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The Intensive Care Unit Bundle Board: A Novel Real-Time Data Visualization Tool to Improve Maintenance Care for Invasive Catheters

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Abstract

Background Critically ill patients are at greater risk of healthcare-associated infections (HAIs). The use of maintenance bundles helps to reduce this risk but also generates a rapid accumulation of complex data that is difficult to aggregate and subsequently act upon.

Objectives We hypothesized that a digital display summarizing nursing documentation of invasive catheters (including central venous access devices, arterial catheters, and urinary catheters) would improve invasive device maintenance care and documentation. Our secondary objectives were to see if this summary would reduce the duration of problematic conditions, that is, characteristics associated with increased risk of infection.

Methods We developed and implemented a data visualization tool called the "Bundle Board" to display nursing observations on invasive devices. The intervention was studied in a 28-bed medical intensive care unit (MICU). The Bundle Board was piloted for 6 weeks in June 2022 and followed by a comparison phase, where one MICU had Bundle Board access and another MICU at the same center did not. We retrospectively applied tile color coding logic to prior nursing documentation from 2021 until the pilot phase to facilitate comparison pre- and post-Bundle Board release.

Results After adjusting for time, other quality improvement efforts, and nursing shift, multiple linear regression demonstrated a statistically significant improvement in the completion of catheter care and documentation during the pilot phase ($p < 0.0001$) and comparison phase ($p = 0.002$). The median duration of documented problematic conditions was significantly reduced during the pilot phase ($p < 0.0001$) and in the MICU with the Bundle Board (comparison phase, $p = 0.027$).

Keywords
- data visualization tool
- critical care medicine
- nursing documentation
- cognitive load
- dashboard
- quality improvement
- Bundle Board

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Conclusion We successfully developed a data visualization tool that changed ICU provider behavior, resulting in increased completion and documentation of maintenance care and reduced duration of problematic conditions for invasive catheters in MICU patients.

Background and Significance

Despite new technologies and the rapid accumulation of data, intensive care units (ICUs) still have high patient morbidity and mortality.[1,2] Reasons may include competing priorities of preventative management with increasingly complicated patient care,[3] cognitive overload, challenges in finding and interpreting data,[2,4] workforce shortages,[5,6] and resource limitations.[7,8] The unprecedented challenge of the coronavirus disease 2019 (COVID-19) pandemic exacerbated these factors, ultimately resulting in decreased compliance with standardized care and worsened clinical outcomes.[3,9–11] Ensuring clinically relevant data is efficiently communicated to and between ICU providers could reduce cognitive overload in the ICU and improve the delivery of evidence-based preventative care.[12–14]

Clinicians have attempted to organize and communicate data and best practices with checklists[15] and by packaging standardized approaches in "bundled care" to improve patient outcomes.[16] Several bundles, such as the ICU Liberation Bundle,[17] Central Venous Catheter Maintenance Bundle,[18] and catheter-associated urinary tract infection (CAUTI) Care Bundle,[19] have improved ICU morbidity and mortality. Despite widespread agreement about the effectiveness of checklists and bundled care, adherence to these tools is limited.[15,20–22] Contributing causes to limited adherence include poor design, little customization for individual patients, duplicative processes, physical access to the checklist, accountability among team members, and checklist fatigue.[15,23–26] Further, checklists can fail if there is ineffective communication surrounding identified problems or concerning findings.[24] The electronic medical record (EMR) is one tool that could be leveraged to accomplish checklist aims; however, current versions of the EMR are not well-designed for real-time communication of checklist data.[27]

Data visualization may help mitigate these challenges. By communicating information through images, data visualization can facilitate a decreased cognitive load, assisting the brain in more easily identifying patterns and outliers in a data set.[28–30] Data visualization theory suggests that by simplifying and displaying relevant data, providers can engage in higher-level situational awareness and troubleshooting for patient care. There have been positive results from data visualization tools in ICU settings, demonstrating decreased cognitive burden, eased clinical care delivery, and improved clinical outcomes.[31–34] However, despite early promising results, these tools are understudied.

This report details how we designed and implemented a novel data visualization tool called the ICU Bundle Board to highlight bundled patient care for invasive catheters and explored initial outcomes.

Objectives

We hypothesized that we could create a continuously updated digital display summarizing nursing documentation of invasive catheters (including central venous access devices (CVADs) and urinary catheters [UCs]) that would improve invasive device maintenance care. Our secondary objectives were to see if this summary would reduce the duration of problematic conditions, that is, characteristics that are associated with increased risk for infection or patient harm. Examples of problematic conditions include overdue hygiene care or redness at the CVAD insertion site.

