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Major Article

Minimizing central line–associated bloodstream infections in a high-acuity liver transplant intensive care unit

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Key Words:
Central line–associated bloodstream infection
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Background: Increases in liver transplant patient perioperative acuity have resulted in frail immunosuppressed patients at elevated risk for nosocomial infections. Avoiding central line–associated bloodstream infections (CLABSIs) is paramount to facilitate transplantation and post-transplant recovery. In 2015, our liver transplant intensive care unit (ICU) CLABSIs accounted for more than 25% of all CLABSI at our institution. We therefore undertook a multidisciplinary collaborative among clinical epidemiology, nursing, transplant surgery, and critical care to eliminate CLABSI events.

Methods: From 2014-2016, using Lean methodology and plan-do-study-act (PDSA) cycles, 14 interventions were implemented in the liver transplant ICU. Interventions were aimed at infection prevention, care standardization, and team-based monitoring. Implementation used quality improvement methodology including audit and feedback, education, standardization, multidisciplinary stakeholder involvement, and PDSA cycles. Process measures were monitored and audited. CLABSI rates per 1,000 central venous catheter (CVC) days were tracked by clinical epidemiology.

Results: During the intervention, 901 CVC catheter audits were completed. Improvements were seen on all process measures, and complete compliance increased from 25%-67%. CLABSI infection rates dropped from 4.2 to 1.8 in 1,000 CVC days, with an average of less than 1 CLABSI per month. This marked a 61.2% annual reduction, which correlated with an estimated $935,000 annual savings.

Conclusion: Concerted ongoing multidisciplinary collaboratives are essential to minimize CLABSI and optimize value and quality in a challenging, high-acuity patient population.

Over the past decade, liver transplantation has been faced with increasing acuity due to continued organ shortages paired with sickest-first allocation policies. Such dramatic increases in perioperative acuity have rendered frail immunosuppressed liver transplant patients at elevated risk for nosocomial infections, particularly central line–associated bloodstream infections (CLABSIs). In a variety of publications evaluating infections after abdominal organ transplantation, liver transplant recipients have been noted to have the greatest incidence of post-transplant bloodstream infections and to have worse overall outcomes.[1-4] In studies that have evaluated the source of bloodstream infections among liver transplant patients, catheter-associated infections are among the most common.[2,5,6] Furthermore, infectious complications have been strongly associated with increased morbidity and mortality, especially in the early post-transplant period.[2] Therefore, preventing infections, particularly after

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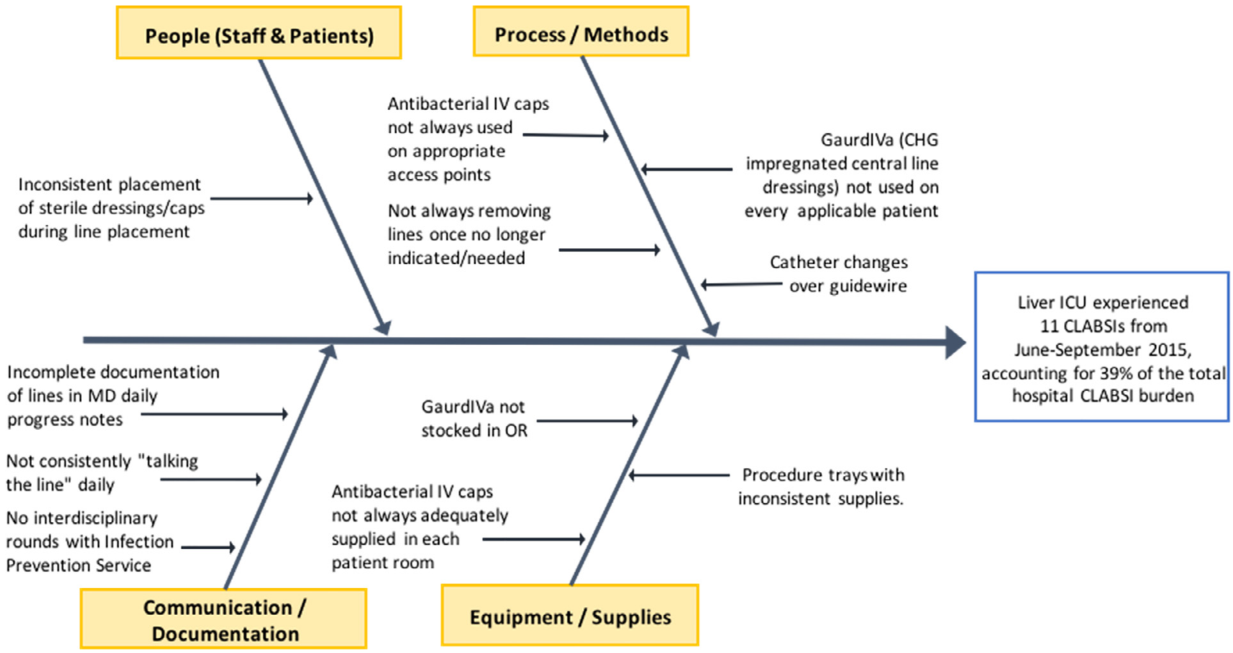


