicaid Services (CMS) no longer reimburses hospitals at a higher rate for the care of hospital-acquired stage III and stage IV pressure ulcers billed as a secondary diagnosis.^{5,6} Numerous evidence-based guidelines and protocols exist for pressure ulcer intervention.⁷ Today, most hospital facilities assess pressure ulcer risk within 24 hours of a patient's admission (followed by periodic reassessments) to determine individualized care plans for patients at risk for developing a pressure ulcer. The Braden Scale for Predicting Pressure Ulcer Risk⁸ is one of the most frequently utilized risk assessment tools for pressure ulcers.⁹ The National Pressure Ulcer Advisory Panel (NPUAP) guidelines are commonly used to develop care plans for pressure ulcer prevention and treatment.⁹

Pressure ulcer prevention protocols include regular repositioning of at-risk patients, use of pressure redistributing surfaces, skin protection, moisture control, and nutritional support.^{9,10} Repositioning the patient to offload areas of high pressure is an essential component of pressure ulcer prevention. However, it is not clear which repositioning protocols are most effective for preventing pressure ulcers. A systematic review found insufficient evidence to recommend any specific turning regimens for patients with impaired mobility.¹¹ Turning every 2 hours is the most common consensus-based repositioning recommendation.^{11,12} However, because this is more dogma than an evidence-based recommendation, experts have trouble supporting this

most universal tenet of patient repositioning.¹²

While turning patients every 2 hours is intuitive, real-world intervention is not always straightforward. Not all patients are willing or able to completely turn from one side to the other and stay in a given position for 2 hours. In most cases, caregivers are repositioning or off-loading at-risk areas of the body using such means as pillows and wedges to relieve pressure at specific sites and to prevent the patient from rolling or twisting back on to those sites.¹³ For repositioning to be effective, the caregiver needs to understand the goals of the maneuver, pathophysiology of pressure ulcer formation, patient-specific requirements, and functional anatomy. For complex patients, the way to safely provide regular and effective pressure relief, keeping the patient's cooperation and comfort in mind, may not be simple. For example, this can be particularly problematic with a postoperative spine surgery patient who is hemodynamically labile. Moving these patients for any reason may make them clinically unstable. Since there is no benefit to doing too much repositioning, and no feedback to confirm adequate off-loading, there may be a tendency to do less, thus minimizing disruption. For an unseasoned caregiver, the task seems insurmountable. An objective parameter of pressure off-loading would be helpful with any patient. This patient is particularly at risk for pressure ulcer development and would benefit greatly from effective patient repositioning.

The authors' hospital reintroduced a NPUAP-based pressure ulcer prevention bundle in January 2011. This skin bundle included repositioning patients every 2 hours (bed or chair), heel elevation and support, incontinence monitoring and care, Braden scale evaluation daily, evaluation of appropriate support surface, skin barrier use, daily evaluation of skin under devices (eg, oral and nasal tubes, and catheters), and nutrition assessment. As part of this effort, the authors' hospital piloted a program specifically for the MICU because of the unit's higher rate of hospital-acquired pressure ulcers. The technology chosen was an innovative continuous bedside pressure mapping system (CBPM) designed to provide real-time imaging of the patient on the support surface. This technology provides both qualitative and quantitative understanding of patient pressure load distribution and the impact of turning and repositioning maneuvers. It allows caregivers to visualize and also educate on the subject of effective patient repositioning. The authors define effective patient repositioning as the off-loading of at-risk tissue

in conjunction with objective confirmation of pressure relief at that location. A retrospective chart review was conducted to evaluate the change in hospital-acquired pressure ulcer prevalence with the use of this pressure ulcer prevention bundle augmented by CBPM in the high-risk MICU population.