Methods

Context

University of Virginia (UVA) Health is an academic medical center and health system with 636 beds, a level 1 trauma center, a nationally recognized cancer center, and a children's hospital. It is a tertiary referral center and receives patients from across Virginia and parts of surrounding states. This project was applied to our 28-bed MICU. Our institution uses EPIC as the EMR.

Application Design and Development

We created an interdisciplinary team of MICU physicians, nurses, data scientists, and clinical informaticians. Our team used prior experience with ICU bundled care, emerging evidence for data visualization in health care, and commonly identified needs among our patient population to design the first version of the application. Invasive catheter maintenance care was based on our hospital's standard work guidelines and specified in collaboration with our hospital's working groups on central line-associated bloodstream infections (CLABSIs) and CAUTIs (►**Supplementary Table S1**, available in the online version). The application complemented another quality improvement effort called patient safety risk rounds (PSRRs), released in February 2022. PSRR is a nursing-driven practice that identifies patients at risk for CLABSI and CAUTI and manually tracks compliance with maintenance care. The study was performed in compliance with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects. It was approved by the UVA Institutional Review Board for Health Sciences Research (HSR #18887).

Application Description

The ICU Bundle Board is a display that communicates documented nursing observations about invasive catheters (►Fig. 1). ►Fig. 1A demonstrates the unit-level overview page. ►Fig. 1B shows information about an individual catheter. Green tiles represent that maintenance care and documentation are complete and that the catheter has no problematic conditions. Red tiles highlight documentation that indicates a catheter has a problematic condition and "needs attention." Yellow tiles represent maintenance that has either not been performed or not been documented. Blue tiles represent that a patient's care goals are focused exclusively on end-of-life care. The hierarchy of colors prioritizes red (needs attention) over yellow (incomplete) over green (complete, no concerns). If patients do not have any catheters, they default to green. An example of how the colors change in response to documented findings is available in ►Fig. 2. The board also displays each patient's length of stay and Sequential Organ Failure Assessment (SOFA) Score, a mortality prediction score.[35] Examples of required maintenance care and associated green or red tiles can be reviewed in ►Supplementary Table S1 (available in the online version).

On the back-end (server-side) of the application, the Bundle Board is built as a Python model running on an in-house platform that generates early-warning scores (EWSs) and other time-sensitive information for the in-patient population using data provided by Epic Interconnect application programming interface. This platform provides near-real-time access to vital signs, medications, labs, and flowsheet histories for in-patients, which the Bundle Board uses to assess the completion of required documentation within specified intervals. The Bundle Board's clinician-facing display refreshes its display every 3 minutes.

Data Security

Patient-protected health information is protected behind the UVA Health firewall and inaccessible to anyone outside the UVA Health network. Within UVA Health, access is managed through Active Directory groups and users are logged. The wall-mounted Bundle Board displays are in secured hospital units; only patient initials and room numbers are displayed.

Pilot Phase

The pilot phase was 6 weeks, beginning in June 2022. All patients in the MICU were included in the pilot; patients boarding outside the MICU were excluded. The Bundle Board was displayed on one display in the provider workroom, and four wall-mounted displays were placed throughout the MICU; the application was also available via an icon on all ICU desktop workstations. To investigate pre-Bundle Board trends, we analyzed catheter documentation from June 2021 until the start of the pilot phase in June 2022.

Comparison Phase

The MICU's physical location within UVA Health was shifted to two different units in July 2022. The two units were located in close proximity. Patients were assigned to their

Fig. 1 ICU Bundle Board displays. (A) The ICU Bundle Board is a display screen with three columns: each patient's room and initials in one column, central lines in the second column, and "other lines, drains, and tubes" (e.g., urinary and arterial catheters) in a third column. Each invasive catheter is represented as a tile on the Bundle Board. The tiles are coded as one of four colors (red, yellow, green, or blue) based on flowsheet documentation for each catheter. (B) When tiles are clicked, more information about the invasive catheter will display in a pop-up window.