Fig 1. Fishbone diagram indicating potential root causes for the elevated central line–associated bloodstream infection rate within the liver intensive care unit by category: People, Process/Methods, Communication/Documentation, and Equipment/Supplies.

transplant, is of paramount importance due to the potential effect of infection on both liver graft and patient survival.[7,8]

There is substantial evidence that both multidisciplinary and bundled interventions can have a significant effect on hospital CLABSI rates, but sustaining these efforts can be challenging.[9,10] Although extensive work has been done to improve the rates of CLABSI among pediatric and hematologic transplant patients, the literature is relatively devoid of reports of CLABSI interventions among adult liver transplant recipients.[11-13]

As part of a hospital-wide infection control initiative, our center has tracked CLABSI for each inpatient ward since the early 2000s. In August 2015, the liver transplant intensive care unit (ICU) at our institution was noted to be a high outlier for CLABSIs compared to other hospital units. From January to August 2015, the average number of CLABSIs in the liver intensive care unit (ICU) reached 2.5 per month, and the average rate was 4.3 per 1,000 central venous catheter (CVC) days. Overall, the CLABSIs within the liver ICU accounted for more than a quarter of all CLABSI events within the hospital. We therefore undertook a multidisciplinary collaborative among clinical epidemiology, nursing, transplant surgery, and critical care to minimize CLABSI events.

METHODS

This study was reviewed and determined to be exempt by our institutional review board.

Study design

Using a multidisciplinary team, Lean methodology was employed with the aim of reducing the rate of CLABSI within the liver transplant ICU. Root-cause analysis identified potential areas for intervention and improvement. Specific interventions derived from the potential root cases were implemented through 2 phases. Over the course of the study, process measures were used to assess implementation, and the rate of CLABSI per 1,000 CVC days was monitored as the primary outcome. The aim of the interventions was to minimize the rate of CLABSI, with a goal of 1.2 or fewer per 1,000 CVC days.

CLABSI monitoring

CLABSI surveillance was conducted daily by our institution's clinical epidemiology and infection prevention department across all hospitalized patients. Patients with at least 1 positive blood culture and at least 1 central line in place for more than 2 calendar days on the date of event were evaluated for bloodstream infection status using the U.S. Centers for Disease Control and Prevention's National Healthcare Safety Network surveillance definitions.[14] Patients who met the criteria were considered to have a CLABSI. All potential CLABSI cases were evaluated by 2 infection control coordinators (certified registered nurses [RNs] or epidemiologists) and verified by an infectious disease physician. CLABSI events were counted per 1,000 CVC days for each unit and for the overall hospital system.

Liver ICU CLABSI intervention

The liver transplant ICU is a 24-bed unit providing comprehensive care to patients prior to and after liver transplantation. A multidisciplinary team composed of physicians, nurses, and clinical epidemiologists, and led by the nursing unit and surgical director of the liver transplant ICU, was established in August 2015 with the primary aim of reducing CLABSIs. Root-cause analysis was completed, and both fishbone and driver diagrams were developed to identify potential interventions (Fig 1). The 4 areas for improvement included technique, awareness, environment, and monitoring. Two early interventions, related to technique and awareness, were implemented immediately, whereas broader interventions from each of the identified areas of improvement were implemented in 2 phases, the first in January 2016 and the second in April 2016. A summary of interventions by phase is included in Table 1.

Prior to the implementation of Phase 1 interventions, random audits were initiated to assess technique, quality, and safety measures related to CVCs, hemodialysis catheters (HDCs), intravenous (IV) tubing, and patient environment. A discussion of these audits is included in the following. These audits were then continued and used as process measures to assess implementation throughout the course of the initiative.

