

Toyota Production System Quality Improvement Initiative Improves Perioperative Antibiotic Therapy

Kelly H. Burkitt, PhD; Maria K. Mor, PhD; Rajiv Jain, MD; Matthew S. Kruszewski, PharmD;
Ellesha E. McCray, MSN, RN, MBA; Michael E. Moreland, MSW; Robert R. Muder, MD;
David Scott Obrosky, MS; Mary Ann Sevick, ScD, RN; Mark A. Wilson, MD, PhD;
and Michael J. Fine, MD, MSc

The Toyota production system (TPS) industrial engineering approach to improve manufacturing quality originated in the automobile industry and is being applied to quality improvement (QI) in healthcare delivery systems. In the TPS model, frontline work groups identify problems, experiment with possible solutions, measure the results, and implement strategies to improve quality, resulting in a “ground-up” rather than “top-down” approach to solving system problems.¹

Although the first article describing the use of the TPS in healthcare was published more than 20 years ago,² numerous recent publications describe the use of the TPS model to improve quality or efficiency in the healthcare setting.³⁻¹⁰ Toyota production system methods are associated with improvements in (1) diagnostic accuracy of thyroid gland fine-needle aspiration and Papanicolaou tests,^{3,4} (2) chemistry test turnaround time,⁵ (3) elimination of dead stock in radiology,⁶ and (4) decreased wait times⁷ and increased medical record completion in the emergency department.⁸

Beginning in 2001, a Veterans Affairs medical center (VAMC) instituted TPS methods to reduce methicillin-resistant *Staphylococcus aureus* (MRSA) infections on a general surgical floor. In addition to using the TPS process to facilitate implementation of MRSA prevention,^{11,12} the intervention evolved to address other areas for improvement in healthcare quality and efficiency on the surgical unit, such as developing and implementing an intervention to increase appropriate prophylactic perioperative antibiotic therapy, redesigning the supply cabinet and wheelchair distribution system, and improving the bar code scanning system for dispensing medications.

The objectives of the present study were to determine (1) whether the QI intervention for perioperative antibiotic therapy was associated with improvements in selection and duration of prophylactic therapy and (2) whether the overall MRSA prevention initiative was associated with a reduction in length of hospital stay (LOS) as a secondary outcome. We hypothesized that implementation of the QI intervention for perioperative antibiotic therapy would increase the proportion

of admissions receiving appropriate prophylactic antibiotic selection and duration and that the overall MRSA initiative would be associated with a decreased LOS.

Objective: To assess the role of a Toyota production system (TPS) quality improvement (QI) intervention on appropriateness of perioperative antibiotic therapy and in length of hospital stay (LOS) among surgical patients.

Study Design: Pre-post quasi-experimental study using local and national retrospective cohorts.

Methods: We used TPS methods to implement a multifaceted intervention to reduce nosocomial methicillin-resistant *Staphylococcus aureus* infections on a Veterans Affairs surgical unit, which led to a QI intervention targeting appropriate perioperative antibiotic prophylaxis. Appropriate perioperative antibiotic therapy was defined as selection of the recommended antibiotic agents for a duration not exceeding 24 hours from the time of the operation. The local computerized medical record system was used to identify patients undergoing the 25 most common surgical procedures and to examine changes in appropriate antibiotic therapy and LOS over time.

Results: Overall, 2550 surgical admissions were identified from the local computerized medical records. The proportion of surgical admissions receiving appropriate perioperative antibiotics was significantly higher ($P < .01$) in 2004 after initiation of the TPS intervention (44.0%) compared with the previous 4 years (range, 23.4%-29.8%) primarily because of improvements in compliance with antibiotic therapy duration rather than appropriate antibiotic selection. There was no statistically significant decrease in LOS over time.

Conclusion: The use of TPS methods resulted in a QI intervention that was associated with an increase in appropriate perioperative antibiotic therapy among surgical patients, without affecting LOS.

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Take-Away Points

We found that the use of Toyota production system methods as part of a nosocomial methicillin-resistant *Staphylococcus aureus* prevention initiative on a surgical unit resulted in interventions to improve the quality of care in other areas.

- Specifically, we found increased compliance with recommendations regarding appropriate prophylactic perioperative antibiotic use.
- Changes were primarily driven by improved compliance with appropriate antibiotic therapy duration not exceeding 24 hours.

To examine differences in LOS between our local VAMC and the other VAMCs nationally, we used the Veterans Affairs (VA) National Patient Care Database (NPCD) to identify a local cohort and a national cohort of patients who had an ICD-9-CM surgical procedure code at the intervention VAMC for 1 of the same top 25 proce-

dures. Finally, to identify the national study cohort, we used the same inclusion and exclusion criteria but extended our patient identification to all 116 remaining VAMCs nationwide.

METHODS

We used a quasi-experimental design to assess the association between implementation of a perioperative antibiotic prophylaxis QI intervention and appropriate perioperative antibiotic therapy over time. We also assessed the effect of the MRSA prevention initiative on LOS as a secondary outcome reflecting the overall efficiency of hospital care. This study received exempt human subject approval from the local institutional review board.

