A Perioperative Systems Design to Improve Intraoperative Glucose Monitoring Is Associated with a Reduction in Surgical Site Infections in a Diabetic Patient Population

Jesse M. Ehrenfeld, M.D., M.P.H., Jonathan P. Wanderer, M.D., M.Phil., Maxim Terekhov, M.S., M.B.A., Brian S. Rothman, M.D., Warren S. Sandberg, M.D., Ph.D.

ABSTRACT

Background: Diabetic patients receiving insulin should have periodic intraoperative glucose measurement. The authors conducted a care redesign effort to improve intraoperative glucose monitoring.

Methods: With approval from Vanderbilt University Human Research Protection Program (Nashville, Tennessee), the authors created an automatic system to identify diabetic patients, detect insulin administration, check for recent glucose measurement, and remind clinicians to check intraoperative glucose. Interrupted time series and propensity score matching were used to quantify pre- and postintervention impact on outcomes. Chi-square/likelihood ratio tests were used to compare surgical site infections at patient follow-up.

Results: The authors analyzed 15,895 cases (3,994 preintervention and 11,901 postintervention; similar patient characteristics between groups). Intraoperative glucose monitoring rose from 61.6 to 87.3% in cases after intervention (P = 0.0001). Recovery room entry hyperglycemia (fraction of initial postoperative glucose readings greater than 250) fell from 11.0 to 7.2% after intervention (P = 0.0019), while hypoglycemia (fraction of initial postoperative glucose readings less than 75) was unchanged (0.6 *vs.* 0.9%; P = 0.2155). Eighty-seven percent of patients had follow-up care. After intervention the unadjusted surgical site infection rate fell from 1.5 to 1.0% (P = 0.0061), a 55.4% relative risk reduction. Interrupted time series analysis confirmed a statistically significant surgical site infection rate reduction (P = 0.01). Propensity score matching to adjust for confounders generated a cohort of 7,604 well-matched patients and confirmed a statistically significant surgical site infection rate reduction (P = 0.02).

Conclusions: Anesthesiologists add healthcare value by improving perioperative systems. The authors leveraged the one-time cost of programming to improve reliability of intraoperative glucose management and observed improved glucose monitoring, increased insulin administration, reduced recovery room hyperglycemia, and fewer surgical site infections. Their analysis is limited by its applied quasiexperimental design. **(ANESTHESIOLOGY 2017; 126:431-40)**

USE of technology to ensure consistent and cost-effective perioperative system performance is an important component of healthcare redesign.[1,2] Care redesign to improve system performance can take the form of technology and work environment redesign,[3–9] as well as interventions using computerized clinical information systems that either blend into or deliberately interrupt clinician workflow.[10–15] One component in our approach to ensuring the delivery of highly reliable care at Vanderbilt University Medical Center (Nashville, Tennessee) has been to integrate technology and clinical decision support systems in ways that these tools can support anesthesia team workflows.[14–17]

We recognized inconsistency in our clinician's management of intraoperative blood glucose and initiated a quality improvement effort, supported by technology, to reduce process variation. While there is no definitive evidence to

What We Already Know about This Topic

- Diabetic patients receiving insulin should have periodic intraoperative glucose measurement, yet it often goes unmeasured during the intraoperative period.
- While there is no definitive evidence to suggest an optimal target for intraoperative blood glucose in diabetic patients and those with impaired glucose tolerance, lack of any intraoperative measurement in patients receiving insulin places them at risk for significant, unrecognized variations in blood glucose.

What This Article Tells Us That Is New

- Use of an automatic system to identify diabetic patients, detect insulin administration, check for recent glucose measurement, and remind clinicians to check intraoperative glucose improved the reliability of intraoperative glucose management. After implementation of this automated reminder system, improved glucose monitoring, increased insulin administration, reduced recovery room hyperglycemia, and fewer surgical site infections were observed.

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Submitted for publication September 8, 2015. Accepted for publication November 22, 2016. From the Departments of Anesthesiology, Surgery, Biomedical Informatics, Health Policy, Vanderbilt University School of Medicine, Nashville, Tennessee (J.M.E.); Department of Surgery, Uniformed Services University of the Health Sciences, Vanderbilt University Hospital, Nashville, Tennessee (J.M.E.); Departments of Anesthesiology and Biomedical Informatics, Vanderbilt University School of Medicine, Nashville, Tennessee (J.P.W.); and Department of Anesthesiology, Vanderbilt University School of Medicine, Nashville, Tennessee (M.T., B.S.R., W.S.S.).