Table 1
Summary of interventions by time period

	Early interventions	Phase 1	Phase 2
Technique	Introduction of GuardIVa central line dressings	Revised sterile dressing procedure CVC dressing change video required for all nursing staff Revised blood culture collection technique GuardIVa required for all CVC dressings CHG treatment daily for patients with CVCs Standardized CVC procedure cart Standardized CLIP	Revised CVC dressing change technique Modified admission order sets
Awareness	Nursing education: CVC and IV care	CLABSI prevention and information board	
Environment		Monitored disinfection of high touch areas Installation of additional hand sanitizer dispensers	
Monitoring		Central line audits (active daily management) Talk the Line during physician rounding and nursing handoffs	New physician note template

NOTE. GuardIVa is a specialized chlorhexidine-impregnated sponge dressing with hemostatic properties placed at the insertion site of venous catheters.
CHG, chlorhexidine-gluconate; *CLABSI*, central line–associated bloodstream infection; *CLIP*, central line insertion procedure; *CVC*, central venous catheter.

Intervention time periods

For this evaluation, the preintervention period was considered January to August 2015; the early intervention period was September to December 2015. Phase 1 was January to April 2016, and Phase 2 was May 2016 to March 2017.

Early interventions

Two CLABSI-related interventions occurred in September 2015 after the initial identification of the high CLABSI rate within the liver transplant ICU. The first of these was the introduction of specialized GuardIVa (Bard Access Systems, Salt Lake City, UT) central line dressings. GuardIVa is a chlorhexidine-impregnated sponge dressing with hemostatic properties placed at the insertion site of venous catheters.[14] During this initial introduction, GuardIVa dressings were encouraged but not mandatory. Additionally, CVC and IV education was done informally by nursing staff.

Audits

Beginning in January 2016, random audits were completed every shift for patients with at least 1 CVC. The audits included 6 process measures for CVCs, 6 for HDCs, 5 for CVC- or HDC-associated IV tubing, and 4 for patient environment (Table 2). Audits were completed by a staff RN with immediate feedback to the bedside nurse. Monthly audits were also completed on all patients with CVCs by the Unit Practice Council (nursing leadership). An audit was considered compliant if all criteria were met and no changes or adjustments were required. Individual compliance on each measure was independently monitored. Results of both random and monthly audits were used as process measures during the intervention period.

Phase 1 interventions

Phase 1 included 7 new interventions for revised technique, 1 for awareness, 2 for environment, and 2 for monitoring.

The revised technique interventions included revised sterile dressing procedures, CVC dressing change training videos required for all ICU nurses and new hires, new blood culture collection technique, GuardIVa patch requirement for all CVC dressings, chlorhexidine-gluconate (CHG) treatment for all patients with a CVC, standardized CVC procedure cart, and central line insertion procedure standardization. The revised sterile dressing procedures required standardized technique and placement of a standardized sterile pressure dressing. To teach this technique, a CVC dressing change video was developed by ICU nursing leadership and was required for all nurses. The video included a step-by-step explanation of unit policies related to CVCs and HDCs and demonstrated the appropriate technique for dressing changes. The video was played during nursing huddles each shift in January 2016, followed by an email to all RNs with a link to the video. Additionally, CVC dressing changes were added to annual nursing competencies and evaluated during annual reviews. The new blood culture collection technique required that samples be taken from all existing venous lines and mandated the volume of blood required for each sample. CHG treatments were required for all patients with a CVC or HDC and were administered daily by the bedside nurse using a standard technique: washing from the neck down with CHG-impregnated wipes.[15,16] A CVC insertion cart was also developed and standardized across the unit. The cart contained all necessary supplies for CVC insertion, and a new CVC sterile kit included all necessary sterile supplies, including saline flushes and dressings. The insertion procedure was also standardized, requiring the presence of the bedside nurse throughout the entire procedure, and the addition of an audit monitoring the sterility of the procedure. The audit was completed during the procedure and documented catheter indication, practitioner

Table 2
Active daily management checklists

CVC/HDC	IV tubing	Environment
☐ Dressing and site are dry	☐ Tubing dated	☐ High-touch surfaces disinfected
☐ Entire border of dressing attached to skin	☐ Tubing not expired	☐ IV pumps disinfected
☐ GuardIVa patch placed	☐ Solution not expired	☐ Daily CHG bath given
☐ Line is indicated	☐ Tubing is not touching floor	☐ Caps on all lines changed (weekly, Sundays)
☐ Talk the Line completed with RN handoff and MD rounding	☐ Caps on all ports of IV line	
☐ Caps on saline locked ports		

CHG, chlorhexidine-gluconate; *CVC*, central venous catheter; *HDC*, hemodialysis catheters; *IV*, intravenous; *MD*, medical doctor; *RN*, registered nurse.

completing the insertion procedure, insertion site, a 5-point sterile barrier checklist, and catheter type.

