Joint Commission Journal on Quality and Patient Safety

100K Lives Campaign

Using Real-Time Problem Solving to Eliminate Central Line Infections

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Central line–associated bloodstream infections (CLABs) exact a tremendous human cost. Of approximately 4 million patients admitted to intensive care units (ICUs) in the United States each year,[1] 48% receive indwelling central catheters to ease the delivery of medication and/or nutrition.[2] That translates to 15 million central catheter days.[3–5] Approximately 200,000 patients contract bloodstream infections from these catheters each year. These infections, which are often considered the inevitable collateral damage that accompanies complex critical care, come with associated mortality of 15% to 20%.[3–6] The financial costs are also considerable, with estimates of $3,700 to $29,000 per infection.[5]

Despite knowledge of the guidelines on central line placement developed by the Centers for Disease Control and Prevention (CDC),[7] in 2002 Allegheny General Hospital (AGH) reported an average of 5.1 infections per 1,000 line days in its medical intensive care (MICU) and coronary care units (CCU). This rate was somewhat better than the National Nosocomial Infection System (NNIS) average for comparable units (5.4 per 1000 line days).[8]

Questioning whether this complication rate was acceptable, in April 2003, the chairman of the department of medicine [R.S.], in collaboration with ICU staff and in partnership with the PRHI, set the goal of eliminating them. AGH looked for methods to improve performance and discovered powerful examples within industry. They found that a few organizations, such as

Article-at-a-Glance

Background: An estimated 200,000 Americans suffer central line–associated bloodstream infections (CLABs) each year, with 15%–20% mortality. Two intensive care units (ICUs) redefined the processes of care through system redesign to deliver reliable outcomes free of the variations that created the breeding ground for infection.

Methods: The ICUs, comprising 28 beds at Allegheny General Hospital, employed the principles of the Toyota Production System adapted to health care—Perfecting Patient Care™—and applied them to central line placement and maintenance. Intensive observations, which revealed multiple variances from established practices, and root cause analyses of all CLABs empowered the workers to implement countermeasures designed to eliminate the defects in the processes of central line placement and maintenance.

Results: New processes were implemented within 90 days. Within a year CLABs decreased from 49 to 6 (10.5 to 1.2 infections/1,000 line-days), and mortalities from 19 to 1 (51% to 16%), despite an increase in the use of central lines and number of line-days. These results were sustained during a 34-month period.

Discussion: CLABs are not an inevitable product of complex ICU care but the result of highly variable and therefore unreliable care delivery that predisposes to infection.

Toyota and Alcoa, have superior internal operations. Even though they provide similar products and services to similar markets as their competitors and used similar process technology, they achieve superior levels of quality, productivity, efficiency, flexibility, and safety. This level of performance is sustained through superior rates of improvement across broad ranges of products, processes, and functions.[9,10]

Leaders' improvement abilities lie in how they manage work to reveal problems as they occur and solve problems as they are revealed. Whereas many health care organizations try to solve problems with retrospective analysis of aggregated data, high-performing organizations improve their work at the time and place where inefficiencies, difficulties, and errors occur.[11–17] Doing so allows problems to be solved in context, taking advantage of information that is tacit to the interaction and that would be lost if aggregated or reported retrospectively.[18–20] The result is a continuous building of process knowledge and performance improvement.

The study reported in this article was designed to determine whether (1) the application of process improvement techniques used by Toyota could be applied to the rapid elimination of central line infections in two ICUs and (2) the results were sustainable during a three-year period. This article represents a more complete and up-to-date treatment of the ideas introduced elsewhere.[21] Reduction of CLABs was subsequently included as a plank in the Institute for Healthcare Improvement's 100,000 Lives Campaign. The campaign recently reported that it has exceeded its expectation with an estimated 122,300 lives saved.[22] AGH served as a mentor hospital for the campaign.