Study Cohorts

We used clinical and administrative databases to identify 2 local cohorts of surgical patients from the intervention VAMC and a national cohort of similar patients from all other VAMCs nationwide. Using the Veterans Health Information Systems and Technology Architecture (VistA) database, we identified a local cohort of patients who were admitted to the local surgical unit between fiscal years 2000 and 2004 with a primary *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* surgical procedure code. To maximize the probability of patients' spending time on the surgical intervention unit, we identified patients who spent their entire hospital stay on the unit and further refined the sample by including only those patients who had 1 of the 25 most common surgical procedures. This was necessary to ensure adequate numbers of patients within each surgical procedure type and to facilitate operationalization of appropriate perioperative antibiotic therapy. Once the top 25 procedures were identified for patients who spent 100.0% of their time on the intervention unit, we expanded our selection to include anyone who spent at least some of his or her admission on the surgical unit (Table 1). Information on antibiotic therapy was only available from VistA and was assessed only in this local cohort defined using VistA. For the LOS analyses, we excluded patients with an LOS longer than 90 days because they were more likely to have a severe surgical or medical complication. Therefore, data from this initial local VistA cohort were used to examine perioperative antibiotic selection and changes in LOS over time.

Study Setting

The TPS intervention was initially implemented on a 36-bed general and subspecialty surgical unit at the intervention VAMC, a 146-bed tertiary care hospital for veterans. On this unit, the attending VA physicians are faculty members of the local university school of medicine and provide clinical training for surgical residents.

Study Intervention

In November 2001, the surgical unit initiated a TPS intervention aimed to reduce nosocomial MRSA. The TPS team leader, a staff nurse (EEM), worked with unit staff to identify obstacles to identification and isolation of patients colonized with MRSA and to engage staff in problem solving for better MRSA infection control. The first interventions, initiated in spring 2002, involved training attending physicians, house staff, nurses, and laboratory technicians on proper hand hygiene, as well as systematic culturing of all admissions and isolating patients colonized with MRSA.¹¹

Although the primary goal of this initiative was to reduce nosocomial MRSA, efforts evolved to address additional processes of care that interfered with the new MRSA prevention procedures. With increased recognition that appropriate antibiotic use in the operating room and on hospital floors may also help prevent the development of MRSA and other postoperative bacterial infections, the staff undertook the task of improving appropriate selection and duration of perioperative antibiotic therapy. Staff on the unit identified the following 4 key barriers to this process of care: (1) reliance on a computerized bar code medication administration system that was frequently nonfunctional, (2) lack of standardization of perioperative antibiotic orders, (3) reliance on paper-based rather than computer-based medication records, and (4) monthly rotations of new surgical residents responsible for writing antibiotic orders. These barriers were identified and addressed in an iterative process as guided by TPS methods.

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Table 1. Comparison of Patient Characteristics and Surgical Procedures in the Local and National Study Cohorts

Patient Characteristic	Local VAMC Cohort ^a (n = 2550)	Local and National Study Cohorts ^b		P
		Local VAMC (n = 2958)	All Other VAMCs (n = 184,907)	
Demographics				
Age, median (IQR), y	66 (57-75)	66 (56-75)	65 (55-74)	<.01
White race/ethnicity, %	88.4	89.4	80.8	<.01
Male sex, %	96.9	97.2	96.9	.39
Proportion of hospital stay on surgical floor, %^c				
100.0	82.4	—	—	—
50.0-99.9	11.7	—	—	—
0.1-49.9	5.9	—	—	—
Admission source, %				
<.01				
Nonscheduled outpatient	25.4	25.9	49.1	
Scheduled outpatient	62.6	61.3	45.7	
Nursing home or domiciliary	6.8	7.2	2.8	
VA or non-VA hospital	5.1	5.5	1.8	
Other	0.1	0.1	0.5	
Comorbid conditions				
Diabetes mellitus, %	29.5	30.4	24.9	<.01
Malignant neoplasm, %	13.1	12.4	16.1	<.01
Chronic pulmonary disease, %	14.8	14.9	13.0	<.01
Comorbid conditions using Charlson Comorbidity Index, median (IQR) ^d	1 (0-2)	1 (0-2)	1 (0-1)	<.01
Type and No. of surgical procedures, %				
Orthopedic				
<.01				
Open reduction of femur fracture with internal fixation	3.3	3.5	3.1	
Open reduction of tibial or fibular fracture with internal fixation	2.3	2.1	1.8	
Total hip replacement	7.2	6.3	5.4	
Partial hip replacement	3.1	3.1	2.1	
Total knee replacement	10.8	9.2	9.2	
Revision of knee replacement	1.9	1.6	1.4	
Vascular				
<.01				
Enderterectomy of vessels of head and neck	7.3	10.9	8.6	
Peripheral vascular shunt or bypass	6.9	6.1	5.9	
Amputation of toe	6.3	6.6	5.4	
Amputation through foot	1.7	1.8	1.5	
Amputation below knee	3.6	3.5	3.8	
Amputation above knee	3.6	3.7	3.2	
Revision of amputation stump	1.9	2.1	2.1	
Genitourinary				
<.01				
Cystoscopy	4.9	5.4	5.0	
Transurethral excision of bladder	2.3	2.5	3.6	
Transurethral prostatectomy	3.7	3.5	6.5	
Radical prostatectomy	4.2	3.7	5.3	

(Continued)

■ **Table 1.** Comparison of Patient Characteristics and Surgical Procedures in the Local and National Study Cohorts (*Continued*)