The awareness intervention included development of a CLABSI prevention and information board in the ICU workroom. The board detailed new unit policies, outlined new procedures, included a chart of the CLABSI rate, and indicated the days since the last identified CLABSI.

The 2 environmental changes included monitored disinfection of high-touch areas and installation of hand sanitizers outside each patient room.[17] High-touch area disinfection included cleaning bed rails, supply carts, over-bed tables, and IV pumps within each room each shift. Prior to the intervention, hand sanitizers were located on the interior of each patient room; however, this was a potential barrier to hand sanitizer use prior to entering the room. Therefore, new hand sanitizer dispensers were placed on the exterior of each room.[18] In addition, new signage was placed encouraging hand washing upon entering and exiting patient rooms.[19]

The 2 monitoring interventions included central line dressing audits and the introduction of "Talk the Line" during physician rounding and nursing handoffs. Central line dressing audits are discussed above and incorporated the use of an active daily management tool to assure daily monitoring of lines and insertion sites. Talk the Line was led by the lead nurse on each shift, assuring each nursing handoff included a discussion of all CVCs and HDCs, and that during physician rounding each line and its indication were discussed for each patient so that unnecessary catheters could be discontinued promptly.

Feedback, monitoring, and plan-do-study-act cycle—round 1

Throughout the course of Phase 1 interventions, monthly meetings were held to monitor progress and identify areas for continued improvement. Data collected from the active daily management tool, monthly audits, and infection rates were presented. All identified CLABSIs were discussed, and potential root causes were identified.

Two drivers included in the first phase were identified as still needing improvement: technique and monitoring. Using physician, nursing, and infectious disease input, 3 additional interventions were designed and included in Phase 2, which was implemented in April 2016.

Phase 2 interventions

The 3 interventions included in Phase 2 addressed technique and monitoring. Technique changes included (1) revision to the CVC dressing change technique and (2) modified physician order set. The revised technique for CVC dressing changes required 2 RNs and assured active monitoring of sterile technique and peer-to-peer feedback. The new physician order set for new admissions to the ICU required blood cultures of all existing venous lines. Culturing all lines assured that all lines had negative cultures at the time of ICU admission.

The monitoring change included a new physician progress note template that included a standardized format and sections for line identification and antibiotic course. These new formats were designed to trigger physician line examination, assure accurate documentation, and assist in determining when lines could be discontinued.

Feedback, monitoring, and plan-do-study-act cycle—round 2

In parallel with Phase 1, meetings were held monthly to monitor progress and identify areas for improvement. Through these meetings, the need for additional educational refreshers were identified and implemented. Two of these interventions were as follows: (1) in November 2016, the dressing change technique video was re-presented during nursing huddles at the beginning of each shift in response to an increased rate of CLABSIs in October 2016; (2) in January 2017, in response to the decrease in compliance in December 2016, audits were assigned to more senior nursing leadership, and the rate of audits were increased per shift.

Statistical analysis

CLABSI rates (number of infections per 1,000 CVC days) were studied using a time series design, with baseline data obtained during the preintervention period, and continuous monitoring after interventions were initiated throughout each phase of the program. Run charts (graphical representation of the CLABSI rates over time) were used to monitor improvement and identify special cause variation.[20] Within quality improvement research, variation was defined as either common cause or special cause. Common cause variation is the typical fluctuation in rates of an outcome over time, whereas special cause variation is the change in the outcome that occurs due to an extrinsic force (intervention). There are multiple indicators of special cause variation. For this study, special cause variation was identified when there was a "shift" such that 8 sequential measurements (CLABSI rate each month) on the run chart were either above or below the preintervention mean; a shift of 8 points is equivalent to $P = .01$.[20-22] As a secondary analysis, bivariate statistics were used to compare the baseline rate (January to August 2015) to the last 6 months of observation (October 2016 to March 2017).

In addition to monitoring the primary outcome (CLABSI rate), process measures were also monitored and plotted on run charts. Process measures included the rate of compliance with each of the 21 active daily management components (6 for CVC, 6 for HDC, 5 for IV tubing, and 4 for environment) (Table 1). Bivariate statistics were used to identify statistically significant improvement in process measures. Comparisons were made between the baseline measures taken prior to the intervention period (December 2015) to the last 6 months of the study period (October 2016 to March 2017).

Hospital-wide CLABSI rates, excluding the liver transplant ICU, were used as a control/comparison group.

Statistical analysis was performed using Stata IC Version 15 software (StataCorp LLC, College Station, TX). Statistical significance was defined by a P value less than .05.

