ORIGINAL ARTICLE

Reducing Central Line-Associated Bloodstream Infections in a Burn Intensive Care Unit: Using a Business Framework for Quality Improvement

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Central line-associated bloodstream infections (CLABSIs) pose a unique risk in burn patients, with rates of infection 2–3 times that of other Intensive Care Unit (ICU) populations. Here we present a detailed account of our experience in reducing CLABSI rates utilizing a business framework called the Four Disciplines of Execution (4DX). The Burn ICU CLABSI rate had risen to the 90th percentile nationally when compared to other burn units on the National Healthcare Safety Network. We applied the 4DX framework. This is a four-step method which includes creating a Wildly Important Goal, establishing measurable and accomplishable process measures, creating a scoreboard, and using a weekly meeting to provide accountability. Process changes included both physician and nursing practices. The physicians changed the criteria for when to order blood cultures, as well as requiring attending approval for cultures. The nurses engaged in a peer-observation practice improvement for "scrub the hub" and line dressing conditions and improved their own expertise for peripheral IV placement. The multidisciplinary team initiated a daily review of line indications to ensure removal as soon as possible. Overall, the CLABSI rate decreased from 7.39 infections per 1000 line days to 2.29 infections per 1000 line days over 1 year. We subsequently achieved over 635 days without a CLABSI. In conclusion, the 4DX was a successful quality improvement technique in our healthcare context. Because of the simplicity of implementation, we think it is broadly applicable in the healthcare setting.

INTRODUCTION

Problem Description

Our burn intensive care unit (BICU) is located in an academic medical center and is a 10-bed unit comanaged by both burn surgeons and anesthesia critical care intensivists. Nationally, BICUs have central line-associated bloodstream infection (CLABSI) rates that surpass the pooled mean of other intensive care units (ICUs) by 2–3 fold.[1] Unfortunately, our CLABSI rate had risen to the 90th percentile of nationally reported rates,[1] an indicator that our quality of care was much worse than national benchmarks.

Burn patients are particularly vulnerable to infection, and for those who survive their early injuries the most common cause of mortality is sepsis.[2–4] The high risk of sepsis is due to loss of the protective skin, immunosuppression, prolonged need for indwelling catheters, and frequent operative interventions.[5,6] Despite this vulnerability, several BICUs across the United States have successfully reduced their rates of CLABSI with good results.[7,8] Remington et al added a line insertion checklist and daily assessment of need for central access on rounds, as well as introducing line insertion "packs" with alcohol-impregnated caps; they also updated their nursing standards for central line care and expanded nursing documentation around the lines, resulting in a reduction of CLABSI rate from 2.2 to 0 over an 18-month intervention period.[7] Another group implemented sequential changes over a 9-year period, which included nursing training for IV site care and maintenance, line changes every 3 days, antibiotic-impregnated catheters, customized line insertion kits, universal gloves, and gowns, implementation of the Institute for Healthcare Improvement (IHI) bundle for CLABSI prevention, and use of a chlorhexidine patch. These changes resulted in a reduction in CLABSI rate from 14.07 to 2.17.

Please note, this report has been structured according to SQUIRE 2.0 guidelines, with additional input from two recent reviews of publications on the quality of quality improvement reporting in the surgical literature.[9–11] The manuscript will guide the reader through an explanation of our process with a focus on its effectiveness in our context, as well as our theory of its success and generalizability.

In light of these successful models, we felt an effort toward CLABSI reduction was warranted in our unit as well. In partnership with a hospital-wide effort to reduce device-associated hospital-acquired infections), our BICU employed a multidisciplinary approach to reduce our CLABSI rate.

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We were already utilizing many fundamental practices (described above) to prevent CLABSI, for example, line changes occurred every 5 days, we used a line placement checklist and "pack" to ensure sterile placement, and nursing training for proper care of the lines. Nonetheless, it was clear a new approach and theory were necessary. In the past, our physician team had relied on new protocols for changing practice, without significant input from nursing staff. These had been met with resistance. The Four Disciplines of Execution (4DX) framework seemed promising because it allowed the entire team to shape the improvement plan. Here we will describe the framework, and how we incorporated it, to decrease the occurrence of CLABSI.[12] We considered using a more traditional Plan-do-study-act (PDSA) framework; however, we had several reasons for choosing 4DX over typical healthcare improvement frameworks like the Model for Improvement.[13,14] First, PDSA requires sequential iterative changes that are studied, then changed. With line infections being rare events, it markedly increases the time frame to recognize the impact of each change.[14,15] Secondly, because 4DX allowed the entire team to develop changes simultaneously, we predicted that it would help with team engagement, especially on the part of the nursing staff. Finally, our team needed inspiration. The language of 4DX is designed to motivate (details below) in a way that is lacking in PDSA cycles.

Specifically, our goal was to reduce the rate of CLABSI by 50% (7.39 to 3.7 per 1000 patient line days) in the span of 1 year extending from July 2018 to June 2019. We adjusted this goal to target a quality improvement endpoint of 635 days without a CLABSI. The goal of this report is to demonstrate that 4DX is an effective framework for improving the outcomes of rare events in healthcare.

METHODS

This project was undertaken as a quality improvement initiative. All patients who were admitted or transferred to our Burn unit were captured in our outcome measures. Notably, the Burn ICU housed off-service patients, whose infections were pooled in hospital-reported statistics. These included medicine step-down and Otolaryngology oncology post-operative patients. Because our unit leadership bore accountability for all the patients in the unit, the interventions needed to span not just burn physician decision making, but also nursing practice for all the patients.