Patient Characteristic	Local VAMC Cohort ^a (n = 2550)	Local and National Study Cohorts ^b		P
		Local VAMC (n = 2958)	All Other VAMCs (n = 184,907)	
Gastrointestinal and biliary	13.7	12.9	13.2	.61
Right hemicolectomy	3.6	3.5	4.1	
Sigmoidectomy	3.6	3.4	3.0	
Incisional hernia repair with prosthesis	2.0	1.8	1.8	
Laparoscopic cholecystectomy	4.5	4.2	4.4	
Skin	10.3	11.4	10.5	.10
Incision and drainage of skin and subcutaneous tissue	2.5	2.8	4.0	
Debridement of wound, infection, or burn	8.1	8.9	7.1	
Neurosurgery	9.6	8.8	9.8	.06
Exploration and decompression of spinal canal	4.8	4.4	4.3	
Excision of intervertebral disc	5.0	4.5	6.0	
Proportion of admissions with >1 procedure, %	8.2	7.9	7.3	.15

IQR indicates interquartile range; NPCD, National Patient Care Database; VA, Veterans Affairs; VAMC, Veterans Affairs medical center; VistA, Veterans Health Information Systems and Technology Architecture.

^aIdentified using VistA.

^bIdentified using the NPCD.

^cThis variable was not available in the VA national sample identified using the NPCD.

^dThe 13 distinct conditions that constitute the Charlson Comorbidity Index are myocardial infarction, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, peptic ulcer disease, liver disease, diabetes mellitus, hemiplegia or paraplegia, renal disease, malignancy, and AIDS.

Problems experienced by nursing staff in using the bar code medication administration system were addressed in late 2002 by purchasing a backup battery pack to ensure constant computer availability. To address lack of medical provider standardization in prescribing antibiotics, beginning in 2003 TPS staff enlisted the assistance of hospital pharmacists to establish evidence-based prophylactic antibiotic selection criteria for all common surgical procedures using the most recently published guidelines for specific surgical procedure types.¹³⁻¹⁶ This list of recommended antibiotics was approved by the head of infectious diseases (RRM) and the chief of surgery (MAW) at the intervention VAMC. By late 2003, guidelines for surgical antibiotic prophylaxis were available in the computerized VA order entry system and were printed on pocket cards distributed to all VA surgical attending physicians and residents. To address issues regarding appropriate duration of antibiotic therapy, a computerized standing order automatically discontinued antibiotics 24 hours after surgery. In addition, education was provided to new surgical attending physicians and residents at regular intervals.

Baseline Patient Characteristics

Patient demographic and clinical data were abstracted from VistA and NPCD from the time of the index admission. The demographic characteristics were age in years, race/ethnicity

(white vs nonwhite), sex, and admission source (nonscheduled or scheduled outpatient, nursing home or domiciliary, other VA or non-VA hospital, or other). We also assessed the number of comorbid conditions using the Charlson Comorbidity Index¹⁷ and the type of surgical procedure using ICD-9-CM diagnosis codes.

Processes of Care

Our assessment focused on 2 processes of care, appropriateness of perioperative antibiotic therapy and LOS. The analytic sample for the assessment of antibiotic therapy was restricted to surgical procedures performed within 1 day of admission, with no subsequent surgical procedures within 2 days. These criteria were used to limit the sample to patients who were specifically admitted for the surgical procedure and did not have more than 1 operation necessitating different types of antibiotic therapy.

Appropriate antibiotic therapy was defined as prescription of the recommended antibiotic agents consistent with the locally developed surgical prophylaxis guideline recommendations for 5 classes of surgical procedures (ie, neurosurgery, vascular, gastrointestinal and biliary, genitourinary, and orthopedic) for a duration not exceeding 24 hours. For carotid endarterectomy, antibiotics were not recommended by

our hospital guideline; therefore, no antibiotic prescription was considered compliant. Operations of the skin were not assessed because of the heterogeneity of surgical infections and a lack of consensus on appropriate antibiotics.

We defined LOS as the date of discharge minus the date of admission and defined postsurgical LOS as the date of discharge minus the date of surgery. For patients who died in the hospital, LOS was censored on the date of death.

Statistical Analysis

We summarized categorical variables using frequencies and continuous variables using medians and interquartile ranges (IQRs) because of the skewed nature of the frequency distributions. To compare surgical patients at the intervention VAMC with those at the other 116 national VAMCs, we used χ^2 tests for categorical variables and Wilcoxon rank sum tests for continuous variables. We used a 2-sided $P < .05$ to define statistical significance. All comparisons were performed using SAS 8.2 (SAS Institute, Cary, NC).

We used logistic regression to analyze appropriateness of perioperative antibiotic prophylaxis before and after implementation of the intervention, while accounting for the correlation of more than 1 surgical procedure for the same person (STATA 9.0; StataCorp LP, College Station, TX). Because the intervention was not applied to appropriateness of antibiotic therapy until the end of 2003, we used 2004 to define the first intervention year for these outcomes. To distinguish the effects of the intervention from any secular changes in perioperative antibiotic prescribing, we included a time variable in the models (year since 2000) and tested the differences in antibiotic compliance after the intervention (2004) compared with before the intervention (2000-2003) with adjustment for this linear trend.