Methods

Setting

AGH is a 778-bed academic health center serving Pittsburgh and the surrounding three-state area. The hospital annually admits nearly 32,000 patients, and employs 4,600 people, including approximately 1,250 physicians. AGH is a major teaching affiliate of the Drexel University College of Medicine. The work was focused in the MICU and CCU, which comprised 28 contiguous beds with more than 1,700 admissions a year. Twenty-one critical care fellows and 60 internal medicine residents, as well as third- and fourth-year students, rotate through the MICU and CCU. Because this study was part of a quality improvement (QI) effort, an Institutional Review Board waiver was obtained.

Perfecting Patient Care™

The AGH working group drew on a local community resource, the Pittsburgh Regional Health Initiative (PRHI)[23,24] to learn about process improvement techniques rooted in the Toyota Production System (Lean thinking). AGH physicians, nurses, and infection control practitioners received five days of intensive training at PRHI in the improvement system called Perfecting Patient Care (PPC),[21,23–25] and then applied those principles in clinical practice. The team, headed by the chairman of the department of medicine, also included unit directors, infection control nurses, ICU nurses, and staff from PRHI [D.F., N.G., J.C.L.].

The PPC methods used at AGH entailed the following five steps:

1. Establish the true dimension of the current problem and establish zero as the goal.
2. Observe the actual work to find opportunities to standardize processes and stabilize systems.
3. Move quickly from retrospective data to actionable, real-time data analyzed and acted on immediately with every symptomatic patient.
4. Solve problems one by one as close to the time and place of occurrence as possible.
5. Provide continuous education in both process improvement and technique for new and rotating staff members.

Step 1: Chart Review of Patients with Central Lines. The team began by looking at individual infections, case by case, reviewing charts of the 1,753 persons admitted to the MICU and CCU between July 2002 and June 2003, during which conventional approaches were employed.

Step 2: Observation of Line Placement and Maintenance. With a clearer sense of the frequency, types, and consequences of CLABs in its MICU and CCU, the team began observing staff to determine how lines were actually placed and maintained. Ten residents, 10 fellows, 8 attending physicians, 16 nurses, 6 nurse aides, and 5 personnel responsible for providing materials were directly observed as they worked. A total of 40 hours of observations were conducted involving 8 central line placements and 12 line maintenance procedures. These observations revealed material, method, training, communication and other subtle factors that compromised line placement and maintenance.

Step 3: Real-Time Investigation of Individual Infections. At the same time that AGH's team studied and improved placement and maintenance methods, it searched for other possible causes by investigating any CLABs as soon as they were identified. Infections were initially defined as CLABs if they met one of three CDC criteria.[8]

During the period from July 2003 through June 2004, all positive blood cultures were reported to the infection control nurse [C.H.], who quickly investigated and classified them according to admitting diagnosis, origin, infection site, line duration before infection, and in-hospital mortality. Each occurrence was examined to its root cause as close as possible to receipt of a positive lab culture (range, 3–24 hours; average, 6 hours, including weekends). The root cause team investigating each occurrence included the infection control nurse, the physician of record, and the residents, fellows, and nurses caring for the patient. The team was headed by the chairman of the department of medicine.

Step 4: Developing Countermeasures. The results of the observations and real-time problem solving were new processes and procedures, collaboratively developed, which began as stopgaps or "countermeasures" (see Results). Four major countermeasures were developed and adopted in the first 90 days, but each new CLAB occurrence created new opportunities for learning and improving processes.

Step 5: Continuous Learning. Solving problems in real-time allowed the team to determine that training in central line placement was inadequate. The team developed a countermeasure that required new trainees (nurses and doctors) to be educated in a multidisciplinary training exercise using patient simulators with the guidance of physician mentors and nursing staff. Multidisciplinary training allowed all team members to understand the work standardization and their specific roles in an unambiguous way. Residents and fellows were also reeducated in subclavian line placement technique, and a portable ultrasound machine was provided to facilitate vein localization. Antimicrobial dressings were used for all catheters remaining in place for longer than seven days and on all femoral catheters inserted emergently.