RESULTS

Process measures

During the study period, 901 CVC audits, 631 random audits, and 270 monthly nursing leadership audits were completed. Compliance, inclusive of both random and monthly audits, increased substantially over the 16-month period, with the initial preintervention rate of 25% and the new median rate of 67% over the last 6 months of the study period (Fig 2).

At the preintervention evaluation (baselines), the audit components with the lowest compliance were related to the placement of caps on port or IV tubing (caps placed on all CVC ports [59%], caps changed weekly on all lines [73%], and caps on all IV tubing lines [74%]) (Table 3). Outside of cap placement, daily CHG baths for patients with CVCs (75%), assuring hemodialysis catheter sites were clean and dry (76%), and Talking the Line during handoffs and physician rounding (78% for CVCs and 76% for hemodialysis catheters) had the lowest rates of compliance. The overall median rate of compliance across all measures was 83%.

Over the course of the intervention, the median for all compliance components was 90% or higher, except for changing caps on all lines once weekly (median 68%). The areas with the greatest improvement

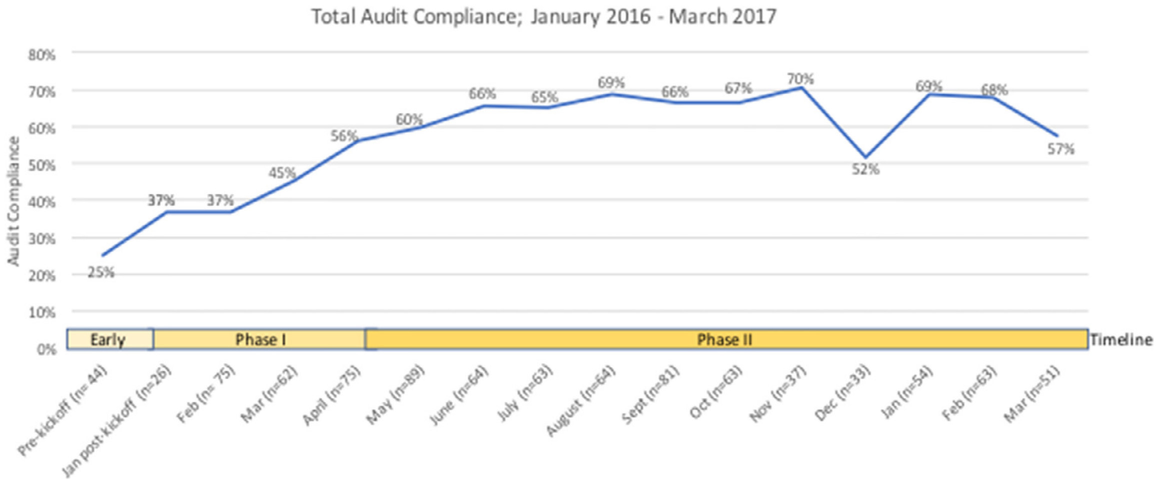


Fig 2. Compliance with daily random and complete audits. Rate of audit compliance—defined as one in which no adjustments need to be made after evaluation—over the study period. Timeline on the x-axis demonstrates the stage of intervention.

Table 3
Audit compliance by individual component

	Baseline	Postintervention (mean)	Change due to intervention	*P* value*
Number of audits	46	802		
CVC				
Dressing and site are dry	94%	91%	−3%	.002
Borders attached to skin	78%	93%	15%	<.001
GuardIVa patch placed	83%	93%	10%	<.001
Line indicated	91%	95%	4%	<.001
Talk the Line completed	78%	87%	9%	.003
Caps on all ports	59%	88%	29%	<.001
HDC				
Dressing and site are dry	76%	90%	14%	<.001
Borders attached to skin	84%	94%	10%	<.001
GuardIVa patch placed	86%	93%	7%	.002
Line indicated	97%	99%	2%	.003
Talk the Line completed	76%	87%	11%	.003
Dressing not expired	93%	96%	3%	.016
IV tubing				
Tubing dated	91%	96%	5%	<.001
Nonexpired IV tubing	96%	96%	0%	.698
Nonexpired solution	82%	96%	14%	<.001
Not touching floor	98%	99%	1%	.027
Caps on all IV lines	74%	90%	16%	<.001
Environmental				
High touch surfaces disinfected	84%	92%	8%	<.001
IV pumps disinfected	77%	89%	12%	<.001
Daily CHG bath given	75%	94%	19%	<.001
Caps changed on all lines (Sunday)	73%	68%	−5%	.144
All components (mean)	83%	92%	9%	<.001