To identify potential confounders, the research team reviewed all demographic and clinical variables that were available within the clinical and administrative databases and identified those variables that they believed could potentially confound the study outcomes. These variables included type of surgical procedure, admission source, age, and number of comorbid conditions. All of these potential confounders were then entered and retained in our models as control variables. An odds ratio greater than 1.0 indicates a greater likelihood of compliance during 2004 than in 2000 to 2003.

Because of the nonnormality of the data and the correlation of admissions for the same person or admissions from the same site, we analyzed LOS and postsurgical LOS using discrete survival analysis in SUDAAN 9.0 (Research Triangle Institute, Research Triangle Park, NC). We modeled LOS using a proportional hazards model that included covariate adjustment for the surgical procedure performed, admission

source, age, number of comorbid conditions, and separate baseline hazards for each year. Hazard ratios (HRs) exceeding 1.0 correspond to a shorter LOS. In-hospital deaths were censored at the time of death. Models were also run that included patients with an LOS exceeding 90 days. These methods were used with the national data from the NPCD to test if the LOS at the intervention VAMC was similar to that at other VAMCs, as well as to test whether change in LOS after the intervention on the surgical unit was similar to the secular trends in LOS observed at the other VAMCs. The national analyses accounted for the correlation of admissions at the same site and admissions for the same person.

In the local cohort defined using VistA, we tested whether LOS changed after implementation of the intervention. The estimate of the intervention effect quantifies the effect of the intervention over and above a linear time trend, as estimated by including a linear term for time in the analysis. The analyses in the local cohort account for the correlation of admissions by the same person. For all LOS analyses, 2003 was considered the first year of the intervention.

RESULTS

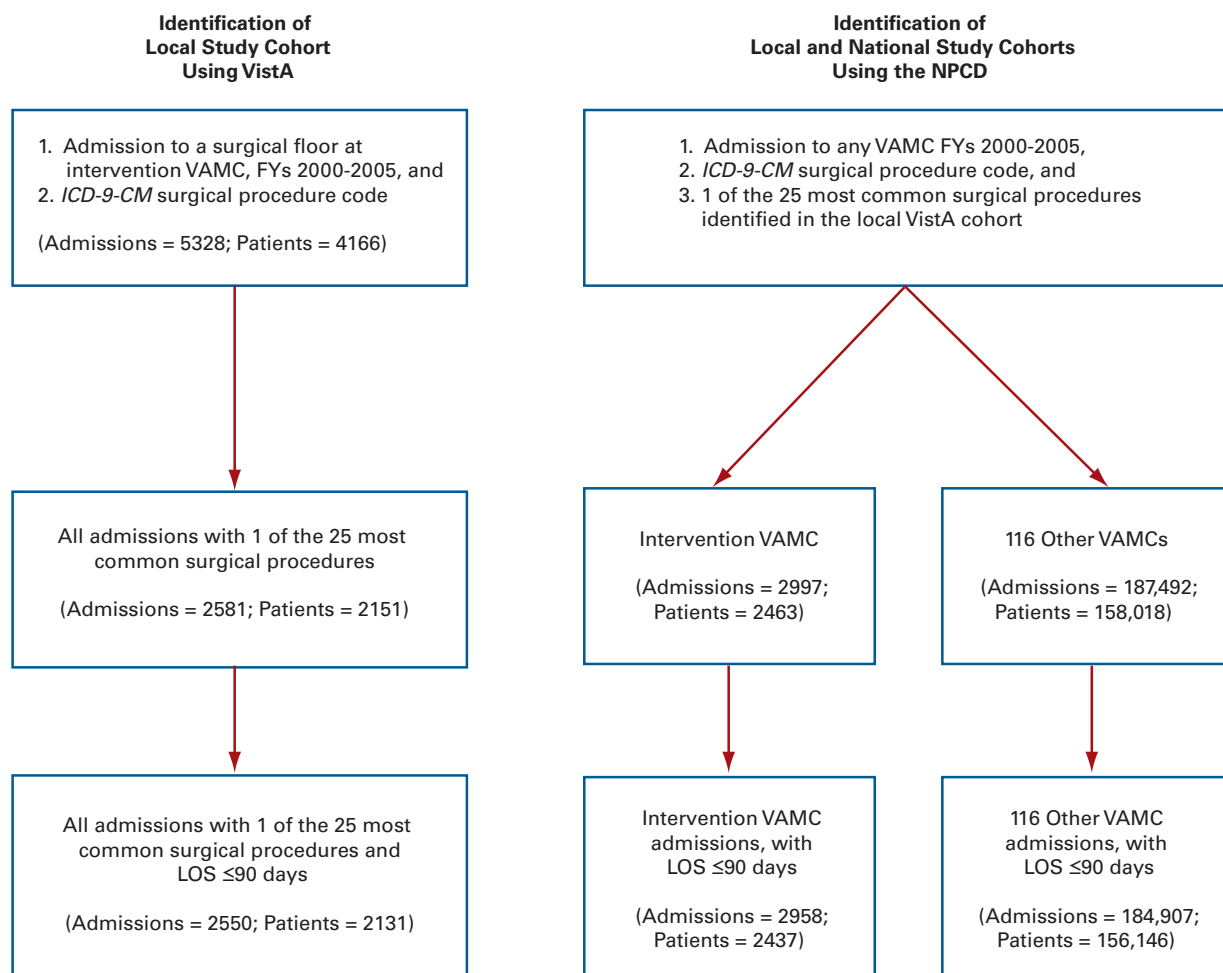
Using VistA, we identified 5328 surgical admissions to the unit between 2000 and 2004, of which 2550 admissions had 1 of the 25 most common surgical procedures and an LOS of 90 days or shorter. Using the NPCD, we identified a similar local cohort of 2958 admissions at the intervention VAMC and 184,907 admissions at the 116 other VAMCs nationwide (Figure 1).