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suggest an optimal target for intraoperative blood glucose in diabetic patients and those with impaired glucose tolerance,[18–20] as a department we agreed that periodic intraoperative measurement is appropriate in both diabetic patients and patients receiving insulin. Pilot data from several centers, including our own, revealed that blood sugar is often unmeasured during the intraoperative period. In 2009 and 2010 at Vanderbilt University Medical Center (Nashville, Tennessee), only 19.8% of diabetic patients had blood sugar measured during surgery and of the 2,224 diabetic patients who received insulin during surgery, only 57% had a follow-up blood sugar checked in the operating room. In order to address this gap between observed and expected performance, we initiated a quality improvement effort designed to automatically facilitate the more consistent execution of intraoperative glucose monitoring. Our primary objective was to understand the ability of this effort to reduce process variability and simultaneously improve health outcomes in diabetic patients.

Materials and Methods

Our quality improvement project received approval from the Vanderbilt University Human Research Protection Program (Nashville, Tennessee). Using our perioperative information management system, we developed a system to automatically identify adult (age greater than or equal to 18 yr) diabetic patients or patients with impaired glucose management during a surgical procedure. Three preoperative and one intraoperative data sources were continuously evaluated to identify the population of interest: (1) a diabetes checkbox selected in the preoperative evaluation module (fig. 1); (2) a glucose lab result documented in preoperative nursing documentation (fig. 2); (3) insulin administration documented in the preoperative nursing documentation (fig. 3); or (4) insulin administered either by infusion or by bolus during the intraoperative phase of care (fig. 4). These inclusion criteria were designed to identify all patients with impaired glucose management, even those where a diagnosis of diabetes had not been entered into the preoperative evaluation module.

For patients identified as having impaired glucose management, we used our perioperative information management system to provide pop-up prompts to the in-room anesthesia care team provider (typically the anesthesia resident or registered nurse anesthetist) to perform a glucose measurement. Based on our departmental guidelines, a pop-up (fig. 5) is delivered one hour after the last measured value if insulin has been given during the perioperative period and every two hours if no insulin has been administered. The upper portion of the pop-up (fig. 5) informs the in-room provider that glucose testing is recommended, the last measured blood glucose, the time and dose of the last insulin bolus, and the currently documented insulin infusion rate if these are available.