In determining the mode of intervention, the unit leadership considered unique aspects of our context, based on prior interventions which had been unsuccessful. We had learned that when nursing staff were not engaged in decision making, there was significant resistance to changes in protocol or practice. This resistance had caused prior change efforts to take significantly longer timeframes than were optimal and resulted in unnecessary conflict.

In addition, our unit is managed by both burn surgeons and anesthesia intensivists who utilize physicians in training (residents) as first-call providers. While this is a standard educational model throughout the United States, it provides challenges for consistency of patient care. The residents had excellent pattern recognition from previous ICU experiences, but some of these practices did not apply to our burn patient population.

Interventions (Figure 1: Key Driver Diagram)

Four Disciplines of Execution Framework

In light of this, we searched for a framework that would engage all the staff in creative problem solving. The 4DX is a

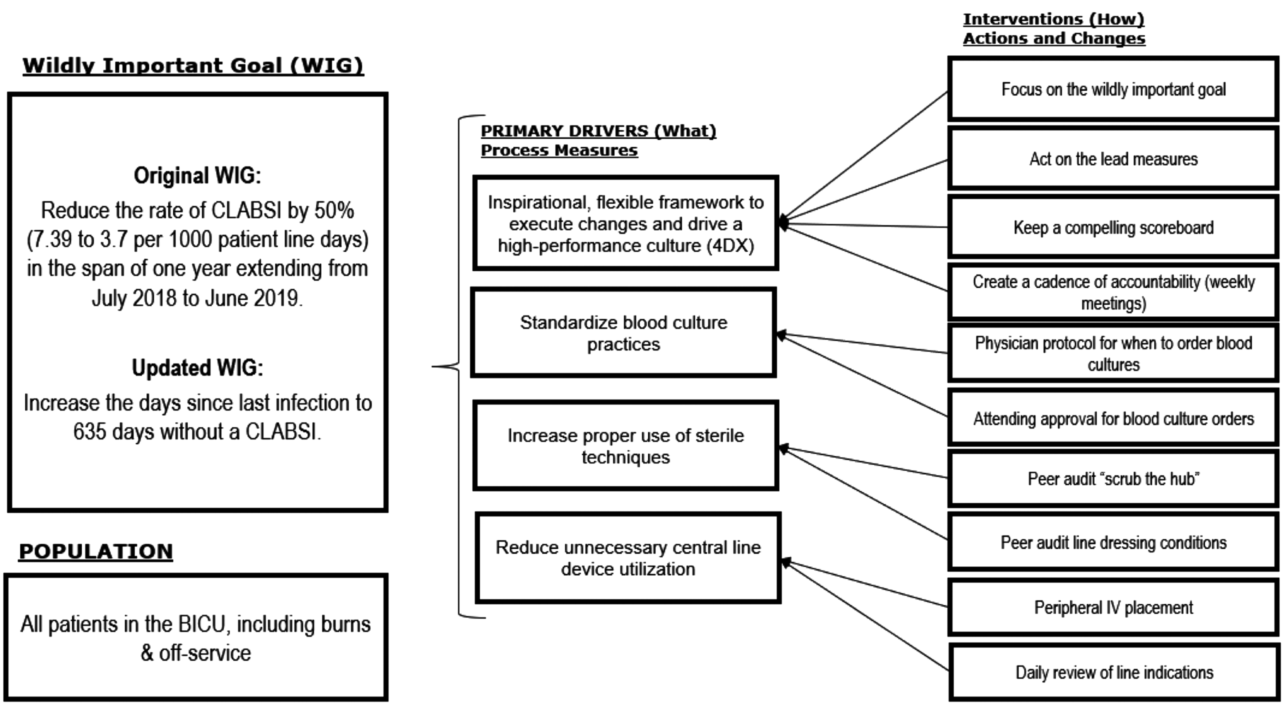

Figure 1. Key driver diagram. This figure summarizes our Wildly Important Goal, along with our process measures and primary drivers, and planned interventions.

four-step method of improvement developed for businesses that allows teams to work toward a common goal with measurable and time-sensitive outcomes, Figure 2. The First Discipline of 4DX is to create a *Wildy Important Goal* (WIG), which is the outcome measure. The guideline for this measure is for the team to conceptualize what is the highest priority endpoint for quality improvement, that will have the greatest impact in overall care. Because of how far our team was from national benchmarks, and the high risk of mortality related to sepsis, we agreed CLABSI reduction should be our quality improvement focus. In our scenario, the WIG was to reduce the CLABSI rate by 50% in the span of 1 year, extending from July 2018 to June 2019 (7.39 to 3.7 infections per 1000 line days). The Second Discipline is to establish *lead measures*, which are the process measures, that are both predictive and accomplishable. These consist of discrete measurable tasks that are likely to have an impact on the WIG. Discipline Three is *creating a scoreboard* for the process measures, followed by Discipline Four: establishing a *cadence of accountability*, which allows for reviewing and adjusting the implementation of process measures. The *cadence of accountability* uses a weekly 15-minute meeting with all physicians, advanced practice providers, and nursing staff. These were deemed "WIG meetings." At this meeting, we reviewed our scoreboard from the previous week. Then, beginning with the team leader, each person reviewed his/her prior week's commitment and performance, and committed to a new personal task for the following week. These meetings allowed for ideas to be shared, and problems to be creatively solved. Notably, the rationale behind the weekly team review of the scoreboard, and making of personal commitments, is that it helps the team maintain focus on the improvement goal. Many improvement projects are met with early enthusiasm that quickly gets lost in the "whirlwind" of daily tasks and responsibilities.[12] The meeting helps to keep the improvement initiative, outcome measure, and process measures at the forefront of everyone's daily practice.

We divided our subsequent interventions into three major categories (see Key Driver Diagram). The first was to standardize blood culture practices (physician-led intervention), the second was to improve the use of sterile techniques for line maintenance, and finally, to reduce unnecessary central line device utilization.