Characteristics of the Study Cohorts

Most patients in the local study cohort identified using VistA were white (88.4%) and male (96.9%) and had a median (IQR) age of 66 (57-75) years (Table 1). Overall, 82.4% spent their entire hospital stay on the intervention surgical floor, and 8.2% underwent more than 1 surgical procedure. The most common types of surgical procedures were orthopedic (28.5%) and vascular (27.5%). As expected, the local VAMC cohort identified using the NPCD had demographic and clinical characteristics almost identical to those of the local VAMC cohort identified using VistA.

Compared with the national study sample, the local VAMC cohort identified using the NPCD was older (median age, 66 vs 65 years), and a greater proportion were white (89.4% vs 80.8%) (Table 1). The VAMC cohort had significantly higher rates of diabetes mellitus (30.4% vs 24.9%) and chronic pulmonary disease (14.9% vs 13.0%). However, the VAMC cohort had a lower incidence of malignant neoplasm (12.4% vs 16.1%). The local VAMC cohort also had a higher frequency

■ **Figure 1.** Identification of Local and National Study Samples Using the Veterans Health Information Systems and Technology Architecture (VistA) Database and the National Patient Care Database (NPCD)



FYs indicates fiscal years; *ICD-9-CM*, *International Classification of Diseases, Ninth Revision, Clinical Modification*. A local study cohort from the intervention Veterans Affairs medical center (VAMC) was identified using data from VistA, an electronic database used for clinical and administrative hospital functions. The local and national study populations from all 117 VAMCs throughout the country (the intervention VAMC and 116 other VAMCs) were identified using data from the administrative NPCD in Austin, Texas. The local and national study populations were restricted to patients with 1 of 25 of the most common surgical procedures identified in the local VistA population with a length of hospital stay (LOS) of 90 days or shorter. The local population using VistA data included fewer patients than the NPCD intervention VAMC sample because the VistA cohort included only patients who spent at least 1 day on a surgical floor.

of vascular and orthopedic procedures and a lower frequency of genitourinary procedures.

Appropriateness of Perioperative Antibiotic Therapy

For the analysis of appropriate perioperative antibiotic therapy, we excluded 660 admissions for which the surgical procedure occurred after the first day of admission to limit the sample to patients more likely to be admitted for surgery. We also excluded 111 surgical procedures involving the skin because of the heterogeneity of surgical skin infections and a lack of consensus on appropriate perioperative antibiotic therapy for these infections. Therefore, appropriateness of antibiotic therapy was assessed in 1779 surgical admissions to the intervention

VAMC. This subset (69.8%) of the local cohort did not differ from the full local cohort with regard to age, race/ethnicity, sex, or number of comorbid conditions (data not shown).

As summarized in **Table 2**, the proportion of surgical admissions receiving appropriate antibiotic therapy was significantly higher ($P < .01$) in 2004 after TPS initiation (44.0%) compared with any of the previous 4 years (range, 23.4%-29.8%). The overall improvement across this interval was attributable to improvements in compliance with duration of antibiotic therapy rather than improvements in appropriate antibiotic selection (**Figure 2**).

Overall, appropriateness of prophylactic antibiotic therapy significantly improved for neurosurgical, vascular, and ortho-

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Table 2. Appropriateness of Prophylactic Perioperative Antibiotic Selection and Duration by Type of Surgical Procedure From Fiscal Year 2000 to 2004