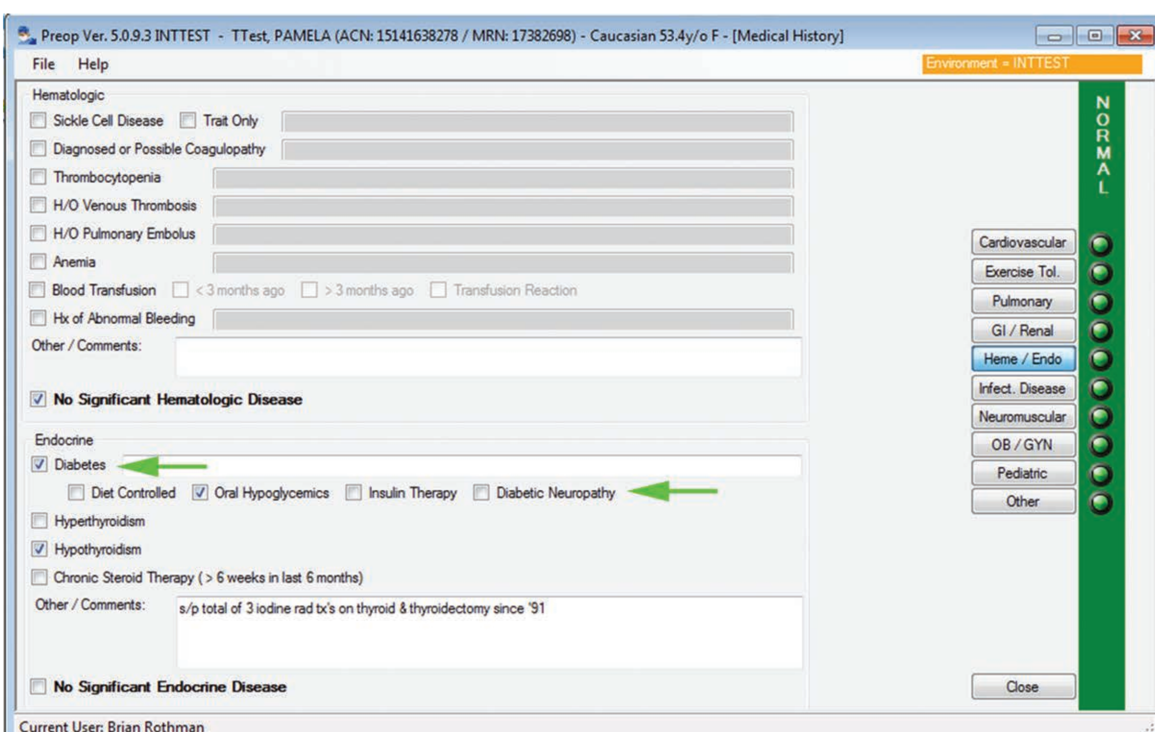

Fig. 1. Preoperative endocrine assessment. The *green arrows* in the anesthesia preoperative "VPEC/DOS" Pmodule's endocrine section indicate where a provider documents that a patient has diabetes. Once the diabetes box is checked, the provider may select any of the four modifier checkboxes indicated by the *lower green arrow*. Discrete documentation of diabetes into a structured, machine-readable data field is one of the several ways our electronic health record identifies those needing intraoperative glucose measurements.