Materials and Methods

Study population and design. Continuous bedside pressure mapping systems were placed on 20 beds in 1 of 6 pods within the MICU at Henry Ford Hospital, Detroit, MI. Patients in this retrospective cohort study were admitted to the MICU based on bed availability, with no inclusion or exclusion criteria for participation in the study. However, patients placed on fluidized air support surfaces were excluded because the CBPM could not be fitted to those beds. Patients admitted to these MICU beds during January and February 2011 were included in the CBPM cohort group. Educators on the unit instructed and assisted with implementation of CBPM technology to augment the pressure ulcer bundle, which was based on internationally accepted NPUAP guidelines. Pressure ulcers present on admission, hospital-acquired pressure ulcers, and staging were recorded in the MICU electronic health record (MetaVision, iMDsoft, Needham, MA). These patients were compared with a historical control cohort occupying the same beds 1 year prior to the study participants (January and February 2010).

The study was approved by the Institutional Review Board and conducted in compliance with the ethical rules of the 1975 Declaration of Helsinki. Because this was a retrospective chart review with no additional patient contact or intervention, patient consent was not required for data collection and analysis.

Continuous bedside pressure mapping. The CBPM system (MAP™ System, Wellsense USA, Inc, Nashville TN) consists of a pressure-sensing mat and a control unit that provides digital imaging of pressures. The mat is a thin, enclosed sensing pad that can be placed over a mattress and under any standard bed sheet (Figure 1A). It contains thousands of sensors designed to measure levels of pressure between 0 mm Hg and 180 mm Hg. Each pressure-sensing cell is approximately 1 square inch and takes measurement samples twice per second to ensure the live image of the pressure map is updated with every movement in a real-time manner. The system continuously retrieves data from the sensors and transfers it to the system control unit (Figure 1B),

which processes and graphically displays the pressure distribution data at different parts of the patient's body. Caregivers can then use the real-time image to identify areas of high interface pressure and more efficiently reduce pressure levels while conducting their standard routine turning protocols. This can result in lower peak pressures across the patient's body. The system control unit can then also provide alerts to staff based on each patient's predefined protocol.

Data collection. The hospital's electronic medical records (MetaVision, iMDsoft, Needham, MA) and corporate database (Bi Query, Hummingbird Ltd [now known as Open Text], Toronto, Ontario, Canada) were queried for data on patients admitted to the 20 CBPM beds in the MICU during the study period. Weekly pressure ulcer prevalence audits had been performed throughout the 2-month study period. Patients with documentation of pressure ulcers were confirmed by manual audit of the medical records. Patient characteristics were collected from the database for comparison of comorbidities and confounding factors between study patients and historical controls. The CBPM also allowed the authors to query the system after the fact to make sure the turning protocol was followed as out-

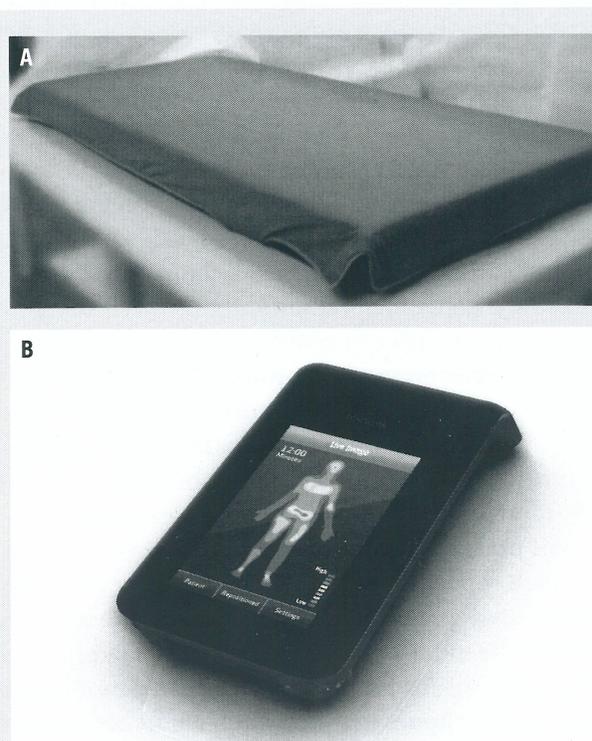


Figure 1. Continuous bedside pressure mapping system. A: Pressure-sensing mat. B: Handheld control unit.