Appropriateness by Type of Surgical Procedure	No. (%)					Adjusted P Value ^a
	2000	2001	2002	2003	2004	
Appropriate selection and duration						
Neurosurgery	29/49 (59.2)	24/51 (47.1)	3/33 (9.1)	5/38 (13.2)	19/48 (39.6)	<.01
Vascular	35/82 (42.7)	36/90 (40.0)	38/103 (36.9)	22/63 (34.9)	36/75 (48.0)	.02
Gastrointestinal and biliary	4/41 (9.8)	7/44 (15.9)	10/58 (17.2)	11/69 (15.9)	6/60 (10.0)	.23
Genitourinary	1/33 (3.0)	4/47 (8.5)	4/30 (13.3)	14/75 (18.7)	43/99 (43.4)	.18
Orthopedic	11/109 (10.1)	34/120 (28.3)	24/113 (21.2)	55/145 (37.9)	66/104 (63.5)	.04
All of the above	80/314 (25.5)	105/352 (29.8)	79/337 (23.4)	107/390 (27.4)	170/386 (44.0)	<.01
Appropriate selection only						
Neurosurgery	41/49 (83.7)	42/51 (82.4)	8/33 (24.2)	17/38 (44.7)	30/48 (62.5)	<.01
Vascular	50/82 (61.0)	50/90 (55.6)	55/103 (53.4)	28/63 (44.4)	41/75 (54.7)	.08
Gastrointestinal and biliary	7/41 (17.1)	10/44 (22.7)	17/58 (29.3)	20/69 (29.0)	9/60 (15.0)	.03
Genitourinary	9/33 (27.3)	21/47 (44.7)	26/30 (86.7)	55/75 (73.3)	76/99 (76.8)	.08
Orthopedic	95/109 (87.2)	108/120 (90.0)	94/113 (83.2)	130/145 (89.7)	89/104 (85.6)	.50
All of the above	202/314 (64.3)	231/352 (65.6)	200/337 (59.3)	250/390 (64.1)	245/386 (63.5)	.49
Appropriate duration only						
Neurosurgery	34/49 (69.4)	33/51 (64.7)	26/33 (78.8)	22/38 (57.9)	30/48 (62.5)	.80
Vascular	50/82 (61.0)	53/90 (58.9)	50/103 (48.5)	40/63 (63.5)	52/75 (69.3)	.07
Gastrointestinal and biliary	20/41 (48.8)	31/44 (70.5)	38/58 (65.5)	39/69 (56.5)	49/60 (81.7)	.04
Genitourinary	7/33 (21.2)	10/47 (21.3)	5/30 (16.7)	22/75 (29.3)	56/99 (56.6)	<.01
Orthopedic	12/109 (11.0)	38/120 (31.7)	33/113 (29.2)	62/145 (42.8)	74/104 (71.2)	.03
All of the above	123/314 (39.2)	165/352 (46.9)	152/337 (45.1)	185/390 (47.4)	261/386 (67.6)	<.01

^aBased on a logistic regression model that compared observed proportions in 2004 with expected proportions based on the linear trends from 2000 to 2003. $P < .05$ indicates that the proportion of compliance observed in 2004 was statistically significantly different from the expected value. Observed and expected values were adjusted for age, number of comorbid conditions, and admission source. The overall comparison ("All of the above" types of surgical procedures) adjusts for surgery type, as well as age, number of comorbid conditions, and admission source.

pedic procedures between 2000 and 2004, but not all surgical procedures demonstrated a similar pattern of improvement (Table 2). The proportion of admissions receiving the appropriate selection of antibiotic therapy was significantly higher ($P < .01$) for neurosurgical procedures in 2004 compared with linear trends from 2000 to 2003; the proportion of admissions receiving appropriate antibiotic agents was significantly lower for gastrointestinal and biliary procedures. The proportion of admissions who received antibiotic therapy for the appropriate duration was significantly higher for gastrointestinal and biliary, genitourinary, and orthopedic procedures in 2004 compared with linear trends for the corresponding procedures from 2000 to 2003.

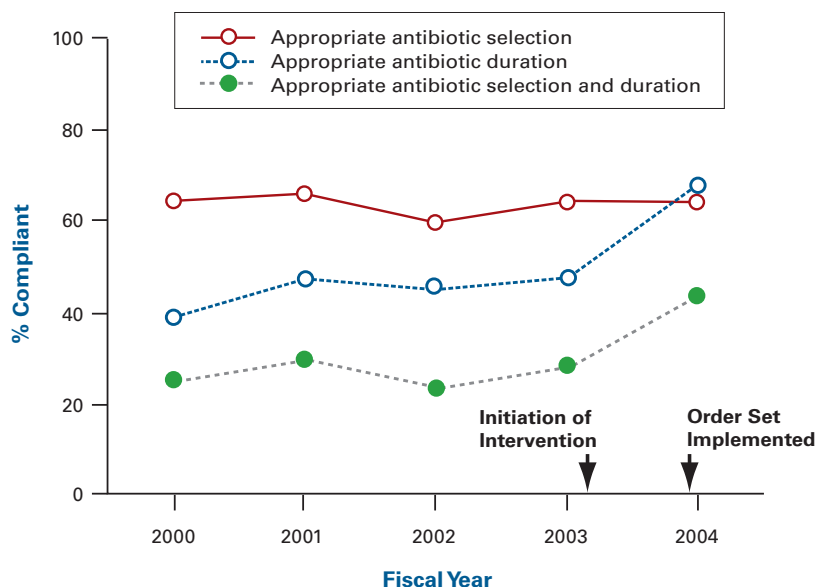
Length of Hospital Stay

As shown in Figure 3A, the median (IQR) LOS for surgical admissions (2000-2004) was shorter at the intervention

VAMC (5 [3-9] days) than at the other 116 VAMCs nationally (6 [3-12] days). Although the overall LOS was shorter for surgical admissions at the intervention VAMC than at the 116 VAMCs nationally (HR, 1.2; 95% confidence interval [CI], 1.12-1.28; $P < .01$), there was no statistically significant decrease in LOS following full implementation of the TPS in 2003 compared with national rates (HR, 0.99; 95% CI, 0.91-1.09; $P = .90$). Including patients with an LOS exceeding 90 days or using postsurgical LOS as the outcome had negligible effects on these analyses.