Measurements and Analytic Methods

We compared the number of CLABs and mortality associated with them before (fiscal year [FY] 03) and after (FY04–FY06) the initiation of the PPC approach. We expressed the improvement in simple unambiguous terms such as number of patients infected and the risk of infection associated with a central line. We also expressed the improvement in process reliability as the risk of infections defined as the number of infections per number of lines placed.

Clinical outcomes were compared using the Chi-square test (age, sex, frequency, rates, lines) and Fisher's exact test (mortality, reliability). Differences were considered statistically significant if the $p < .05$.

Results

Between July 2002 and June 2003, the reported rate of CLABS, on the basis of NNIS criteria, in the MICU and CCU was 5.1 infections/1,000 line-days. When these data were decoded and reported in clinical terms, a dramatically different picture emerged (Table 1, page 482). Of the 37 patients who had a CLAB, up to one third suffered more than one infection (total CLABs, 49). Nineteen (51%) of the 37 patients died in the hospital. The unadjusted mortality rate of patients with CLABs was twice the overall mortality rate in the two ICUs (21%). Even when compared with critically ill, ventilated patients (35% mortality), patients with CLABs had a one- to twofold greater mortality.

The microbiology of CLABs involved more virulent organisms (*Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus*, and Gram-negative rods) likely contributing to the excess mortality. Importantly, femoral catheters accounted for 43% of the CLABs but were not included in the NNIS definition. Therefore, they were not "counted" previously, so rates were under-reported. With femoral lines included, the actual infection rate was 10.5/1,000 line days. Thus, the magnitude of the problem was far greater in terms of the frequency of infections, the virulence of the organism,

Table 1. Summary of Findings from Chart Review, Medical Intensive Care Unit and Coronary Care Unit, July 2002–June 2003*

Number of patients	1,753
Number of patients with central lines	1,067
Number of patients with central line–associated bloodstream infections	37
Number of central line–associated bloodstream infections	49
Infection Sites	
Femoral	21
Internal jugular	14
Subclavian	8
Radial arterial	3
Percutaneous (PICC)	3
Infections/1,000 line-days	10.5
Total Number of Lines Employed	193
Lines/patient	5.2
In-hospital mortality of central line–associated bloodstream infection patients	19 of 37 (51%)
Unit's overall in-hospital mortality	368 of 1,753 (21%)
In-hospital mortality of patients with DRG 475[†]	52/153 (35%)
Average Duration of Line Before Infections (days)	
Femoral	6 (2–9)
Internal jugular	8 (4–13)
Subclavian	14 (10–28)
Radial arterial	6 (4–8)
Percutaneous (PICC)	17 (8–32)
Organisms	
Coagulase-negative *Staphylococcus*	17 (35%)
Staphylococcus aureus	15 (30%)
MRSA	10
Candida species	9 (19%)
Gram-negative rods	8 (16%)

* PICC, peripherally inserted central catheter; MRSA, methicillin-resistant *Staphylococcus aureus.*

[†] Diagnosis-related group (DRG) 475 is used for ventilated patients with respiratory failure. This was the most common admitting diagnosis for patients who developed central line–associated bloodstream infections.

and the associated mortality than was conveyed in the epidemiological metric.

Observations revealed variations in line placement and management practices (Table 2, page 483). Interpretations varied among nurses as to what constituted appropriate technique. For example, site selection was based on clinician preference or perceived skill in performing a certain approach. Physicians did not always explain to patients and family members the procedure's risks, benefits, and indications. Communication among team members was inconsistent, with nurses hesitant to question physicians about breaches in sterile technique or the lack of procedure notes. Often, team members did not recognize that a patient had a central line or question its continued need. Certain clinical situations lacked clear procedures. For example, should a line present on transfer from another facility be removed when its integrity could not be verified, or should it remain pending signs of induration or erythema?