NOTE. Audits were completed and monitored monthly. The number of audits varied by the number of patients present in the intensive care unit with central lines. Mean number of audits per month was 53.4 (range, 22-80); the total number of audits over the entire postintervention period was 802. The mean rate of compliance in the postintervention period is the mean of the monthly compliance rates after implementation.
CHG, chlorhexidine-gluconate; *CVC*, central venous catheter; *HDC*, hemodialysis catheter; *IV*, intravenous.
**P* value for 1 sample t test of the baseline value compared with the postintervention period.

included caps placed on all CVC ports (31% improvement), daily CHG baths (21% improvement), caps on all IV tubing, and CVC dressing borders attached to skin (16% improvement for both). The median improvement across all components was 11%. Overall trends for each compliance audit component are included in Figure 3.

Outcome measures

In the preintervention period, the median CLABSI rate within the liver transplant ICU was 4.3, with a peak rate of 7.1 in July 2015. Beginning in September 2015, a statistically significant special cause variation was observed in CLABSI rates, with a new median rate of 1.8 per 1,000 CVC line days, which was sustained throughout the study period (P = .01 by Statistical Process Control rules). Over the course of Phase 1 and 2 interventions, the number of CLABSIs was 1 or fewer per month, except for October 2016 (2 CLABSIs identified during this period) (Fig 4). Bivariate comparisons indicated a significant decrease from the preintervention period to the last 6 months of observation (P = .017).

Hospital-wide CLABSI rates throughout the study period were relatively constant, with a median rate of 1.2 per 1,000 CVC line days (no significant trends or shifts) (Fig 5).

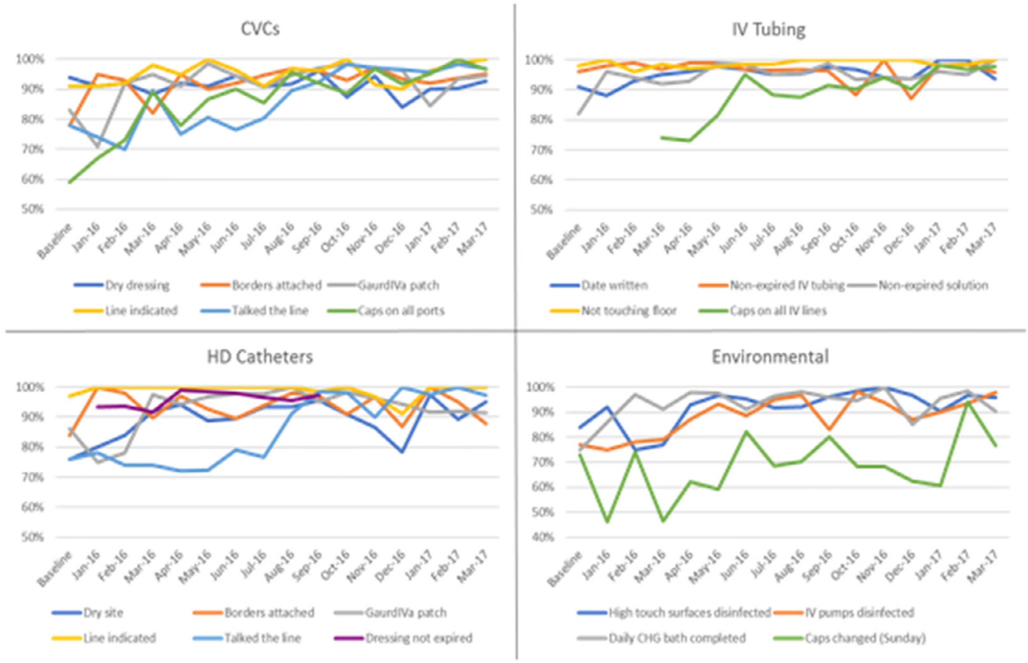
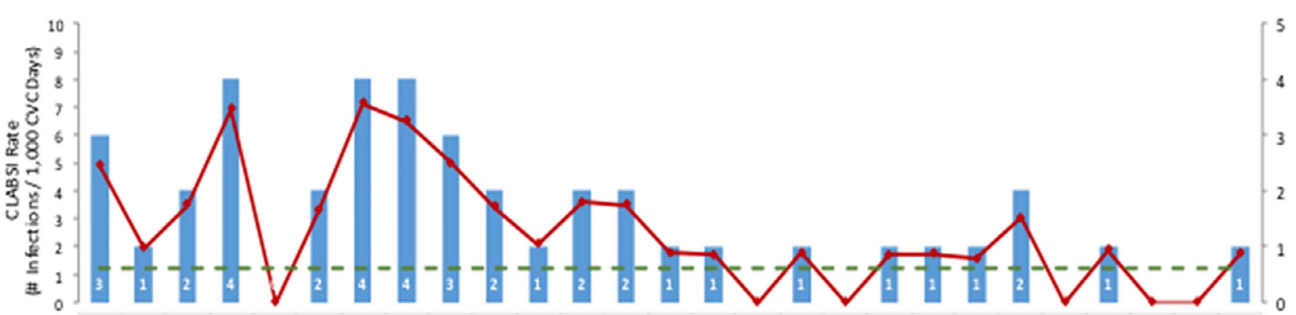