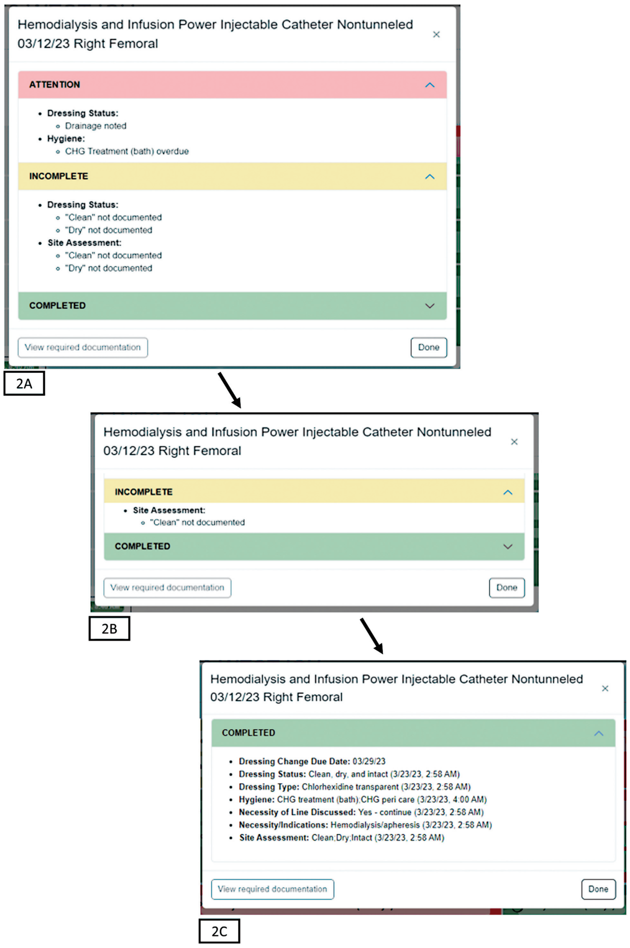

Fig. 2 Tile color changes relative to nursing documentation. (**A**) In this example, a nontunneled hemodialysis and infusion power injectable catheter is appearing as a red tile. The default information display is that the catheter needs attention because there is drainage noted at the catheter dressing and that the patient's chlorhexidine gluconate (CHG) bath is overdue. Additionally, the patient is lacking documentation for the dressing status and site assessment. (**B**) In this example, the patient receives their CHG bath and has a dressing change. However, the nurse has forgotten to document a required observation: that on the site assessment, the site is "clean." Therefore, the tile now appears yellow. (**C**) The nurse then observes that the tile is yellow. They then document that the site is clean. The tile updates to a green color. Clicking on the green tile will display all completed and documented care. (Data present in the figure are imaginary).

rooms by availability and without consideration for the Bundle Board investigation. Bedside and charge nurses rotated freely between MICUs, and the leadership teams for the two MICUs were the same. The permanent unit had two wall-mounted displays and desktop icons for the application throughout that unit. The temporary unit served as a control group and did not have any displays or provide access to the Bundle Board for patients in that MICU. The supply rooms and available resources between MICUs were otherwise similar. This comparison phase lasted 6 weeks.

Outcome Measures

Our primary outcome of interest was improved device maintenance care as measured by reduced duration of documented problematic conditions and improved documentation of complete care. The duration of problematic conditions was measured by the duration of red tiles, and complete maintenance was measured by the frequency of green tiles. Secondary outcomes included decreased device utilization ratios (DURs), calculated by the number of catheter days divided by the number of patient days for each catheter. Median device duration was measured in catheter days of temporary catheters, excluding implanted ports and tunneled CVADs. We extracted data from our institution's data warehouse.

Statistical Analysis

We retrospectively applied tile color coding logic to nursing documentation from June 2021 until the Pilot Phase to facilitate comparison pre- and post-Bundle Board release. We identified DURs for CVADs, arterial catheters, and UCs for each group. DURs by catheter type were compared using the estimated marginal means of Poisson regression with Sidak multiple comparison adjustment (emmeans package[36]).

We used multiple linear regression to investigate the effect of the Bundle Board on the completion of catheter care and documentation while controlling for other factors that may have influenced the outcome. In our pilot phase model, we included nursing shift (day or night), PSRR, time (months), and potential interaction between the Bundle Board and nursing as factors. Time was included to account for the possibility of an increase in completion over time unrelated to the Bundle Board. We included the interaction effect with nursing shift, documentation practices, and the Bundle Board given that there may be differences between days and nights.[37] For the comparison phase, we only controlled for the nursing shift and the potential interaction of the Bundle Board related to the nursing shift (day or night) because the effects of time and PSRR were already controlled for by comparing the two units within the same period. Data were analyzed using R Statistical Software (v4.2.1; R core Team 2022.