On the basis of observations made by and of staff, the units developed standards for evaluating site integrity and dressing changes. Practices were standardized by adopting a single common line insertion kit, specified sterile techniques, and standardized documentation for each procedure. Line placement protocols were reviewed and implemented through unit medical directors, fellows, and house staff. The decline in femoral catheter use led to a decline in the time required to change dressings from 15 minutes to 5 minutes. The presentation of data on standardized, unambiguous bedside displays about line sites and duration eliminated time wasted by physicians looking for information. The standardized practices allowed variations to be easily identified, so their consequences could be contained before they propagated into an infection. The standardized practices were accompanied by reinforcement of the value, as expressed in weekly working sessions, that safety and reliability in line placement and maintenance were not merely a priority but a precondition to the work.

Table 2. Observed Variations in the Practice of Central Line Placement and Care and Summary of Countermeasures that Were Developed During Step 2

Placement	
Observed sources of variation	**Resulting changes in practice**
No standard pre-procedure checklist	Pre-procedure checklist developed, including request for informed consent
Informed consent obtained infrequently (< 25%)	
No standard site specification	Standardized line insertion kit developed, including disinfectant, drape, gown, and gloves. System improvements ensure kit always available when/where needed.
No standard line kit	
No standard procedure for disinfecting site prior to line placement	
No standard procedure for draping the patient	
No standard procedure for gowning and gloving	
No standard documentation of the procedure	Standardized documentation of procedure developed, implemented
Line Care	
Observed sources of variation	**Resulting changes in practice**
No standard kit for dressing lines	Standardized dressing kit developed, always available
No standard definitions for site induration	Standardized definition for erythema and induration
No standard use of disinfectant	Chlorhexidine standard as disinfectant
No standard procedure for when a dressing would be changed	Daily observation of dressing site; document dressing changes at least every 5 days
No mechanism for following line location and duration	

At the same time that AGH's team studied and improved placement and maintenance methods, it searched for other possible causes by investigating any CLABs as soon as they were identified. These investigations uncovered other factors that had not been accounted for in line placement and maintenance guidelines that AGH had developed so far. Investigating close in time and place to the actual occurrence provided contextual information that would otherwise have been lost.

For example, one patient who developed an infection had a femoral line in place for four days. Yet CDC guidelines state a preference for the subclavian site. The team investigated this site choice by asking a series of "whys," designed to reveal the root cause of the problem:

1. *Why did the patient have a femoral line?* Because the line was inserted emergently at night.
2. *Why would inserting the line at night cause a physician to choose femoral placement?* As a teaching hospital, fellows generally end their shift at 6 P.M., although several remain on call. House officers either must call a fellow in from home or insert the line themselves.
3. *Why would house officers choose the femoral site?* Because femoral lines were perceived to be easier and safer to insert than subclavian lines, on which many house officers may not yet be trained.
4. *Why would a femoral line be left in place for four days?* Because the risk of infection had been understated, there was little sense of urgency about removing that line and inserting a new one at a preferred site.

The real-time investigation and problem solving transformed central line infections from mysterious processes shrouded in inevitability to recognized processes that could be improved and error avoided. Examples of countermeasures developed using real time problem solving included the following:

1. Remove femoral lines within 12 hours and replace with a line at a preferred site.
2. Replace dysfunctional catheters: do not rewire them.
3. Replace lines present on transfer.
4. Prefer the subclavian position for central lines.

These countermeasures were developed, implemented, and disseminated within 90 days of initiating the process. Notably, many of these countermeasures are not captured in CDC guidelines but are specific to the work and context of these ICUs.