Standardization of Blood Culture Practices
We changed our blood culture ordering criteria to use the American Burn Association (ABA) consensus criteria for when to obtain blood cultures in the setting of a fever[16] (July 2018). A nurse then designed a simplified chart describing appropriate indications for blood cultures in burn patients, which helped the entire team easily reference the new protocol. We subsequently (August 2018) created a barrier to blood culture orders such that they required attending approval.

Other related changes that emerged as a result of using the 4DX framework were increasing line duration from 5 to 7 days, based on a recent study in a burn ICU,[6] as well as insisting that line change occur approximately 24 hours after an operation, and that no cultures be drawn in the immediate 24 hours after operation, as this is a period during which burn patients are frequently transiently bacteremic, but their fever does not represent a bloodstream infection (July 2018).

Increased Use of Sterile Techniques
The two primary nursing measures were "scrub the hub" and central line dressing maintenance. "Scrub the hub" meant that prior to accessing a central line port, the nurse was required to scrub it with an alcohol-impregnated wipe for at least 15 seconds. Central line dressing maintenance meant that dressings around central lines had to be both dry and intact. That meant the dressing had to be sealed down to the skin around the entire periphery, and there was to be no fluid or blood pooled underneath it. These measures were aligned with hospital process measures, and each unit was tasked with how to record and display these results.

Reduced Unnecessary Central Line Device Utilization
This change was accomplished utilizing a line assessment tool daily, which hung as an erasable sheet outside the room. This included date of line placement, as well as a requirement to check a box with one of four hospital-approved criteria for need for IV access (Medications that require central line, diuresis/dialysis/extracorporeal membrane oxygenation, hemodynamic monitoring, or inability to obtain other IV access). Because there were two rounding teams daily (the ICU and Burn Surgery team), this provided clear communication between physicians and nurses about line needs and duration,

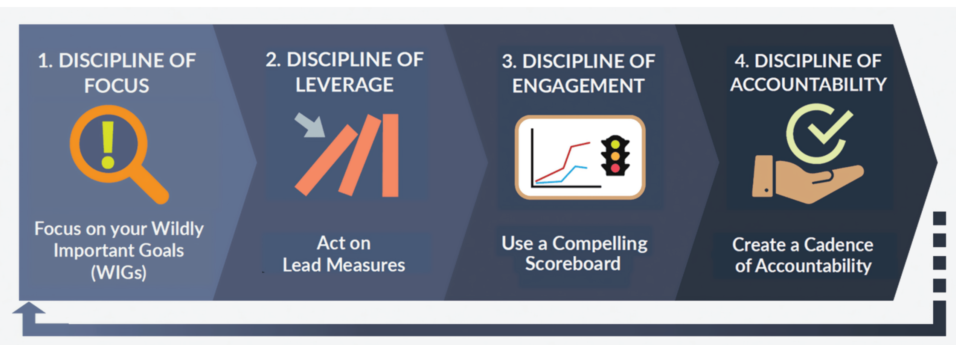

Figure 2. The four disciplines of execution. This is a well-known four-step method of improvement developed for businesses that allows teams to work toward a common goal with measurable and time-sensitive outcomes.

and served as a reminder to remove the lines as soon as possible.

During the weekly WIG meetings, the team assessed the impact of process measures by reviewing the scorecard and discussing qualitative feedback about the effectiveness of the 4DX framework. The CLABSI rate and line utilization were assessed monthly on a line chart and P' chart, respectively, and posted on the board. The T chart of days between CLABSI was added to assess the statistical significance of the outcome measure. We established a long historical period on the T chart in order to create a baseline with a stable bias, then compared the baseline mean to the postintervention data. The only changes made were the planned interventions described in the key driver diagram, so our theory attributes the changes to the special cause signals on the control charts.[17] As described above, some of our changes were learned from published success stories from other units.

Using a Laney P' Control chart, and a T chart (described below), we were able to demonstrate a special cause during the initiative.[18,19]

Noting that the methodology used (4DX) was the major intervention, it allowed, as a global strategy, for rapid change in practice across disciplines (physician and nursing), which sped the rate of change compared to the more typical PDSA cycles frequently used in the healthcare setting. Through our WIG meetings, process measures were identified and employed for both nursing staff and physicians.

There were changes that we instituted as part of the WIG meeting, but that did not constitute process measures in the sense that we did not track their before and after frequency. These were clearly a useful aspect of the overall intervention technique (4DX), but we did not quantify the fidelity of these changes. These will be described in detail in the results section.

We used an erasable whiteboard to demonstrate progress on the two nursing process measures (scrub the hub and line dressing maintenance). Unfortunately, we did not keep this data. However, we observed a trend from low compliance to nearly 100% over about 6 weeks.

Similarly, we did not measure compliance with blood culture practices. However, this became a weekly discussion at the WIG meeting, that is, cultures that had been ordered and canceled, or cultures that were drawn because the patient met criteria. Because of the frequent discussions around blood cultures, it quickly became a hardwired practice in the unit; even travel nurses were aware that it was a fundamental practice to confirm appropriateness of the order with the medical director prior to proceeding with the blood draw.