Results

Patient Demographics, Median Device Duration, and Device Utilization Ratios

During the Pilot Phase, 211 patients received care in the MICU; during the Comparison Phase, 65 patients received care in the MICU without the Bundle Board and 94 patients received care with the Bundle Board. ►Table 1 summarizes patient characteristics across study periods. Patient characteristics, notably including median ICU length of stay and use of vasopressors were similar across study periods. DURs for all types of catheters were increased in the pilot phase compared to before. During the comparison phase, the unit with the Bundle Board had decreased DUR of CVADs, but there was no difference in DURs for arterial or UCs (►Table 2). In addition, the duration of temporary catheters was similar across all periods studied (►Supplementary Table S2, available in the online version).

Distribution of Tiles

►Fig. 3 describes the distribution of tiles across periods of the Bundle Board study. The multiple linear regression to evaluate

Table 1 Patient demographics

Pilot study ($n = 1,900$)		
Variable	**Prepilot ($n = 1,689$)**	**Pilot ($n = 211$)**
Age, years, mean ± SD	60 ± 17	62 ± 16
Age ≥ 65 y, *n* (%)	41%	43%
Sex, female (%)	47%	44%
BMI (IQR)	28 (11)	27 (9)
ADI (IQR)	6 (4)	6 (3)
Median SOFA score (IQR)	6 (6)	7 (6)
Length of ICU stay, median days (IQR)	3 (6)	4 (6)
Ventilator during ICU stay, *n* (%)	37%	40%
Length of mechanical ventilation, median days [IQR]	4 (7)	4 (7)
Vasopressors during ICU stay, *n* (%)	45%	51%
Length of vasopressors, median days (IQR)	4 (5)	5 (5)
Comparison study ($n = 159$)		
Variable	Without BB ($n = 65$)	With BB ($n = 94$)
Age, years, mean ± SD	57 ± 18	60 ± 18
Age ≥ 65 y, *n* (%)	35%	48%
Sex, female (%)	41%	48%
BMI (IQR)	28 (8)	27 (10)
ADI (IQR)	6 (3)	6 (4)
Median SOFA score (IQR)	6 (5)	6 (4)
Length of ICU stay, median days (IQR)	8 (11)	6 (8)
Ventilator during ICU stay, *n* (%)	32%	34%
Length of mechanical ventilation, median days (IQR)	3 (4)	3 (4)
Vasopressors during ICU stay, *n* (%)	41%	40%
Length of vasopressors, median days (IQR)	3 (4)	2 (2)

Abbreviations: ADI, area deprivation index by state ranking;[43,44] BB, Bundle Board; BB Pilot, 6-week period of Bundle Board pilot; BMI, body mass index; ICU, intensive care unit; IQR, interquartile range; Pre-BB, year prior to Bundle Board pilot; SD, standard deviation; SOFA score, Sequential Organ Failure Assessment; With BB, MICU that had Bundle Board available on displays and workstations; Without BB, MICU that did not have access to Bundle Board.

Table 2 Device utilization ratios (DURs) across study periods

Pilot phase (ratio)			
Catheter	**Prepilot**	**Pilot**	***p*-Value**
CVAD	0.31	0.49	<0.0001
Arterial catheter	0.14	0.18	<0.0001
Urinary catheter	0.29	0.47	<0.0001
Comparison phase (ratio)			
Catheter	Without BB	With BB	*p*-Value
CVAD	0.66	0.40	<0.0001
Arterial catheter	0.16	0.15	0.99
Urinary catheter	0.30	0.36	0.25

Abbreviations: BB, Bundle Board; CVAD, central venous access device; MICU, medical intensive care unit.
Note: Without BB, MICU that did not have access to Bundle Board data, during August 2022. With BB, MICU that did have access to Bundle Board data during August 2022; Prepilot, June 2021 through May 2022. Pilot, pilot phase, corresponding to June, July 2022. Device utilization ratio was calculated as (*n* catheter days)/(*n* patient days) for each catheter, and comparisons of ratios by catheter type were conducted using the estimated marginal means of Poisson regression with Sidak multiple comparison adjustment (emmeans package[36]).