In the local intervention VAMC cohort identified using VistA (Figure 3B), the median (IQR) LOS was significantly shorter ($P < .01$) in 2003 to 2004 (5 [3-8] days) compared with 2000 to 2002 (6 [3-9] days). However, this difference in LOS was no longer statistically significant in analyses that adjusted for the surgical procedure, admission source, age, and number of comorbidities for the full sample (HR, 0.91;

■ **Figure 2.** Appropriateness of Prophylactic Perioperative Antibiotic Therapy for All Intervention Veterans Affairs Medical Center (VAMC) Surgical Procedures Over Time



Appropriateness of prophylactic perioperative antibiotic therapy was defined as receipt of antibiotics within but not exceeding 24 hours of the surgical procedure (duration) and receipt of antibiotic therapy consistent with the local VAMC surgical prophylaxis guidelines (selection). During the first few months of fiscal year 2003 (October to December 2002), the Toyota production system team leader began working with a local VAMC pharmacist and the chief of surgery to create interventions to improve appropriate perioperative antibiotic therapy (initiation of intervention). By the end of fiscal year 2003 (September 2003), a computerized Veterans Affairs order entry system nomogram and order set were implemented at the local VAMC (order set implemented).

95% CI, 0.76-1.08) or among those patients who spent their entire hospital stay on the intervention unit (HR, 0.87; 95% CI, 0.72-1.06).

DISCUSSION

In this study of the effect of a QI intervention to improve perioperative prophylactic antibiotic therapy, the TPS-driven intervention was temporally associated with an increased proportion of patients receiving appropriate prophylactic perioperative antibiotic therapy. The observed improvements in the overall compliance with appropriate antibiotic therapy were primarily the result of changes in compliance with appropriate postoperative antibiotic duration. Although the proportion of surgical admissions who received antibiotics not exceeding 24 hours from the time of operation increased significantly for 3 of 5 surgical procedure types (gastrointestinal and biliary, genitourinary, and orthopedic), higher rates of compliance with guideline recommendation for the selection of agents were restricted to neurosurgical admissions.

Our findings regarding improvement in postsurgical antibiotic duration are likely due to implementation of a standing

order to discontinue antibiotics within 24 hours of surgery. The effectiveness of such an automatic stop order for reducing the duration of postsurgical antibiotic therapy is consistent with prior studies demonstrating that standardized postoperative order sets are effective at decreasing the duration of postsurgical antibiotic therapy^{18,19} and are more effective than educational interventions alone.²⁰

However, to avoid a “one size fits all” approach to improving postsurgical antibiotic therapy, surgeons were able to edit the electronic stop date of 24 hours to re-order antibiotics if indicated by the clinical situation. The explanation for the lack of a significant decrease in antibiotic therapy duration for neurosurgical and vascular procedures is not entirely clear and may be due to discretionary reordering of antibiotics by these surgeons. Our finding of variability in practice patterns by type of surgeon is consistent with a prior QI study²¹ using Six Sigma methods, which found that the timing of preoperative prophylactic antibiotics improved for orthopedic, colorectal, and gynecologic surgical procedures but not for vascular surgical procedures.

Another possible explanation for the lack of universal improvements across surgical procedure types is that the TPS team chose to focus their efforts on the surgical procedures and surgeons they encountered most often. For example, the most common surgical procedures were orthopedic; initial evaluation revealed high compliance for antibiotic selection (>80%) but low compliance for appropriate duration (<15%). Discussions conducted by the QI team with orthopedic residents revealed a belief that antibiotic therapy needed to be administered until all surgical drains were removed. Subsequently, the TPS team met with new residents each month to educate them about the appropriate duration of antibiotic therapy.

We did not find evidence of significant changes in the overall or postsurgical LOS as a result of implementation of the TPS MRSA prevention initiative on the surgical unit. Length of stay is a general measure of hospital efficiency and, in contrast to appropriateness of perioperative antibiotic therapy, was not directly targeted as part of the TPS methods. Although we identified no prior studies about the effect of QI interventions on LOS, we identified 2 studies^{7,22} that used TPS or Lean methods to decrease emergency department