Analysis

In order to establish significance in our outcome measure (our WIG), we used historical data of CLABSI events and line days from patients, some of whose demographic data was not available in our current electronic medical record. Available demographic data is summarized in Table 1. Outcome and process measures over time were analyzed using Shewhart control charts for statistical process control, which is a quality improvement tool supported by the IHI. Data were analyzed using software package QI Macros v2019.06 (KnowWare International, Inc., USA) and Microsoft Excel (Microsoft, USA). Baseline means and control limits should ideally be established with 20–30 points of preintervention historical data from a stable process, in order to capture common causes of variation in the process, and then extend or "freeze" them into the future. Interpretation of statistically significant signals followed The Health Care Data Guide rules for determining special cause.[20]

Our original outcome measure was the CLABSI rate per 1000 central line days as defined by the Centers for Disease Control and Prevention's National Healthcare Safety Network (NHSN), which is calculated by dividing the number of CLABSI by the number of central line days and multiplying the result by 1000. However, rare events in healthcare present a unique analytical challenge. For process improvement work, we need to look at our system data at least monthly, because annual aggregations would require at least 20 years of preintervention data and a shift signal of process change would require at least 8 years of monitoring to determine if interventions were effective. When more than 25% of baseline data points are zero, standard Shewhart attribute control charts will not have a lower control limit, which indicates that the measure of the event is rare in that stratification and/or aggregation method; therefore, the calculations and rules for determining signals of special cause become questionable. Since our CLABSI rate met the above criteria for a rare event, we converted the rates to continuous data as days between events on a T chart for our outcome measure. The preintervention baseline was established using all documented preintervention events consisting of 21 CLABSIs from September 13, 2010 through June 18, 2018, and excluded 455 days between December 2014 and February 2016 when the unit was closed. An outcome change during the postintervention period was deemed significant when a point above the upper control limit was reached; therefore, we updated our WIG to achieve over 635 days (the value of the upper control limit) without a CLABSI.[20]

Our data-driven process measure was central line device utilization ratio as defined by NHSN, which is calculated by dividing the number of central line days by patient days and multiplying the result by 100. We chose this as it proved to have the most rigorously collected data across the interventions. While a Shewhart P chart is appropriate for percentage ratio

Table 1. Patient demographics

Demographic	Value
Number of CLABSI	24
Missing Demographic Data	25% (6)
Median Age (yr)	46.5
Gender	83% Male
	17% Female
Race	83% White
	11% Black
	6% Other
Ethnicity	0% Hispanic or Latino

Demographic data of our BICU population with CLABSIs over a 10-year time frame from 2011 to 2020. Of note 25% of the demographic data was unable to be retrieved and is excluded from the patient characteristics in this table.

Table 2. Interventions

Intervention	Responsible Discipline	Month Intervention Started	Process Measure or Protocol or Practice Change
Blood Culture Criteria (ABA Consensus)	Physician	July 2018	Protocol
No Cultures 24 hr After Operation	Physician	July 2018	Protocol
Line Change at 7 d, Within 24 h of Operation	Physician	July 2018	Protocol
Scrub the Hub	Nursing	August 2018	Process measure
Burn Attending Approval for Blood Cultures	Physician	August 2018	Protocol
Line Dressing Clean and Intact	Nursing	August 2018	Process measure
Peripheral IV Access Expertise	Nursing	December 2018	Practice modification
Engaged Interventional Radiology	Physician	December 2018	Protocol
Line Indication Tool	Nursing	January 2019	Process measure

List of interventions, the discipline responsible for implementation, and the month and year in which the intervention was started.

data, our central line device utilization was unstable and overdispersed due to large subgroup sizes, where the majority of baseline points were outside the tight-appearing control limits. Since we were unable to aggregate the data to a time period less than monthly, we chose to analyze the data with a Laney P' control chart. The preintervention baseline was established using 28 months of data from March 2016 (after the unit reopened) through June 2018. A process change during the postintervention period was deemed significant when a shift occurred, defined as eight or more points on one side of the centerline, either all above or all below (Table 2).[4,8,9,20]

This was a quality improvement project, and was therefore deemed exempt from human subjects guidelines, per our institutional review board. There were no conflicts of interest on the project team. While we did not identify ethical concerns, we could see a theoretical concern that our decision to limit ordering of blood cultures might mean we were simply avoiding recognition of a bloodstream infection. Because we based this decision on clear criteria from an expert consensus panel focused on burn patients, we disagree with this assessment.[16] Instead, our practice became more evidence based and less aligned with nonburn patient practice in our institution.

RESULTS

We began the intervention with our first WIG meeting, at which we described the rationale behind both the framework chosen (4DX) and the WIG. We discussed what the most effective "scoreboard" would be for the team, as well as how the process measurements would be captured, that is, the nurses conferred and agreed that open audits made the most sense in our context. We then demonstrated the round-table commitments. The Medical Director began with a commitment to change the blood culture ordering protocol to be consistent with ABA guidelines, the nurse manager committed to designing the scoreboards, and the nurses each made individual commitments related to their practice with scrubbing the hub and line maintenance.

Standardization of Blood Culture practices

Burn patients are often febrile throughout their hospital stay as their burn injuries cause systemic inflammatory response syndrome. Fevers were paged to the on-call resident who responded by getting blood and urine cultures, as this is a practice learned in other ICU settings. However, the majority of time the burn patient does not meet criteria for being at high risk for bacteremia due to an isolated fever. This diagnostic challenge was addressed by an ABA Consensus conference, and recommendations were published in 2007.[16] Our team added the specific recommendations of that consensus to our BICU. This consensus addressed six areas of clinical change, three of which must be present to warrant obtaining blood cultures due to concern for bacteremia or impending sepsis. Furthermore, we recognized that simply listing these recommendations in the BICU would not ensure that an inexperienced provider would follow those recommendations. In this regard, we added an additional layer of limitation, whereby nursing staff did not draw blood cultures without verifying that the attending had approved this order

A unique aspect of our burn unit is that it is the home of off-service patients as well as burn patients, and the outcome measure includes all patients in the unit. One of the interventions, limiting blood culture ordering, presented a unique challenge, as the burn physicians did not have oversight of medical decision making for these patients. While the initial intention was to limit culture orders to any attending physician, it was soon interpreted by the nursing staff as needing approval from the burn attending. Thereby, the nursing staff essentially became the unit "guard dog" each time a blood culture was ordered. We learned that other service lines exhibited more generous criteria for ordering cultures, and sometimes an attending physician-level conversation over the patient condition and utility of the cultures prevented an unnecessary blood draw. We did not measure this protocol change, unfortunately, that is, the number of blood cultures ordered per week was not compared pre and postintervention. However, the physicians noticed a change in the practice of ordering blood cultures, and it anecdotally appeared to correlate with a decreased rate of skin-flora contaminated blood cultures, which is a hospital measure of quality that is tracked by our infection prevention team.