Fig 3. Compliance rates by each audit component from the baseline period through the end of the study period. Each graph indicates the measures for the specific type of line or environment being evaluated during the audit.



	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
	Pre-Intervention								Early Intervention				Phase I				Phase II										
CLABSIs	3	1	2	4	0	2	4	4	3	2	1	2	2	1	1	0	1	0	1	1	1	2	0	1	0	0	1
CLABSI Rate	4.92	1.96	3.48	6.92	0	3.32	7.13	6.50	4.98	3.42	2.07	3.58	3.50	1.78	1.71	0	1.76	0	1.70	1.74	1.56	3.04	0	1.86	0	0	1.73
Target Rate	1.20																										

Fig 4. Liver intensive care unit CLABSI rate and incidence. The line indicates the CLABSI rates, and the bar graph indicates CLABSI incidence per month throughout the study period. Timeline along the x-axis demonstrates the stage of the intervention. *CLABSI*, central line–associated bloodstream infection.

DISCUSSION

Given the high incidence of CLABSIs within our ICU and the potential effect on our already high-risk patient population, we undertook a broad multidisciplinary quality improvement project to minimize these events. Our study demonstrates that even in the setting of such high-risk, complex patients, multifactorial and interdisciplinary efforts can have a dramatic effect on the incidence of CLABSI. Using Lean methodology, our team identified a variety of potential root causes that contributed to the elevated rate of infection within our ICU. These root causes, which spanned a variety of health care roles, informed our core interventions: standardized CVC insertion procedures, standardized dressings, daily CHG baths, and active daily management monitored through peer-to-peer auditing. Over the course of the intervention, we noted a substantial improvement in overall audit compliance, with nearly every individual compliance measure reaching a median of 95% compliance. Such broad improvement led to a significant decline in the mean rate of CLABSIs, from 4.3 to 1.8 per 1,000 CVC line days. This rate continues to decline, and within the last 6 months of monitoring, 3 of 6 months had no CLABSIs identified. Overall, the CLABSI reduction program has contributed to a 61.2% decrease in the annual liver transplant ICU CLABSI rate, from 4.1 to 1.6 from 2015-2016.

Our interventions, which included prevention measures, process standardization, and awareness, are similar to those that have previously been published in other settings.[9,23-25] In particular, recently published meta-analyses have demonstrated that multimodal CLABSI bundles that harness quality improvement methodology consistently lead to reductions in infection rates.[26] The current study builds upon these previous works and demonstrates that even among the most complex patients, high