Fig. 3 Distribution of tiles across study periods. The *x*-axis shows the tile distributions of a particular week; we specify phase of the study at the top of (**A** and **B**) (pre-BB, pilot, without BB, with BB.) Pre-BB = Year prior to Bundle Board Pilot. BB Pilot = 6-week period of Bundle Board pilot. Without BB = MICU that did not have access to Bundle Board data. With BB = MICU that did have access to Bundle Board data. The *y*-axis shows the distribution of tile colors for invasive catheters as a percentage. Tile colors can only be red, yellow, or green and thus add to 100%. The percentage of invasive catheters with complete care and documentation with no problematic conditions is shown in green. Yellow corresponds to the percentage of catheters with incomplete documentation. Red is the percentage of catheters with a concerning feature documented. (**A**) The tile distribution trends over time in the year before the Bundle Board Pilot, as well as the 6-week Pilot, starting in June 2022. Postlaunch completion of care and documentation increased significantly compared to pre-launch (8.9% increase; CI: 6.6–11.1; $p < 0.0001$). (**B**) The comparison in tile distribution for invasive catheters between MICUs with and without access to the Bundle Board. Comparison phase lasted 6 weeks. The MICU with access to the Bundle Board had a significant increase in catheter care completion and documentation compared to the MICU without access (8.0% increase; CI: 4.0–12.0; $p = 0.0001$).

the effect of the Bundle Board (during the Pilot Phase) on the completion of catheter care and documentation was statistically significant ($R^2 = 0.42$; $F(3, 821) = 122.4$; $p < 0.0001$). Display of the Bundle Board was associated with an 8.9% increase in care completion (confidence interval [CI]: 6.6–11.1; $p < 0.0001$). All catheters had improved frequency of green tiles, representing complete care delivery and documentation without problematic conditions (►**Table 3**). Day shifts had an overall 10.1% higher completion rate than night shift in documentation (CI: 8.1–12.2; $p < 0.0001$), but there was no interaction between the display of the Bundle Board and shift (−0.9%; CI: −3.8–2.0; $p = 0.55$). We did not observe a linear trend toward improvement in catheter care completion in the time before the Bundle Board pilot (0.09%; CI: −0.2–0.4; $p = 0.59$).

The overall regression to compare MICUs with and without the Bundle Board was significant ($R^2 = 0.08$; $F(3,130) = 5.1$;

Table 3 Percentage of invasive catheters with complete care delivery and without problematic conditions

Pilot phase (%)		
Catheter	**Prepilot**	**Pilot**
CVAD	34.5	56.5
Arterial catheter	38.3	60.3
Urinary catheter	62.0	70.1
Comparison phase (%)		
Catheter	Without BB	With BB
CVAD	49.0	53.1
Arterial catheter	46.4	67.5
Urinary catheter	60.2	69.8

Abbreviations: BB, Bundle Board;, central venous access device; MICU, medical intensive care unit.
Note: Complete care delivery and documentation without problematic conditions was determined by percentage of green tiles for invasive catheters across nursing shifts. Without BB, MICU that did not have access to Bundle Board data, during August 2022; With BB= MICU that did have access to Bundle Board data during August 2022; Prepilot, June 2021 through May 2022; Pilot, pilot phase, corresponding to June, July 2022.

$p = 0.002$), and the presence of the Bundle Board was associated with a 7.8% increase in catheter care completion (CI: 2.2–13.4; $p = 0.007$). Neither the shift (−0.3; CI: −5.9–5.4; $p = 0.93$) nor the interaction between the shift and the Bundle Board display (0.4; CI: −7.6–8.4; $p = 0.92$) were associated with a change in care completion.

►Fig. 3 describes the duration of problematic conditions (in hours) across study periods. In the year before the Bundle Board launch, the median duration of documented problematic conditions was 12 hours (interquartile range [IQR]: 7,22.5). The median duration was significantly lower during the Bundle Board Pilot at 7.7 hours (IQR: 4.5, 13; Wilcoxon's rank sum test $p < 0.0001$). During the comparison phase, the median duration of red conditions remained lower for the unit with the Bundle Board (median = 7.5 hours; IQR 4.7,10.9), while the unit without Bundle Board returned to prelaunch durations (median = 11 hours; IQR: 6,12.9). The difference in durations between the two units was statistically significant (Wilcoxon's rank sum test $p = 0.027$). The median duration of problematic conditions by catheter type across periods is summarized in ►Table 4. The median duration of problematic conditions by catheter type across periods is summarized in ►Table 4; a grouped-level summary of the median duration of problematic conditions for catheters is shown in ►Fig. 4.