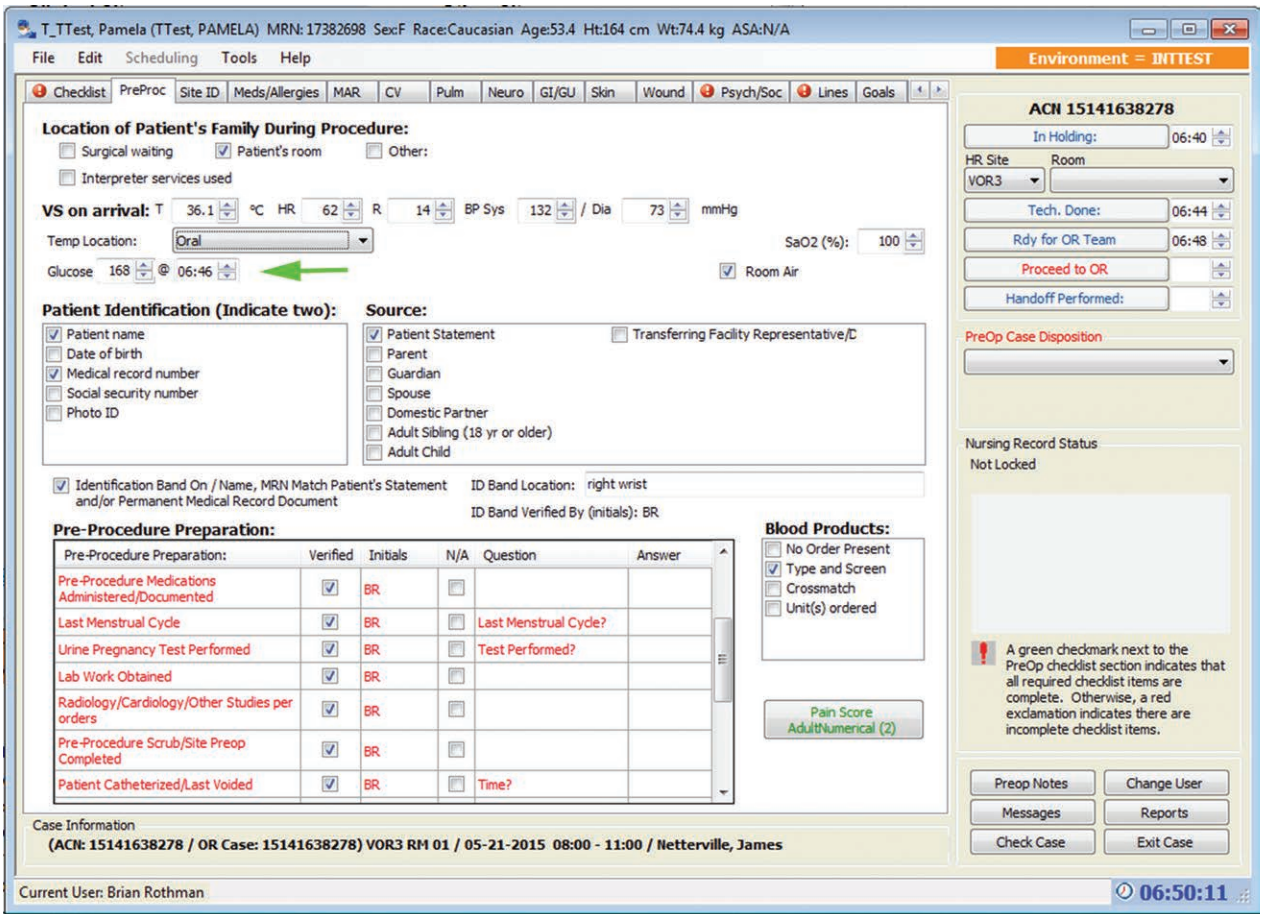

Fig. 2. The perioperative nursing's electronic health record module, Patient Tracker Preop. The *green arrow* in the "PreProc" tab identifies where preoperative nurses document a measured glucose and the time of measurement if blood glucose is measured in the preoperative process.

The lower portion of the pop-up (fig. 5) provides three choices for providers to select from to inform the system of their planned response to the recommendation. If the provider can measure the glucose at the time of the notification, "Will measure now" removes the window and starts a 15-min countdown, and if "Will measure in 15 minutes" is selected, a 30-min countdown starts (15 min to draw the sample and 15 min to complete the measurement and document the result). If a central laboratory or point-of-care glucose measurement is not recorded within the 15- or 30-min period, respectively, then the pop-up window returns to remind the provider. "Deferred–case completion within 30 minutes" allows the provider to signal the end of the case is near, allowing measurement deferral. While no glucose measurement is expected, the window returns, reminding the provider, if the case does not conclude within the expected 30-min period.

We implemented our system on July 1, 2011, and performed an interrupted time series intervention analysis to quantify the impact of the perioperative glucose alert on diabetic patient outcomes. Interrupted time series design is the strongest, quasiexperimental approach for evaluating longitudinal effects of interventions in a research design with a temporal component. We separated patients into two groups of diabetic patients: a preintervention cohort who underwent surgery between January 2010 and June 2011, and a postintervention cohort who underwent surgery between July 2011 and December 2014. Segmented regression analysis was used to draw a formal conclusion about the impact of an intervention adjusted by age, gender, body mass index, weight, race, American Society of Anesthesiologists Physical Status Classification, emergency case status, anesthesia type, anesthesia duration, surgery duration, history of alcoholism, smoking status, history of diabetes, albumin, total bilirubin, history of dyspnea, antibiotic prophylaxis, insulin administration, preoperative anemia, and intraoperative transfusion, by quantifying the change in trend and level across segments. An autoregressive integrated moving average model with an impulse intervention was performed to account for possible autocorrelation of error terms. Frequencies, means, and SDs were used to describe the characteristics of each cohort. Propensity score matching was then used to address differences in case mix. Cases from the preintervention phase were matched to those from the postintervention in a 1:1