Table 3. Comparison of Clinical Outcomes: Traditional Approach versus Perfecting Patient Care (PPC) Approach*

	Traditional Approach FY 03	PPC Approach FY 04 Year 1	PPC Approach FY 05 Year 2	PPC Approach FY 06 (10 months) Year 3
Intensive care unit admissions (*n*)	1,753	1,798	1,829	1,832
Atlas severity grade	1.9	2.0	2.1	2.2
Age (years)	62 (24–80)	62 (50–74)	65 (39–71)	64 (52–79)
Sex (M/F)	22/15	3/3	4/7	1/2
Central lines employed (*n*)	1,110	1,321*	1,487*	1,898*
Line days	4,687	5,052*	6,705*	7,716*
Infections	49	6*	11*	3*
Patients infected	37	6*	11*	3*
Rates (infections/1,000 line days)	10.5	1.2*	1.6*	0.39*
Deaths	19 (51%)	1 (16%)*	2 (18%)*	0 (0%)*
Reliability (no. of lines placed to get one infection)	22	185*	135*	633*

* $p < .05$ compared with the traditional approach.

The system redesign also included the creation of a help chain that cut through the organization's hierarchy. A nurse who experienced or observed a problem was to notify the charge nurse, who, if help was needed, would contact the unit director. Notification would continue up the help chain as necessary to the chair of medicine until the defect was addressed.

Table 3 (above) illustrates the magnitude of the impact of these system redesigns on clinical outcomes. From July 2003 through June 2004 (FY04), 6 CLABs in six patients were reported in the two units, compared with 49 infections the previous year (FY03). Central line infection rates fell from 10.5 infections to 1.2 infections/1,000 line-days. In keeping with the approach of analyzing problems when they occur, all six infections were investigated when they were detected. Four infections involved peripherally inserted central catheter lines, one a subclavian line, one an internal jugular line. Each line was in place for more than 15 days, requiring new countermeasures to deal with chronic indwelling catheters.

As the infection rate declined, so did the associated mortality rates. In the baseline year, 19 of the 37 (51%) patients who contracted CLABs died. In the following year, the number was 1 out of 6 (17%). All six CLABs in FY04 were attributable to coagulase-negative staphylococcal species. Methicillin-resistant *Staphylococcus aureus*, Gram-negative organisms, and fungal infections, which had constituted two-thirds of previous CLABs, were eliminated. The process reliability from 1 infection in every 22 lines placed to 1 in 185 lines placed.

Table 3 also illustrates the results in the second year of the continuous learning process on the basis of real-time problem solving. Notably, the number of CLABs increased from 6 to 11 patients but remained significantly lower than the incidence before the introduction of PPC initiative. Whereas ASG score, age, and sex distribution were not different, there was a 34% increase in line usage and a 33% increase in line days compared with the first year of the initiative. The rate of CLAB infections was 1.6 compared with 1.2 infections/1,000 line-days, but the process reliability decreased from 1 infection in 185 lines placed to 1 infection in 135 lines placed. The associated mortality remained the same and significantly lower than that observed before the PPC initiative. Rather than view the increase in CLABs as a failure, the team applied the same principles that led to the early success and seized the opportunity to learn from these more complex cases. They discovered that 7 of the 11 CLABs in FY05 were in PICC lines, where standardized processes had not been developed.

Specific and unique problems were identified with the use of peripherally inserted central catheter, including more frequent catheter manipulation and their use for phlebotomy in addition to infusion. These continuous learning processes have resulted in further reductions in actual infections in FY06 to 3 (0.39 infections/1,000 line days) and an improvement in process reliability to 1 infection in 633 lines through April 30, 2006. The units have not experienced a CLAB since August 14, 2005, despite an 11% increase in admissions, increased acuity, and a near doubling of line use.