Discussion

Major Findings

We developed a tool that improved device maintenance care, as demonstrated by increased completion and documentation of maintenance care and reduced duration of problematic conditions for catheters in MICU patients. These findings were confirmed after adjusting for other quality improvement efforts, gradual improvement over time, and potential interactions of the Bundle Board with nursing shifts. Importantly, this was accomplished without additional documentation or changes to standard operations. Assuming the identification and resolution of red tile conditions reduces the incidence of CLABSI along with the improved adherence to the Central Venous Catheter Maintenance Bundle,[18] significant reductions in health care-associated infections

Table 4 Durations of problematic conditions by invasive catheter type

Pilot phase (h, IQR)		
Catheter	**Prepilot**	**Pilot**
CVAD	12.1 (8.0–23.4)	8.8 (4.9–14.1)
Arterial catheter	12.0 (6.324.0)	7.6 (2.4–12.9)
Urinary catheter	4.0 (2.5–10)	6.5 (5.7–7.2)
Comparison phase (h, IQR)		
Catheter	Without BB	With BB
CVAD	11.3 (6.3–14.3)	6.4 (4.5–10.8)
Arterial catheter	9.7 (2.9–12.4)	10.4 (8.8–11.4)
Urinary catheter	4.1 (2.4–5.8)	0.8 (0.8–0.8)

Abbreviations: BB, Bundle Board; CVAD, central venous access device; IQR, interquartile range; MICU, medical intensive care unit.
Note: Without BB, MICU that did not have access to Bundle Board data, during August 2022; With BB, MICU that did have access to Bundle Board data during August 2022; Prepilot, June 2021 through May 2022; Pilot, Pilot Phase, corresponding to June, July 2022.

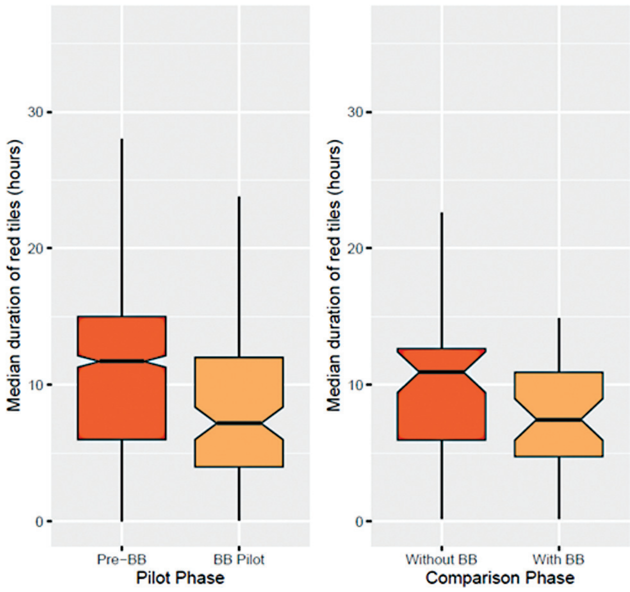

Fig. 4 Grouped summary of median duration of problematic conditions across study periods. The *y*-axis shows the median duration in hours of problematic conditions (as shown on the Bundle Board by red tiles.) Before the launch of the Bundle Board (Pre-BB), the median duration of problematic conditions for invasive catheters (on a grouped level) was 12 hours (IQR: 7,22.5). During the pilot (BB Pilot), the median duration was significantly lower (median 7.7 hours, IQR: 4.5, 13, Wilcoxon's rank sum test $p < 0.0001$). During the comparison phase, the median duration of red conditions remained lower for the MICU with Bundle Board access (median 7.5 hours, IQR: 4.7, 10.9). The MICU without the Bundle Board returned to prelaunch durations, with a similar duration of problematic conditions to that of pre-BB periods, with a median duration of 11 hours (IQR: 6, 12.9). The difference in durations during the comparison phase was statistically significant (Wilcoxon's rank sum test $p = 0.027$).

(HAIs) could be achieved if the Bundle Board is integrated into ICU operations.

The ICU is a demanding environment, with care demands often at odds with the burden of entering and finding documentation.[3] Our findings support the growing body of literature investigating how data visualization with multi-patient dashboards may impact ICU care.[34,38] Like our study, Pageler et al utilized patient-specific, EMR-enhanced checklists and a unit-wide dashboard with colors to demonstrate compliance with CLABSI prevention care. Their tool also offered links to educational resources and addressed other evidence-based best practice bundles, such as ventilator-associated pneumonia prevention. They showed increased compliance with four of five elements of CLABSI care in a pediatric ICU population and decreased rates of CLABSIs.[39] The Chemparath group expanded on this work and implemented a bundle adherence dashboard for CLABSI prevention across their pediatric hospital.[38] Our study builds on this work by demonstrating increased compliance for CLABSI prevention care in an adult population, with evaluation via a comparison study between two MICUs at the same institution. Some differences between prior tools and the Bundle Board are that our tool displays information for several types of catheters, and information is shown continuously on large screens throughout the unit, as opposed to a dedicated central line dashboard utilized during twice-daily bundle checks.[38]