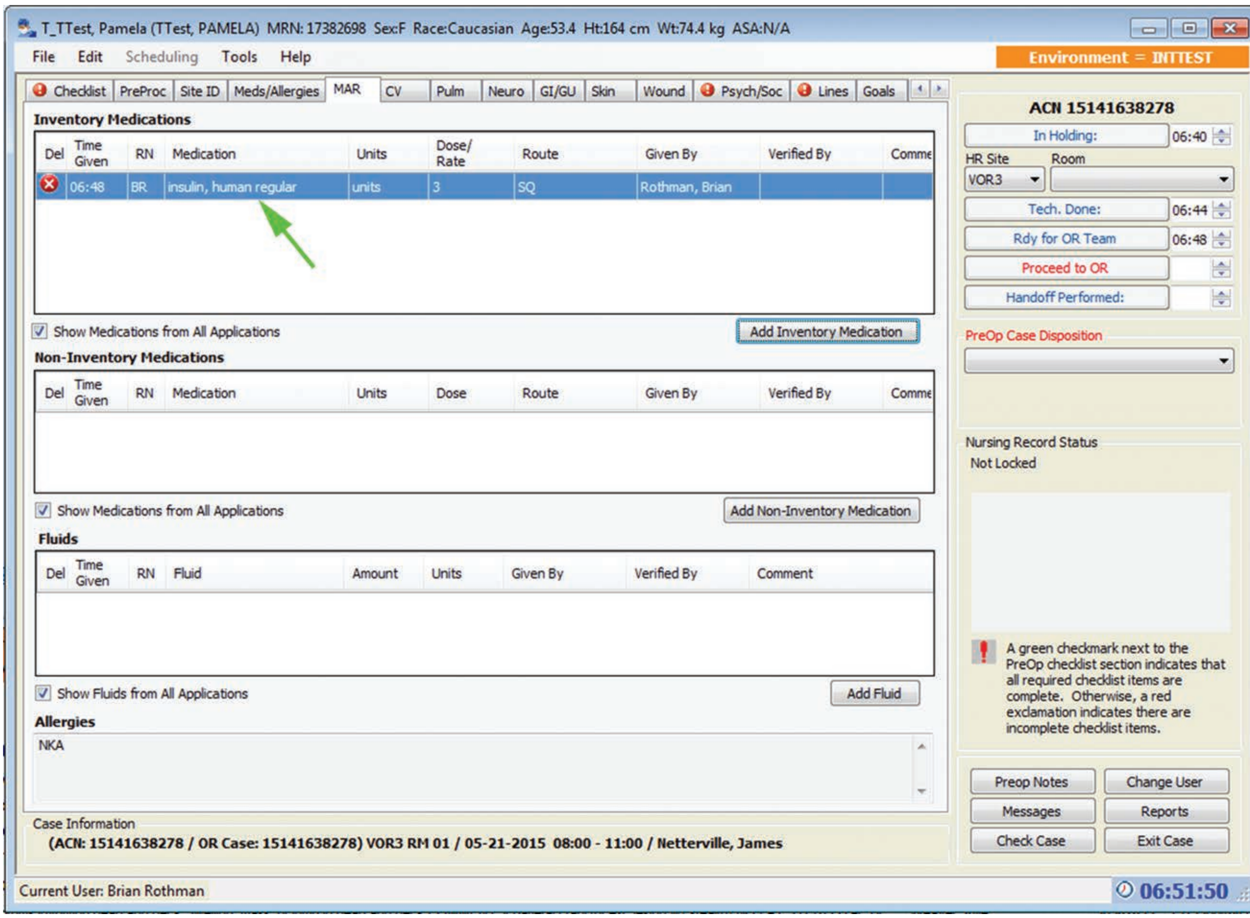

Fig. 3. Preoperative insulin administration. Perioperative medications ordered by physicians and then administered by a preoperative nurse are documented in the preoperative nursing module, called Patient Tracker Preop. Insulin administration documented in the MAR (medication administration record) tab preoperatively results in the notification window displaying in the anesthesia module (called GasChart) 60 min after the last documented blood glucose or the operating room "In Room" time, whichever time is later, until the case is completed.

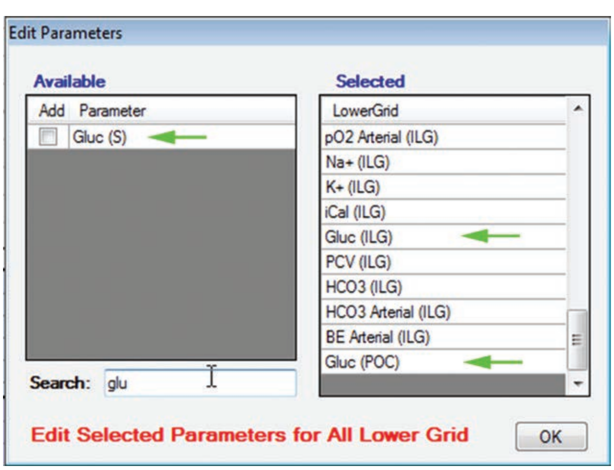

Fig. 4. Glucose parameters. The "Lower Grid" parameter selection window demonstrates the various glucose parameters that may be used for blood glucose entry: Gluc (S), serum glucose; Gluc (POC), point of care glucose testing with a bedside glucometer; and Gluc (ILG), ILGem (Instrumentation Laboratory, Bedford, Massachusetts)–measured glucose. Documenting any of these glucose parameters restarts the countdown timer for the next measurement.