Discussion

In the present study, we demonstrated that applying process improvement techniques and system redesign used in industry to the problem of CLABs resulted in rapid, dramatic, and sustainable improvement in clinical outcomes. The findings are in contrast to the results observed when traditional QI efforts were employed. Relying on aggregated, retrospective trend analysis of standardized reports meant that the severity of the problem was not fully appreciated. For example, because extensively used femoral lines were not being counted in the traditional reporting metric, only 19 of the 49 infections met CDC/NNIS reporting criteria. Although the risk of femoral lines remains controversial,[26] it was the most frequent CLAB site in our experience. Furthermore, the reporting of these infections in clinical terms, replete with their dire consequences, motivated workers to engage in process redesign in contrast to the use of complex epidemiological metrics, which were reportable but not actionable. The notion of inevitability is embedded in complex definitions and epidemiological metrics by which the data are generally reported, such as infections/1,000 line-days, which lack clinical context or accountability, and by benchmarking, which implies that there is an acceptable rate.

Moving to a one-by-one identification of variations with real-time problem solving was emotionally difficult. The construction of a clinical vignette about individual cases put nurses and physicians in the position of discussing complications and their potential consequences, with peers, patients and families. Ongoing education was required for house staff, fellows and faculty, some of whom challenged openly agreed-upon countermeasures. Such circumstances illustrate the continuous struggle between standardizing practice and the fierce adherence to physician autonomy that constitutes a significant barrier to patient safety efforts in organized medicine.[27] AGH had to contend with issues of status and hierarchy because nurses, by the nature of the direct, continuous care they provide to patients, were most often in a position to identify shortcomings in the methods used by physicians. This meant that the MICU and CCU units had to create a culture and mechanism for drawing attention to problems as they occurred.[28,29]

Despite these concerns, this work provides evidence that CLABs are nearly all preventable when real-time data are used to solve problems as they occur. AGH's experience encourages similar efforts to combat other systemic issues that compromise the delivery of care and demonstrates that the work, properly fostered, can move quickly. Most important, real-time problem solving has transformed the culture from one of blame to one of continuous learning in the pursuit of the elimination of these conditions.

Busy clinicians may see the discipline of real-time problem solving as too time intensive. However, AGH's experience was that solving problems—both in procedure and outcome—as they occurred reduced the need for staff to compensate for ineffective processes (for example, searching for material, information, or help). Having more reliable processes meant that staff members had more time to implement known infection control procedures consistently, and continually improve on them. Patients experienced fewer severe complications that needed time-consuming attention. Taken together, these improvements actually created more time for staff to solve problems and be involved in direct patient care. In addition, the number of admissions to the unit grew steadily without adding new staff or more beds, reflecting greater efficiencies associated with reducing central line infections and their extended length of stay. By focusing on processes, implementation and improvement occurred within 90 days.

Limitations

There are several limitations in our early work. Specifically, this is a single-center QI initiative employing methods used to eliminate defects in industry to the clinical problem of health care–associated infections. We compared the outcome of this initiative to retrospective results during a comparable period in which traditional QI approaches based on CDC guidelines were employed. We did not test to see whether the CDC guidelines were being applied with fidelity so we cannot determine conclusively whether our method is better. Our work goes beyond improvement efforts to date that focus principally on issues of proper placement to include a focus on line maintenance as well. The units treated medical intensive care and cardiac patients such that the results may not be applicable to other patient populations (pediatrics, oncology, surgical), although similar improvements have been reported recently from a surgical ICU[30] during a three-year period.

Summary

Real-time problem solving as a method of process improvement was applied to the clinical issue of CLBAs in two medical ICUs at AGH. A series of specific, actionable learning activities were created from observations of the care process and real-time analysis of problems. Data were expressed in clinical terms (actual number of patients infected and the risk of infection for central lines) as opposed to using ambiguous epidemiological metrics that tended to conceal the magnitude of the problem and provide little insight into the barriers to improvement. Instead, specific variations in the way care had been delivered prompted staff to make changes in the materials, procedures, and methods of communication used to insert and maintain central venous catheters. These modifications were associated with a 90% reduction in CLABS and a 95% reduction in mortality, sustainable for 34 months. J

The authors wish to thank Dr. Frank Davidoff for his advice on the manuscript.

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