Increase Use of Sterile Techniques

The specific process measures that we used for our weekly scoreboard were nursing interventions, namely scrub the hub and central line dressing maintenance (August 2018). Prior to the intervention, we used silent audits, and found that our nurses scrubbed the hub so quickly it was nearly imperceptible to the auditor, which clearly represented a high risk for getting line-related infections. After the intervention began, we chose to have nursing staff audit each other openly, rather than silent audits, which provided two reminders of the effort, one provided by those auditing and one by those being audited. Blank audit forms were provided to each nurse at the beginning of her/his shift and returned at the end of the shift. These were compiled weekly and then placed onto the scoreboard located in our staff breakroom. The greatest labor cost was in ensuring nursing staff completed these audits, a task that was assumed by the health unit coordinator on each shift, and that the data were compiled and placed on the scoreboard in time for the weekly meeting. The nursing manager oversaw the latter task. As described above, we used an erasable whiteboard to demonstrate progress on these measures. The nurse manager posted the day shift team next to the night shift team, and this "competition" kept the entire group engaged in the process.

Reduced Unnecessary Central Line Device Utilization

Changes initiated as a result of the line indication tool (described above) (January 2019) were measured on the line utilization P' chart. We noticed that the entire team began to view central lines as a "threat" to patient safety, and worked harder to find alternatives as we focused on this intervention. One of the results of this culture change was a nursing-initiated effort to increase expertise in placement of peripheral IVs (PIVs), which led to heavier reliance on midlines. At one meeting, a nurse recognized that if she was more capable at placing PIVs, there could potentially be a decreased need for central lines. She then went on to independently initiate an effort to learn how to place ultrasound-guided PIVs. Many other nurses followed her lead. (December 2018). These two changes in practice led to a significant decrease in central line utilization (Figure 3), and was the best evidence that this measure impacted our WIG (outcome measure).

Overall, the CLABSI rate decreased from 7.39 infections per 1000 line days to 2.29 infections per 1000 line days over the intervention period spanning from July 2018 to June 2019 (Figure 3), so our original WIG was exceeded, and while this is not statistically relevant from a process improvement standpoint, it was inspiring for the team. That said, we altered our specific aim to "days between" to ensure we could demonstrate a benefit of the 4DX intervention, and we continued this outcome measurement beyond the initial proposed timeframe to demonstrate sustainability.

On analysis of our updated outcome measure of days between CLABSI on the T chart (Figure 4), the mean days between the 21 CLABSIs during the baseline period was 69 days and the upper control limit was 635 days. There were only three CLABSIs after the project started, with days between the previous infections at 14 days, 165 days, and 640 days, respectively. Our altered WIG of 635 days since the last infection was exceeded when a special cause above the upper control limit was detected on September 14, 2020 as we achieved 640 days since the previous CLABSI on December 14, 2018.

On analysis of our process measure of central line device utilization ratio on the Laney P' chart (Figure 5), the baseline

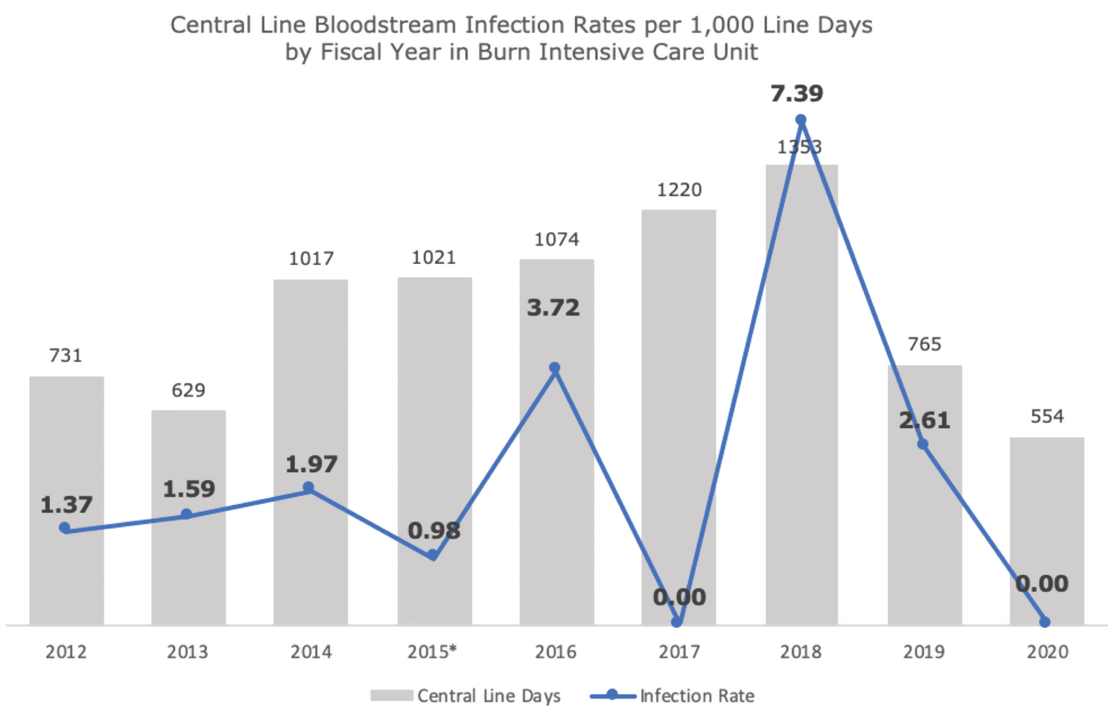

Figure 3. Central line bloodstream infection rates per 1000 line days by fiscal year in burn intensive care unit. This chart shows both yearly total central line days, and central line infection rates per 1000 line days.