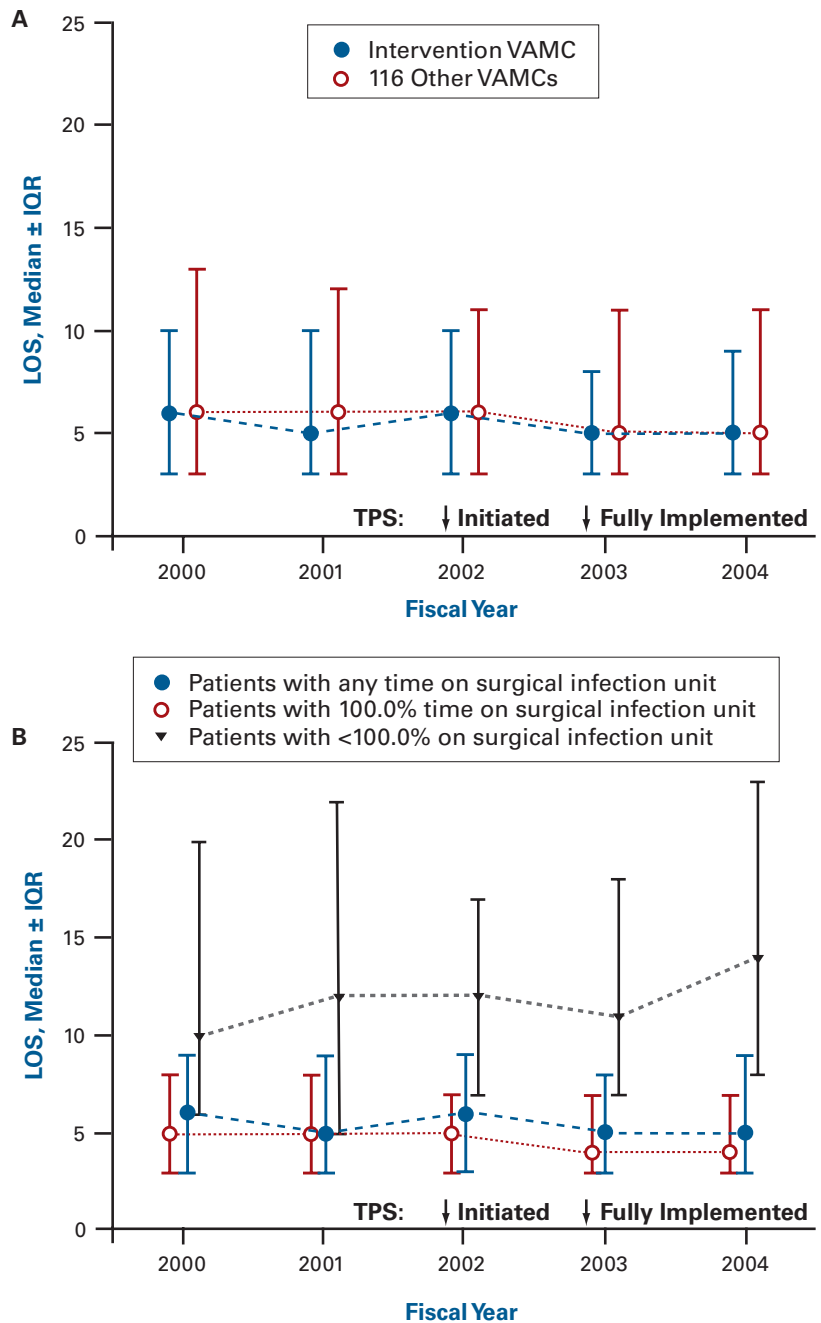
LOS by redesigning patient flow. Therefore, there is a lack of evidence that QI approaches targeting specific aspects of healthcare quality and efficiency result in a more generalized reduction in LOS.

Our study has several limitations. First, the intervention was conducted at one surgical unit in one VAMC and may not be generalizable to other hospitals or healthcare systems. Second, the intervention was intentionally designed to be an ongoing iterative process to address new problems as they were identified. Consequently, we defined the time frames (beginning of 2004 for antibiotic prophylaxis and 2003 for LOS) for a comparative analysis retrospectively based on notes and progress reports maintained by the team leader and project coordinator (EEM). Although useful for tracking program implementation, these data were not collected with the scientific rigor of a research study, and we did not have specific enough details on the exact time line of the implementation of all components of the perioperative antibiotic bundle or intervention to conduct the analyses across shorter intervals (ie, on a monthly or quarterly basis). Third, the study involves a before-and-after design without additional external controls for the perioperative antibiotic use end point, making it difficult to control for contemporaneous events or secular changes arising independent of the study intervention. Fourth, given the administrative nature of our data, the primary efficiency outcome was LOS rather than more robust outcome measures such as resource use for an episode of care or recuperation time.

CONCLUSIONS

This study adds to the growing body of literature demonstrating the effectiveness of a TPS approach to improve quality in a healthcare setting. Implementation of such an approach on a surgical unit was associated with higher

Figure 3. Comparison of Length of Hospital Stay (LOS) Over Time for Surgical Admissions



TPS indicates Toyota production system.
A, At the intervention Veterans Affairs medical center (VAMC) and 116 other VAMCs. This figure shows the median LOS and associated interquartile ranges (IQRs) for patients with 1 of 25 of the most common surgical procedures performed at the intervention VAMC vs at all other 116 VAMCs nationally. These data were identified using the administrative Veterans Affairs National Patient Care Database (NPCD).
B, At the intervention VAMC stratified by time spent on the surgical unit. This figure shows the medical LOS and associated IQRs for patients with 1 of 25 of the most common surgical procedures at the intervention VAMC identified using the Veterans Health Information Systems and Technology Architecture (VistA) database. It shows the median LOS over time for patients who spent 100.0% of their hospital stay on the surgical unit compared with those who spent less than 100.0% of their hospital stay on the surgical unit.

rates of appropriate perioperative antibiotic therapy but not reductions in LOS. Although TPS strategies have the potential to improve quality and efficiency of healthcare, it is important when measuring the effectiveness of such an intervention to prospectively collect information about the implementation process and to directly measure all outcomes that were targeted as part of the intervention.

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Author Affiliations: From the Center for Health Equity Research and Promotion (KHB, MKM, DSO, MAS, MJF), VA Pittsburgh Healthcare System, Pittsburgh; Department of Biostatistics (MKM) and Department of Medicine (DSO, MAS, MJF), University of Pittsburgh, Pittsburgh; VA Pittsburgh Healthcare System (RJ, MSK, EEM, RRM, MAW), Pittsburgh; and Veterans Integrated Services Network 4 (MEM), Pittsburgh, PA.

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Address correspondence to: Kelly H. Burkitt, PhD, Center for Health Equity Research and Promotion, VA Pittsburgh Healthcare System, 7180 Highland Dr (151C-H), Pittsburgh, PA 15206. E-mail: kelly.burkitt@va.gov.

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