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- Educators on the unit instructed and assisted with implementation of CBPM technology to augment the pressure ulcer bundle, which was based on internationally accepted NPUAP guidelines.
- The CBPM also allowed the authors to query the system after the fact to make sure the turning protocol was followed as outlined in the care bundle.

lined in the care bundle. The electronic health record allowed tracking of Braden scale score, positive end-expiratory pressure (PEEP) score, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, changes in respiratory status, ventilatory support, hemodynamic status, circulatory support, and serum biochemistry throughout the MICU course of stay. Nurses and other caregivers who used the CBPM on this MICU pod were surveyed to obtain their opinions about the utility and effectiveness of the CBPM for guiding their patient repositioning efforts.

Statistical Analysis

Demographic data are presented as means (standard deviation) for continuous data and as N (%) for categorical data. Chi-square tests were used to compare categorical variables and Wilcoxon 2-group tests were used to compare continuous variables due to non-Gaussian distributions as determined by skewness and kurtosis measurements, Shapiro-Wilk tests, and histograms.

Results

This study included data collected on 627 MICU patients: 307 patients placed on beds with a CBPM system and 320 historical controls placed on the same beds without the CBPM system 1 year prior. During the 2-month study period, 1 (0.3 %) patient in the CBPM cohort developed a pressure ulcer while in the MICU. In the historical control cohort, 16 (5%) patients developed a pressure ulcer while in the MICU ($P = 0.001$). The pressure ulcer that developed during the study period was a stage II ulcer of the sacrum. This ulcer resolved within 2 months of hospital discharge. The 16 hospital-acquired pressure ulcers in the historical control group included 6 (1.9%) patients with stage II ulcers, 9 (2.8%) with stage III ulcers, and 1 (0.3%) with a stage IV ulcer.

Table 1. Patient characteristics and development of pressure ulcers in a MICU.

	Historical Control Group (n = 320)	CBPM System Group (n = 307)
Mean age (years)	60.7	59.7
Gender (male) (%)	53	50
Surgery during previous 3 months (n)	22	18
Immunosuppression (n)	42	38
Spinal cord injury (n)	4	2
Vasopressor use (n)	85	95
Mean days in MICU*	6.16	7.54
On ventilator (% of patients)	36	40
Mean days on ventilator	5.55	6.28
PEEP > 8 (n)	15	29
Serum lactate > 4.0 mmol/L (n)*	37	60
APACHE II score > 20 (n)*	60	118
Mean comorbidities per patient	7.1	5.8
Braden score ≤ 12 (% of patients)	65	71
Mean Braden score on admission	15.72	15.24
Pre-existing pressure ulcers (n)	5	7
Institution-related pressure ulcers (n)*	16	1
PEEP = positive end-expiratory pressure APACHE = Acute Physiology and Chronic Health Evaluation * Statistical significance for Chi-square test at $P < 0.05$		

As shown in Table 1, the CBPM population and the historical control population were comparable with regard to age, race, gender, recent surgery, associated comorbidities, history of pressure ulcers, immunosuppression, spinal cord injury, vasopressor use in the MICU, ventilator use, and average Braden scale score on admission. Some markers for patient acuity, including highest PEEP, highest serum lactate level ($P < 0.05$),