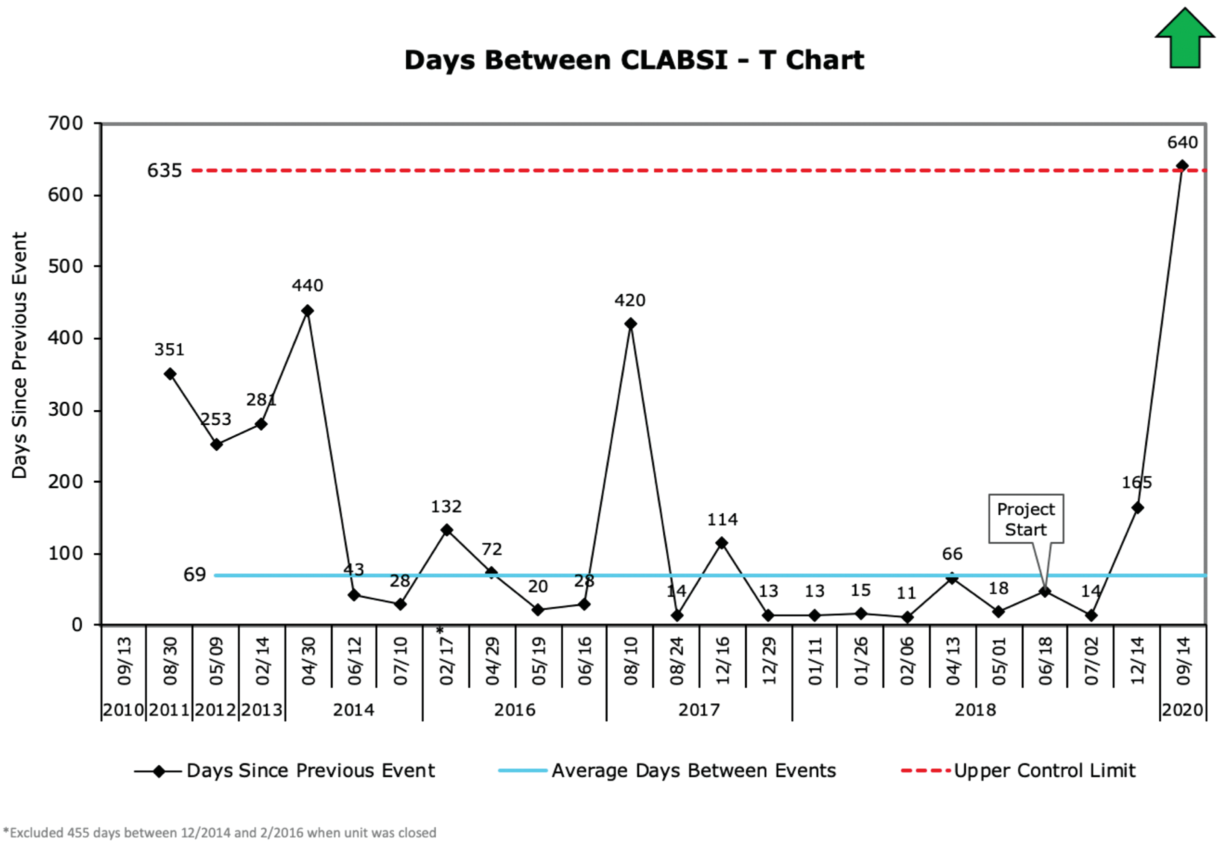

Figure 4. Days between Central line-associated bloodstream infection (CLABSI) events—T chart. This figure details days between CLABSI, and shows a significant increase in this interval since the commencement of our interventions.

mean was 42%. Two special cause signals were detected in April, 2019; this data point was below the lower control limit and was also the eighth consecutive point below the centerline, indicating that our interventions targeting central line utilization days resulted in a significant process shift starting in August 2018, 1 month after our project started. The postshift mean was 25%, representing a 40% decrease from the baseline mean. Additionally, our monthly case mix index was compared to our monthly central line device utilization ratio and found to have no correlation, suggesting that the decrease in line days was due to our targeted interventions and not because of a change in patient complexity.

An unintended consequence was engagement with the Interventional Radiology (IR) team. In December, one of our patients got a CLABSI after having an IR procedure. As part of our investigation into why the CLABSI occurred, we learned the IR team had not been included in the hospital-wide effort to improve practice around line placement and maintenance, which loomed as a threat to tunneled lines throughout the hospital. After a physician-level discussion with IR leadership (a commitment the Medical Director made during a WIG meeting), sweeping changes were instituted and IR was included in the hospital's protocol changes for central line safety (December 2018). We felt this was a particularly unique outgrowth of the 4DX process, as it was prompted during the WIG meeting for the unit leader to commit to engaging on this broader level.