ratio using 8 to 1 greedy matching. Covariates used for propensity score matching included age, gender, weight, race, American Society of Anesthesiologists Physical Status Classification, emergency case status, anesthesia type, anesthesia duration, surgery duration, surgical service, history of alcoholism, smoking status, history of diabetes, albumin, total bilirubin, history of dyspnea, antibiotic prophylaxis, insulin administration, preoperative anemia, and intraoperative transfusion. Continuous variables included patient's age (10-yr increments), patient's weight (10-kg increments) as well as anesthesia, and operating room duration (1-h increments). Additionally, we examined whether there were temporal differences in patient wound class, use of implantable medical devices, and type and dosage of prophylactic antibiotics over the course of the study period. Chi-square/likelihood ratio chi-square tests were used to compare the instances of surgical site infections (SSI) across cohorts, as well as the rates of hyperglycemia and hypoglycemia on entry into the postanesthesia care unit (PACU; defined as the number of initial postoperative glucose readings greater than 250 or less than 75, respectively). Our hospital uses criteria from Centers

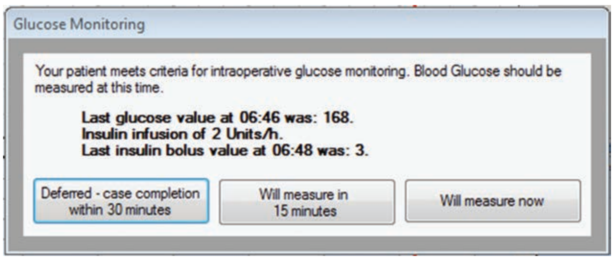

Fig. 5. Measure glucose notification. This pop-up appears when a provider should measure the next glucose value. The *upper portion* of the window informs the provider what should be done and the last glucose value, either from the anesthesia or from preoperative nursing documentation. The section also displays, if appropriate, the current documented insulin infusion rate and the amount and time of the last insulin bolus. At the *bottom* of the window, providers must select what action they will take based on the recommendation. "Will measure now" informs the system that the provider will perform a glucose measurement immediately. If a glucose value is not documented within the next 15 min, another notification pop-up will appear. "Will measure in 15 minutes" informs the system that the provider will be delayed in measuring glucose but will do so within 15 min and document the value within the following 15 min. When this option is selected, another notification pop-up will appear after 30 min. Finally, if the provider anticipates that the case will be completed within 30 min, selecting the Deferred button closes the pop-up, which will reappear after 30 min if the case is not yet complete.

for Disease Control National Healthcare Safety Network (Atlanta, Georgia) for SSI identification and categorization, and reports of infection are collated by a centralized team for unified reporting of SSI events across the medical center. Finally, we used a Shewhart statistical process control chart to assess our intervention. Control charts were generated to represent (1) the unadjusted SSI rates for all study patients and (2) the rates of hyperglycemia upon entry into the postanesthesia care unit.

Results

During the time period of our quality improvement project, 15,895 cases that met inclusion criteria were identified. This included 3,994 preintervention and 11,901 postintervention cases. Baseline patient characteristics were similar between the two groups and are shown in table 1. Of note, 29.8% of cases were not identified as diabetic in the preoperative phase of care. The rate of intraoperative glucose monitoring rose after the intervention from 61.6 to 87.3% (P = 0.0001). Hyperglycemia on entry into the PACU fell from 11.0 to 7.2% after the intervention (P = 0.002). Hypoglycemia on entry into the PACU was unchanged (0.6 *vs.* 0.9%; P = 0.22) after the intervention. The unadjusted SSI rate fell from 1.5 (n = 61) to 1.0% (n = 117; P = 0.0061) after the intervention, representing a 55.4% relative risk reduction. More patients received intraoperative insulin after the intervention (30% before *vs.* 38% after; P < 0.0001), and during the intervention phase of the study, insulin administration occurred more often (42 *vs.* 34%; P < 0.0001) in response to receiving a system notification. The majority of patients in the study (87%) returned for follow-up care after the initial surgical procedure. An interrupted time series analysis showed a statistically significant drop in the SSI rate across phases (P = 0.01 for level and P = 0.04 for trend in the segmented regression analysis, P = 0.012 in the autoregressive integrated moving average model). A significant change (P = 0.01) in trend was observed for hyperglycemia, although the level was not significantly different (P = 0.16). The results of the propensity matching are shown in table 2. Within this well-matched cohort of 7,604 patients, we confirmed a statistically significant drop in the SSI rate from 1.6 (n = 59) to 1.0% (n = 37; P = 0.02; table 3). Unplanned 30-day hospital readmission rates were not significantly different (P = 0.06). There was no difference in overall hospital length of stay before (5.5 days) and after (6.0 days) the implementation (Wilcoxon signed-rank test, P = 0.99). Finally, there were no statistically significant differences in patient wound class, use of implantable medical devices, type and dosage of prophylactic antibiotics, or frequency of laparoscopic approach found in the two groups of patients. Control charts demonstrating the drop in SSI rates and hyperglycemia on entry into the PACU are shown in figs. 6, 7, and 8.[21] Statistical programming was implemented in Statistical Analysis Software 9.4 (SAS Institute Inc., USA) and R (version 3.2.1, R Core Team; R Foundation for Statistical Computing, Austria, https://www.r-project.org, accessed January 9, 2017).