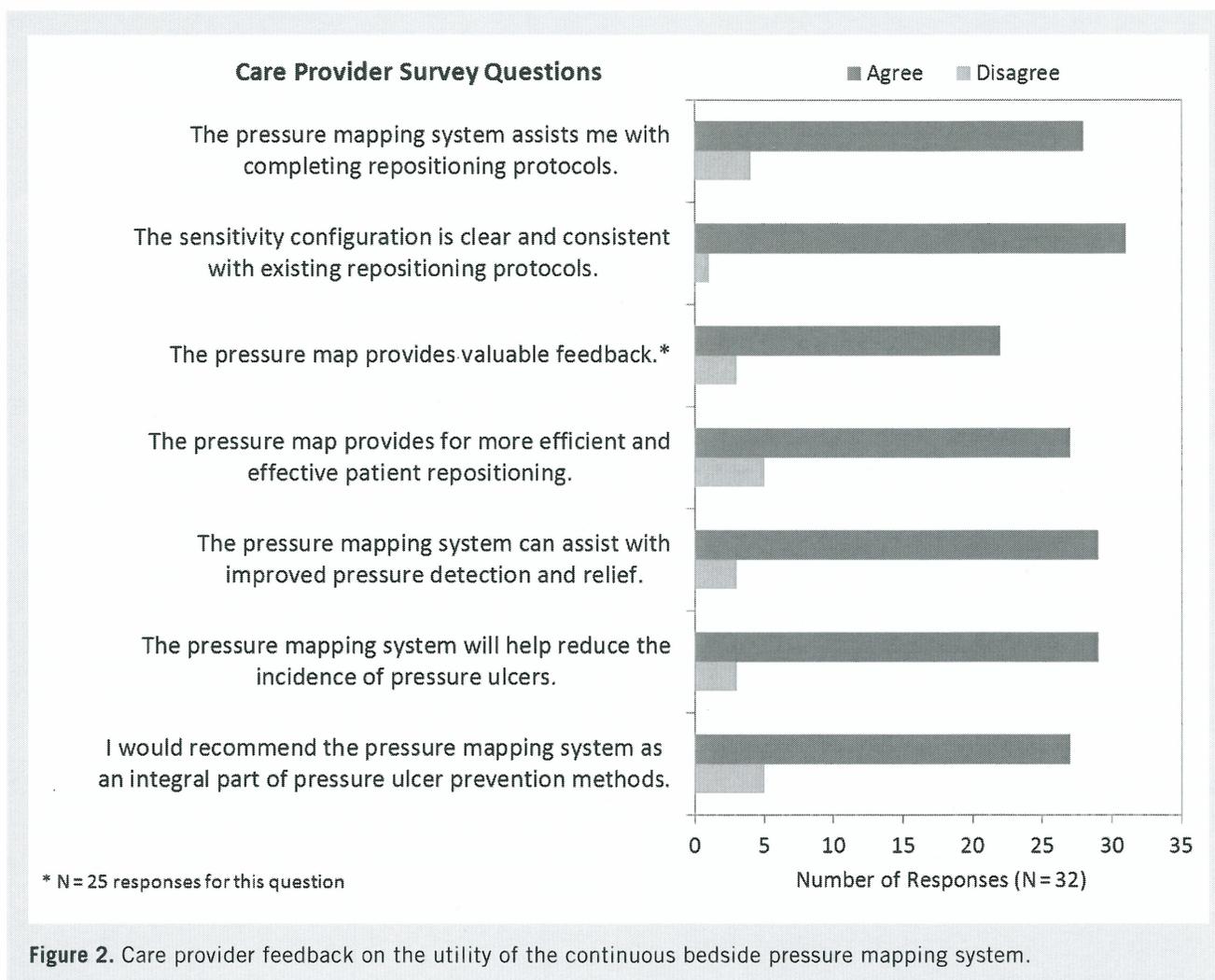


Figure 2. Care provider feedback on the utility of the continuous bedside pressure mapping system.

and APACHE II scores ($P < 0.05$), suggest higher acuity in the CBPM group compared with the historical control group.

As shown in Figure 2, feedback from the nurses and other caregivers using the CBPM reflects overall acceptance of the CBPM system and the belief that it provided valuable benefits for patient repositioning efforts. Overall, 90% of respondents believed the CBPM contributed to improved pressure detection and relief, 88% reported that the CBPM assisted them with repositioning protocols, and 84% reported that the pressure map provides for more efficient and effective patient repositioning. In addition, 97% of respondents reported the CBPM's sensitivity configuration is clear and consistent with existing repositioning protocols. No technical or safety concerns with the device were reported during the study period.

KEYPOINTS

- During the 2-month study period, 1 (0.3 %) patient in the CBPM cohort developed a pressure ulcer while in the MICU.
- In the historical control cohort, 16 (5%) patients developed a pressure ulcer while in the MICU ($P = 0.001$).
- Some markers for patient acuity, including highest PEEP, highest serum lactate level ($P < 0.05$), and APACHE II scores ($P < 0.05$), suggest higher acuity in the CBPM group compared with the historical control group.