DISCUSSION

We exceeded our WIG of decreasing the CLABSI rate from 7.39 infections per 1000 line days to 2.29 infections per 1000 line days and achieved over 635 days without a CLABSI. This success was effective in our context because it promoted input from each team member. Rather than a consensus approach of stepwise interventions measured in sequential cycles (PDSA), each team member created solutions, some of which were adopted broadly, while maintaining focus on the overall goal discussed at our weekly meetings.

As we improved, there was a clear morale boost that increased the enthusiasm among the entire team to maintain focus on our daily practice changes. Our overall intervention framework (4DX) corresponded with statistically significant changes on both the Laney P' chart and T chart, giving credence to the association between the intervention and the outcome.

Some centers have had success with single interventions, such as changing the duration between line changes,[21,22] adding chlorhexidine baths,[23,24] adding IV port covers, using antibiotic-impregnated lines,[25,26] and using topical antimicrobial ointment at line sites.[27] As a unit, we already practiced most of these, the exception being using topical ointment at the line site. Because our infection rate was still high, we felt a broader intervention that gave us the opportunity for iterative changes, behavioral modification, and

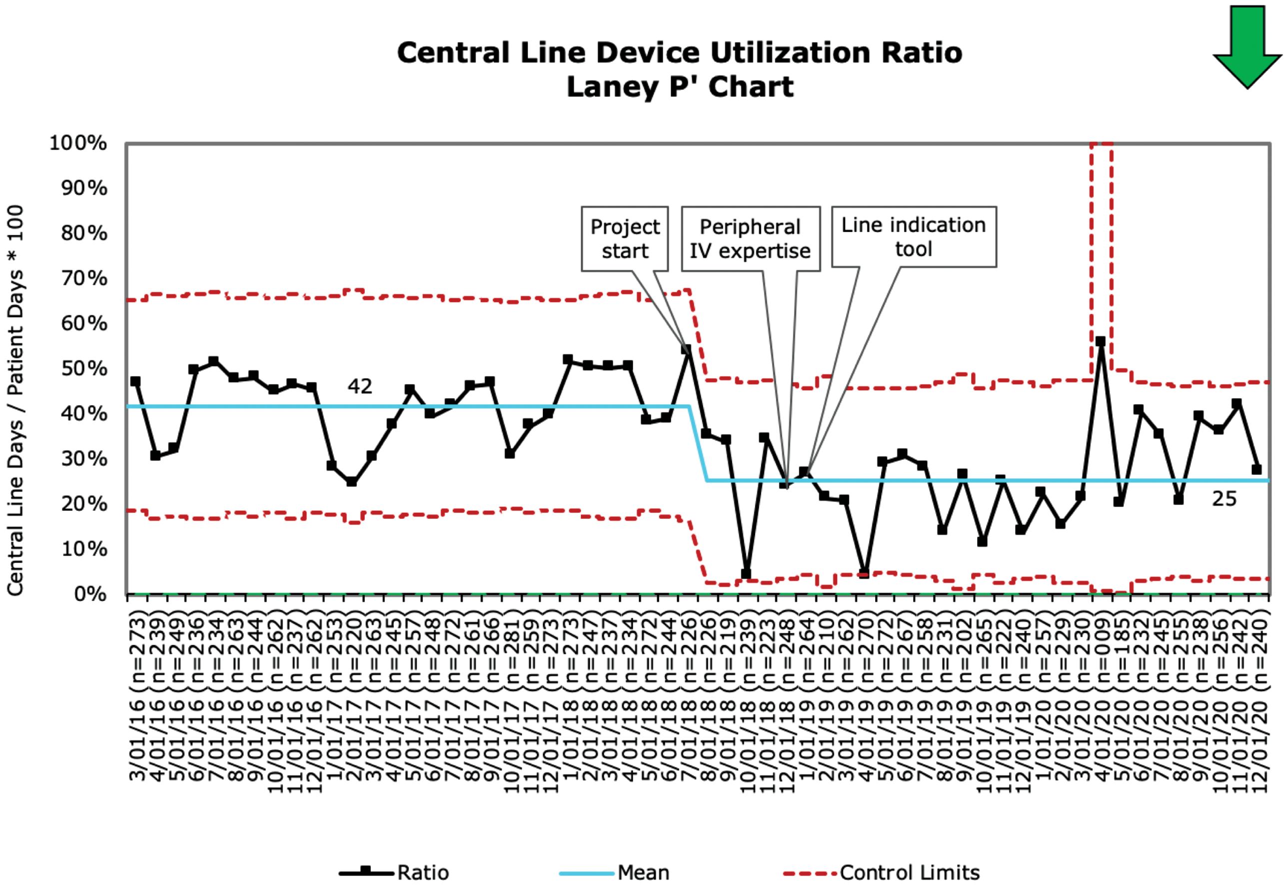

Figure 5. Central line device utilization ratio Laney P prime chart. This chart shows central line utilization as a ratio of central line days per patient days and is expressed as a percentage, as well as annotations for the interventions targeted to reduce line days. As seen here, there is a significant decrease in overall central line utilization throughout our intervention period.

more team involvement would be necessary. Therefore, this quality improvement intervention involved a longitudinal, multiintervention approach.

There were two similar published interventions comparable to our own. Remington et al reported an effective multiintervention approach: over 2 years they reduced their rate of infection from 1.2 infections per 1000 line days to 0 infections per 1000 line days, although only 30 months of historical data were reported with 11 CLABSIs which were analyzed with parametric *t*-test hypothesis testing on nonnormal data.[7] They divided their approach into checklists, equipment, and nursing care. In contrast to our study, the number of blood cultures drawn increased after their intervention but they were able to maintain a rate of zero CLABSIs over the study period. Another study performed by van Duin et al describes multiple interventions over a 9-year period which decreased their central line infection rate from 14.07 infections per 1000 line days to 2.17 infections per 1000 line days.[8] This was an impressive improvement, although the duration to accomplish such change was lengthy, and preintervention data are not available for analysis. In comparison, our intervention caused rapid improvement, that was demonstrably sustainable over nearly 2 years.