There are several potential reasons why the Bundle Board improved catheter maintenance. The Bundle Board overcomes several barriers to checklist adherence, including user-centered design, customization for catheter types and patient needs, and simplified communication regarding checklist findings.[15,23–26] The Bundle Board also highlights opportunities for action while being noninterruptive. For example, if a patient's CVAD has an occluded lumen, the Bundle Board amplifies that finding and can prompt discussion regarding potential interventions.

The Bundle Board also facilitates shared knowledge and awareness among ICU nurses, despite diverse levels of training or institutional experience. In highlighting catheter maintenance documentation needs or problematic conditions, the Bundle Board communicates our institution's expectations for care. This is especially valuable in a post-COVID era with staffing shortages and more travel nurses staffing ICUs.[7] The Bundle Board helps to manage information overload by facilitating situational awareness, easing the burden of finding information, and reducing the cognitive load required for identifying important information.

During the comparison phase, there was a significantly decreased CVAD DUR. There was no difference for arterial catheters or UCs. It is possible that the Bundle Board promoted decreased DUR of CVADs, given the focus on complete care delivery and increased awareness of CVADs across the unit with the Bundle Board. During the Pilot Phase, there was increased DUR of all catheter types compared to before the pilot. This may have been a seasonal variation, as the Pilot Phase included a year of data, but the Pilot Phase was limited to 6 weeks. Overall, our study phases were underpowered to determine the impact on DURs, but this warrants future investigation.

Limitations

A qualitative analysis of MICU nursing interviews to analyze needs and gather feedback on the Bundle Board's iterative designs would have been valuable. However, there was an urgent hospital need to reduce HAIs, so we opted to move forward with implementation. Similarly, more extended study periods would have been valuable in exploring the Bundle Board's impacts on care. Additionally, during the Comparison Phase, there may have been differences in behavior related to the temporary nature of the MICU without the Bundle Board. However, this was inherently a pragmatic study. Another limitation is that we have only demonstrated the effect of the Bundle Board in an MICU, specifically with an MICU team that contributed to the development of the Bundle Board. We do not yet know if it will have the same benefits in surgical ICUs or ICUs outside our institution.

The tool itself has limitations. The Bundle Board cannot verify that appropriate care was provided or identify errors in documentation. For this study, we grouped maintenance care delivery (bundle task completion) and documentation for outcome analysis. This limitation is inherent to tools based on documentation within the EMR. Future analysis may benefit from the addition of direct observation to distinguish if improvements in process outcomes are related to maintenance bundle completion or documentation of bundle tasks.

Our evaluation of the pilot phase compared to prior periods is a retrospective analysis, which limits our conclusion that the Bundle Board directly caused process improvements in device maintenance care. However, the comparison phase supports our hypothesis that the Bundle Board was likely to drive the observed differences. In the future, we will perform a Bayesian analysis of these measures over an extended period to assess the probability that observed differences can be attributed to the Bundle Board.

Lastly, the project scope was to develop a digital display summarizing nursing documentation of catheters to improve device maintenance care. The comparison phase did not run for a sufficiently long-enough period and thus was not powered to evaluate if the tool could improve other outcome measures, such as reducing HAI like CLABSI or CAUTI.

Challenges, Unintended Consequences, and Lessons Learned

The burden of documentation also challenged engagement with the Bundle Board. The Bundle Board was aligned with recommended nursing documentation from nursing leadership and coalitions to reduce CLABSI and CAUTI. However, EMR documentation is not straightforward, often requiring several clicks and significant focus. For example, the documentation requirements for a triple-lumen CVAD require a minimum of 19 clicks. Missing one of these nineteen clicks will result in a persistent yellow tile, irritating nurses who had performed and then tried to document complete maintenance care. An unintended consequence of the Bundle Board may be a greater focus on documentation instead of directly improving patient outcomes. The demand for documentation directly conflicts with the time required to perform patient care and nursing satisfaction with providing comprehensive care.[40–42] Critical care nurses are a limited and valuable resource; clinical informaticians and stewards of the EMR must reduce the cognitive energy and time required for documentation. We highlighted to our nursing team that the Bundle Board does not add any extra documentation to nursing workloads and has prompted review of and improvements to documentation requirements; however, there is more work to be done in simplifying nursing documentation.