Discussion

The CBPM allowed the authors to understand and further develop the concept of effective patient repositioning (EPR). With CBPM, EPR becomes a visually

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- Pressure mapping technology aids bedside caregivers by providing real-time feedback on individual patients.
- Caregivers are able to immediately visualize whether the pressure has been eliminated. If not, further intervention may be performed immediately, rather than waiting for a problem to develop.
- This technology is a tool to be used as part of a larger program of education and commitment to better patient outcomes with ongoing vigilance on the part of the caregivers.

assessed, objectively verifiable technique for achieving pressure relief. With the guesswork of EPR reduced, the learning curve can be minimized for many bedside caregivers, and differences between experienced and novice caregivers eliminated.

Knowing that pressure relief is being performed effectively is very important. Without a way to provide real-time visual feedback to caregivers that confirms pressure relief, any further steps (ie, nutrition, support surfaces, moisture control) in a pressure ulcer reduction program may be futile. Without CBPM there is no objective way to confirm that one has achieved the pressure relief documented in the chart.

Much of the present-day pressure ulcer prevention plans are based on stratifying risk and modifying support surfaces. All of these approaches are predicated on proper pressure relief. Unfortunately, with these protocols there is no evidence base to give us confidence in the ability to effectively and consistently reposition patients for optimal pressure relief. For example, a recent systematic review of pressure ulcer prevention strategies was unable to discern which turning/repositioning strategies work best to prevent ulcer development.¹¹ Furthermore, there is no good way to teach effective repositioning or provide feedback to busy bedside caregivers. Even the most well-intentioned nurse cannot be sure that appropriate pressure relief has been achieved. Only when the patient does not develop an ulcer can we be confident that proper patient care was achieved. If an ulcer does develop, effective patient repositioning has to be called into question. Because an ulcer may manifest days later, however, without CBPM there is no way to close the loop for a caregiver who performed suboptimal repositioning. In the author's experience, some in this field have suggested eliminating the term "repositioning" due to these ap-

parent problems with proper repositioning. They believe turning is an easier concept to teach and convey than repositioning. Effective patient repositioning guided by CBPM may be the answer to this dilemma.

Pressure mapping technology aids bedside caregivers by providing real-time feedback on individual patients. Caregivers need to efficiently and effectively off-load at-risk patients. Ineffective repositioning that results in a pressure ulcer may not manifest for hours or days. Unless the patient or a more experienced provider gives feedback, it may be difficult for the caregiver to recognize that a specific poorly-performed repositioning resulted in the unexpected outcome. The CBPM can eliminate the guesswork. Caregivers are able to immediately visualize whether the pressure has been eliminated. If not, further intervention may be performed immediately, rather than waiting for a problem to develop. In addition to aiding in the repositioning of complex patients, CBPM may be able to level the playing field for new, less-experienced bedside caregivers.

While this pilot study demonstrates the potential benefit of using real-time pressure data to guide effective patient repositioning, it is important to consider the study's inherent limitations. This retrospective study reflects the experience of 1 unit within 1 acute care hospital. Due to its historical-cohort design, there is potential for confounding factors to result in unknown and unmeasured differences between the 2 treatment groups. However, the pressure ulcer prevention bundle that was in place for both the historical group as well as the CBPM group was based on the internationally accepted NPUAP guidelines for pressure ulcer prevention. Certainly, prospective, randomized studies, which are less prone to bias and confounding errors, are needed to confirm a benefit associated with this pressure mapping system in reducing pressure ulcer prevalence in acute care and long-term care settings. A prospective, concurrent-controlled study of this CBPM system is currently under way at the authors' medical center.

The authors believe technology is only part of the solution to preventing pressure ulcers. Continuous bedside pressure mapping obviously does not move the patient. This technology is a tool to be used as part of a larger program of education and commitment to better patient outcomes with ongoing vigilance on the part of the caregivers. All stakeholders in the process must buy into the goal of better patient care and results. The technology provides needed information

but cannot replace individualized, compassionate, evidence-based care.

Conclusion

Continuous real-time measurement of pressure beneath a bed-bound patient's body using a pressure-sensing mat appears to be a valuable tool to help bedside care providers effectively reposition patients within the context of existing standardized protocols for the prevention and minimization of pressure ulcers.

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