We chose 4DX over PDSA as a framework in part because we felt it held a greater motivational opportunity for our team. The language of 4DX is inspiring (WIG and "Scoreboard") compared to a rather boring acronym of PDSA. In addition, while we appreciate the scientific rigor of PDSA (studying each intervention sequentially), this still requires more of a top-down approach, that is, a leader or small cohort needs to decide on the next single iteration of change and instruct the team to change. Because we had seen prior top-down efforts fail, 4DX offered the promise of team engagement that leveled the playing field with regards to who directed the innovations. In addition, it is important to recognize that PDSA is a method borrowed from the car manufacturing industry, specifically Toyota, and it is only one of 14 principles used in their context for quality improvement.[28] It has been frequently heralded in the medical literature as a gold standard for methodological superiority of quality improvement efforts.[29] However, Ornstein et al called this into question.[30] The authors utilized mathematical modeling to demonstrate that when a problem is universal, that is, the same problem presents itself identically no matter the context, and the problem is simple, PDSA is most effective. However, for context-dependent and highly complex problems, PDSA is not very effective. Instead, a combination of what is termed "Evidence-Based Decision Making" and PDSA seem to have the greatest impact. A notable difference between car manufacturing and critical care is that much of car manufacturing is now automated, while the majority of patient care still requires direct human interaction and behavior. In light of this, a process that impacts human behavior (like 4DX) toward higher-quality performance may be particularly effective to produce a quality shift.

Studies using PDSA often have high-volume interventions with rapid access to assessing change, for example, hundreds of trauma admissions per week in a recent report by Stonko et al that allowed for quick 2-week cycles with demonstrable impact.[31] Because line infections are already rare events, this type of sequential cycling produces slowly visible results. While we understand that the intended output of PDSA is learning and informed action,[14] our approach allowed for the same as we adjusted our practice weekly based on each participant's observations and our "scoreboard" of process measures.

When discussing quality improvement changes, one important aspect is opportunity cost. One opportunity cost was our weekly 15-minute meeting, given that time is an extremely valuable commodity in the healthcare setting. Coordinating a meeting between physician and nursing staff was difficult initially due to clinical responsibilities and lack of enthusiasm. Over the course of our initiative, the value of our interventions and weekly meetings was recognized, leading to increased participation.

The meeting provided multiple benefits. Primarily, it focused the entire time on our interventions and engaged team members on all levels. Our scoreboard review was performed during this weekly meeting and was a powerful tool as it allowed the team to see our performance quickly. Initially, there was some concern regarding night shift team members input and participation as our weekly meeting was hosted during the day. To address this concern, our scoreboard consisted of both day-shift and night-shift process measures. This improved our night shift team members' participation and enthusiasm. In fact, the simplified chart describing appropriate indications for blood cultures was designed by a night shift nurse; a demonstration that 4DX inspired the entire team.

Another opportunity cost was the decision to take away authority from the resident physician team to order blood cultures when not indicated. We modeled this practice after the Neurological ICU in our hospital, who instituted a similar practice in their ICU regarding urine cultures. As a result, the Neurological ICU greatly reduced the number of Catheter-Associated Urinary Tract Infections. While this added the unpleasant aspect of attending physicians being called to approve blood cultures at all hours of the day, it was used as a learning point for all residents that rotate in our Burn ICU.

Analyzing data visually on Shewhart control charts can help mitigate some of these opportunity costs as well as other losses by facilitating accurate decision making and taking actions with the necessary information. Shewhart charts help achieve an economic balance of mistakes made in an attempt to improve. Mistake One—reacting to an outcome as if it came from a special cause when it actually came from common causes of variation—incurs both financial and emotional losses. Losses may include the resources spent erroneously investigating something special that is really not special. In addition, there are opportunity costs inherent in failing to push for the changes needed to the underlying processes. The costs associated with Mistake Two—treating an outcome as if it came from common causes of variation, when it actually came from a special cause—include failing to learn from the special cause signals that let us know when improvement interventions are effective or ineffective.[20]

Limitations of our initiative include the open collection and weekly review of our process measures. The 4DX model takes full advantage of the Hawthorne effect, which is the theory that when people are being knowingly observed, they will modify aspects of their behavior. However, we found it highly useful to capture audits openly rather than collect information blindly. The improved and sustained consistency is an indicator that there was likely more than an observational effect; rather the system itself changed such that these behaviors became "hardwired" into the process. We believe this collectively was habit forming and led to the significantly decreased CLABSIs.

We believe that our intervention, 4DX, as outlined above, can be applied to a broad range of burn care providers and other clinicians. Furthermore, we found it equally important that all team members, especially those in leadership positions, would prioritize attending our weekly meetings. Despite the difficulties in scheduling clinical responsibilities, our medical director made it a top priority to be present at all weekly meetings and found that this contributed to the Burn ICU's overall morale and cohesiveness. Full engagement of leadership was critical.

In conclusion, the 4DX was a quality improvement framework that was profoundly successful in our healthcare setting. Because of the process of change that included the entire team's efforts at behavior modification, we found it to provide sustainable results in how our team approached the care of patients with central lines. It was a simple framework, that has proven itself in the business realm, and was equally effective in the healthcare setting. We think the global concept of providing concrete goals, short-term feedback, and accountability from the entire team were hallmarks of its effectiveness. This method improved our team's innovation and collaboration, and created a more cohesive team. We have since applied this method to other aspects of patient care, including hand hygiene, and have found that it is continues to be an impactful tool for quality improvement in our center.

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