Discussion

By embedding a clinical decision support notification into our perioperative workflow, we substantially improved and sustained the rate of intraoperative glucose monitoring in patients with impaired glucose control, decreased the frequency of postoperative hyperglycemia, and demonstrated a statistically significant drop in the SSI rate in both unadjusted and propensity-matched groups of patients. Although we cannot conclusively demonstrate that our system-level changes lead to the drop in SSIs, as could only be done in a well-constructed prospective randomized clinical trial, providers responded to system-generated notifications by measuring glucose more frequently and subsequently administering insulin therapy. It is likely that these improvements led to the prevention of at least 60 SSIs during the course of our study. Based on previously published cost analyses,[22,23] this likely represented a substantial direct savings to the healthcare system on the order of $600,000, not taking into consideration the additional revenue likely generated by the additional hospital capacity that was subsequently available due to a reduction in follow-up visits and the treatment of complications.

While a number of previous studies have evaluated perioperative glucose management strategies, there is still no consensus on what blood glucose target optimizes outcomes and in what patient populations. The strongest evidence for

Table 1. Patient Characteristics

	Preintervention (January 1, 2010 to June 30, 2011) n = 3,994	Postintervention (July 1, 2011 to December 31, 2014) n = 11,901	Standardized Difference
Age, yr	58.9 (± 12.7)	59.6 (± 12.8)	0.06
Gender, n (%)			−0.04
Male	2,208 (55.3)	6,786 (57.0)	
Female	1,786 (44.7)	5,113 (43.0)	
Race, n (%)			0.11
Caucasian	9,872 (83.4)	3,339 (84.0)	
African American	1,490 (12.6)	502 (12.6)	
Unknown	350 (3.0)	89 (2.2)	
Asian	99 (0.8)	26 (0.7)	
American Indian	30 (0.3)	8 (0.2)	
Other	0 (0.0)	17 (0.4)	
ASA Physical Status, n (%)			0.14
1	9 (0.2)	19 (0.2)	
2	570 (14.3)	1,240 (10.4)	
3	2,354 (58.9)	7,227 (60.7)	
4	1,047 (26.2)	3,307 (27.8)	
5	14 (0.4)	108 (0.9)	
BMI	32.9 (± 8.6)	32.7 (± 9.0)	−0.04
Weight	95.4 (± 26.3)	95.7 (± 26.6)	0.01
General anesthesia, n (%)	3,801 (95.2%)	11,431 (96.1%)	0.04
Regional anesthesia, n (%)	241 (6.0%)	565 (4.8%)	−0.06
MAC anesthesia, n (%)	175 (4.4%)	434 (3.7%)	−0.04
Emergency case, n (%)	173 (4.3%)	682 (5.7%)	0.06
Surgical duration, min	271 (± 120)	274 (± 124)	0.01
Anesthesia duration, min	290 (± 123.0)	292 (± 125.0)	0.00
PACU duration, min	174 (± 116.0)	142 (± 100.0)	−0.37
Alcoholism, n (%)	114 (2.9)	653 (5.5)	0.13
Diabetes, n (%)	2,694 (67.5)	8,470 (71.2)	0.08
Antibiotic prophylaxis, n (%)	3,115 (78.0)	9,704 (81.5)	0.09
Insulin administration, n (%)	1,199 (30.0)	4,521 (38.0)	0.17
Albumin < 3.5 mg/dl, n (%)	339 (8.5)	995 (8.4)	0.00
Total bilirubin > 1.0 mg/dl, n (%)	472 (11.8)	1,351 (11.4)	−0.01
Dyspnea, n (%)	563 (14.0)	1,735 (14.6)	0.01
Steroid, n (%)	4 (0.1)	25 (0.2)	0.03
HgbA1C	6.97 (± 1.8)	6.85 (± 1.8)	−0.14
Intraoperative transfusion	885 (22.2)	2,388 (20.1)	−0.05
Preoperative anemia	1,756 (44.0)	5,372 (45.1)	0.02

HgbA1C available for a subset of patients: 810 preintervention and 3,088 postintervention.