Nursing expertise was vital in developing this tool and overcoming these challenges. The MICU bedside nurses had significant input in every aspect of the tool's creation, from shades of the tile colors to selecting required documentation. This was a "home-grown" tool and was directly shaped by the nurses managing the largest number of central lines at our institution. Without their counsel, our team suspects the project would have failed. In addition, our team built and designed the tool not to enforce documentation requirements but to broadcast nursing observations through the ICU, amplifying their concerns. Sharing this goal allowed us to align with nurses and increase engagement. User-centered design was critical for the Bundle Board's development and implementation.

Updates and Next Steps

A review by Waller et al identified studies with data visualization techniques in critical care settings that occurred between 1990 and 2018.[34] Several studies were characterized as comprehensive (combined information from various sources within the EMR to support clinically meaningful grouping of related information) or multipatient (which displayed multiple patients in a unit to improve compliance with standard care protocols). We aim to meet both characteristics. In future versions of the Bundle Board, we will integrate all elements of the ICU Liberation Bundle[17] and other bundled care topics related to harm reduction in the ICU.

We have now developed a standard workflow for how a team can use the Bundle Board through the 24-hour cycle of critical care. Given that the pilot and comparison studies only had data visualization and were without formal workflow integration, we suspect this may also impact clinical outcomes. We have also performed a usability survey among MICU nurses to determine ease of use and perceived value of the Bundle Board in the MICU (these results will be shared in a separate manuscript.) In addition, the Bundle Board will be evaluated in a surgical and trauma ICU, which may help explore whether the tool's benefits are generalizable to other ICUs. Lastly, as the Bundle Board has demonstrated the ability for line review and compliance with nursing maintenance care requirements of catheters, our team is collaborating with hospital leadership on reducing duplicative processes in current operations.

Conclusion

Summary Sentence

Display of nursing observations through the ICU Bundle Board facilitates improved care of invasive catheters.

Clinical Relevance Statement

1. Collaboration with end-users is critical for developing data visualization tools.
2. The ICU Bundle Board is a real-time data visualization tool that categorizes nursing observations so the ICU team is aware of invasive catheters that need attention, have received complete care, or have yet to receive comprehensive care or have complete documentation.
3. Display of ICU documentation in near-real-time provides a visual signal to prompt focused opportunities for action to improve clinical outcomes.

Multiple Choice Questions

1. How can data visualization assist clinicians in caring for critically ill patients?
   a. Data visualization decreases cognitive load, simplifying information and making it easier to identify patterns and outliers.
   b. Data visualization is more engaging to look at than the electronic medical record.
   c. There is no data to support data visualization in patient care.

d. Data visualization increases cognitive load and there is only data to support avoiding it in healthcare settings.

Correct Answer: The correct answer is option a. Data visualization can facilitate a decreased cognitive load, eased clinical care delivery, and improved clinical outcomes in ICU settings.[31–34]

2. Why are checklists a unique challenge in the ICU?
   a. There are many checklists to complete, these require time to complete, and there is only sometimes effective communication concerning results.
   b. They are perfect for the ICU.
   c. Checklists fail because providers don't perform them.
   d. Bundles are poorly designed and don't work.

Correct Answer: The correct answer is option a. Successful implementation of checklists in the ICU can be challenged by limited customization for individual patients, duplicative processes, physical access to the checklist, accountability among team members, ineffective communication surrounding identified problems or concerning findings, and checklist fatigue.[15,23–26]

3. What is the potential benefit of displaying nursing documentation with data visualization?
   a. Flowsheet rows are often not accessible to or reviewed by the entire team; displaying nursing documentation can communicate findings to the whole team.
   b. There is no potential benefit.
   c. It forces team members to get work done faster.
   d. Everyone already has access to flowsheet rows, so displaying the information increases information overload.

Correct Answer: The correct answer is option a. Current versions of the EMR are not well-designed for real-time communication of checklist data27. Displaying nursing documentation with data visualization may help to communicate findings to the broader care team, as suggested by this study, as well as prior work by Paegler and Chemparathy.[38,39]

Protection of Human and Animal Subjects

The study was performed in compliance with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects and was approved by the Institutional Review Board for Health Sciences Research (HSR #18887).

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Conflict of Interest

None declared.

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