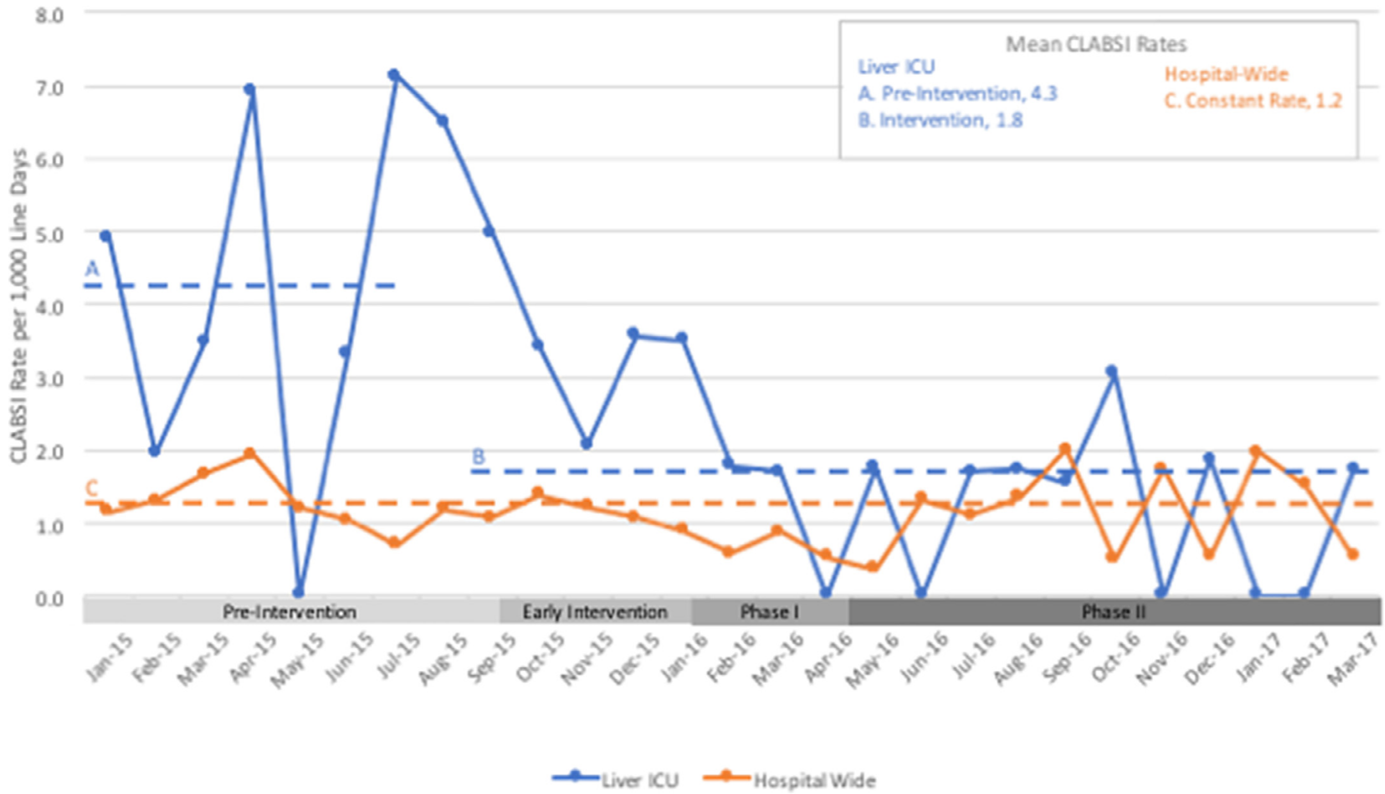


Fig 5. Comparison of the liver ICU to the hospital-wide rates. Comparison between the rates of central line–associated bloodstream infection per 1,000 central venous catheter line days for the liver ICU and entire hospital. Graph demonstrates that during the intervention periods, the liver ICU rates fell to meet the hospital average. *ICU*, intensive care unit.

compliance with evidence-based infection prevention principles and constant staff engagement can result in substantial improvements.

A key component of our intervention that we think greatly contributed to successful reduction in infections rates was real-time auditing and infection monitoring with causal analysis for each new infection. Real-time auditing and feedback at the bedside assured that each prevention measure was in place on each patient, and that lapses in technique or dressings were addressed rapidly. Paired with constant infection surveillance, audit monitoring allowed our team to quickly address dips in compliance or increases in infection rate, as noted in October and December 2016. Addressing these issues rapidly assured that attention remained on the goal of CLABSI reduction and contributed to an overall culture change within the liver transplant ICU, which heavily prioritized the daily maintenance and monitoring of CVCs and HDCs. Finally, the multidisciplinary nature of our team assured that each new infection was assessed from all clinical angles.

Prevention of CLABSIs contributes to both an improved patient experience and a decrease in overall morbidity associated with use of CVCs and HDCs. In addition to these patient-centered improvements, reducing CLABSI rates also reduces health care costs. Previous literature has indicated that individual CLABSIs are associated with an estimated $55,000 per event, indicating that our annual reduction from 2015-2016 is likely associated with an estimated savings of $935,000.[27]

This study had notable limitations. First, it was initiated at a point when the infection rate was at its peak; therefore, the reduction in rates of infections over time may be influenced by a regression to the mean. Second, the unit of analysis was the ICU; therefore, individual changes in patient characteristics and risk factors were not controlled for or collected over time, both within the liver transplant population and in the comparisons between the liver transplant ICU and controls. Third, all interventions were made simultaneously; therefore, the individual effects of each intervention cannot be assessed independently.

As demonstrated by both our outcome and process measure run charts, there is still room for continued improvement. Our group continues to strive for elimination of CLABSI events and plans to make further adjustments and interventions as necessary.

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