Data are presented as mean (± SD) unless noted otherwise.

ASA = American Society of Anesthesiologists; BMI = body mass index; HgbA1C = glycosylated hemoglobin; MAC = monitored anesthesia care; PACU = postanesthesia care unit.

a particular management strategy is in the cardiac surgical population, where several studies have demonstrated reduction in infections and overall in-hospital mortality.[24,25] This evidence has led to the promulgation of several quality metrics focused on control of immediate postoperative blood glucose in cardiac surgical patients,[26] although these metrics themselves have been called into question.[27]

One recent study did demonstrate the ability of a clinical decision support system to increase perioperative administration of insulin in response to previously detected hyperglycemic states.[28] This tool was not, however, aimed at increasing the overall frequency of blood glucose surveillance in diabetic patients. Additionally, this same study did not report any impact on patient-centered outcomes, such as SSI. Given the uncertainty of what blood glucose level is best targeted in surgical patients, the focus of our perioperative system design quality improvement project was to increase measurement of blood glucose during surgery, rather than target the administration of insulin or attainment of a certain blood glucose value. We succeeded in this objective as demonstrated by the 25.7% increase rate in glucose measurement.

There are a number of important implications of our study as it relates to the role of anesthesiologists as perioperative system managers. We have demonstrated how anesthesiologists can leverage a perioperative information management system to improve the reliability of a

Table 2. Patient Characteristics after Propensity Score Matching

	Preintervention (January 1, 2010 to June 30, 2011) n = 3,802	Postintervention (July 1, 2011 to December 31, 2014) n = 3,802	Standardized Difference	*P* Value
Age, yr	59.0 (± 12.6)	58.9 (± 13.1)	−0.01	0.77
Gender, n (%)			−0.00	0.91
Male	2,093 (55.1)	2,098 (55.2)		
Female	1,709 (45.0)	1,704 (44.8)		
ASA Physical Status, n (%)			0.01	0.98
1	9 (0.2)	11 (0.3)		
2	542 (14.3)	539 (14.2)		
3	2,271 (59.7)	2,279 (59.9)		
4	968 (25.5)	963 (25.3)		
5	12 (0.3)	10 (0.3)		
Weight	95.5 (± 26.4)	96.0 (± 27.2)	0.01	0.57
BMI	33.0 (±8.7)	32.9 (± 8.9)	−0.02	0.39
Race, n (%)			0.02	0.96
Caucasian	3,200 (84.2)	3,185 (84.0)		
African American	489 (12.9)	509 (13.4)		
Unknown	79 (2.1)	74 (2.0)		
Asian	26 (0.7)	26 (0.7)		
American Indian	8 (0.2)	8 (0.2)		
General anesthesia, n (%)	3,619 (95.2)	3,635 (95.6)	0.02	0.38
Regional anesthesia, n (%)	236 (6.2)	233 (6.1)	−0.00	0.89
MAC anesthesia, n (%)	166 (4.4)	160 (4.2)	−0.01	0.73
Anesthesia duration, min	287.6 (± 120.7)	286.0 (± 122.4)	−0.03	0.19
Surgical duration, min	269.6 (± 118.1)	268.9 (± 119.8)	−0.02	0.32
Alcoholism, n (%)	109 (2.9)	106 (2.8)	−0.00	0.84
Emergency case, n (%)	150 (4.0)	152 (4.0)	0.00	0.91
Diabetes, n (%)	2,577 (67.8)	2,537 (66.7)	−0.02	0.33
Antibiotic prophylaxis, n (%)	2,983 (78.5)	2,974 (78.2)	−0.01	0.80
Insulin administration, n (%)	1,107 (29.1)	1,113 (29.3)	0.00	0.88
Albumin < 3.5 mg/dl, n (%)	317 (8.3)	326 (8.6)	0.01	0.71
Total bilirubin > 1.0 mg/dl, n (%)	443 (11.7)	431 (11.3)	−0.01	0.67
Dyspnea, n (%)	550 (14.5)	560 (14.7)	0.01	0.75
Preoperative anemia, n (%)	1,659 (43.6)	1,673 (44.0)	0.01	0.75
Intraoperative transfusion, n (%)	1,121 (29.5)	1,137 (29.9)	0.01	0.69
Surgical service, n (%)			0.06	0.99
Adult cardiac	537 (14.1)	532 (14.0)		
Urology surgery	386 (10.2)	369 (9.7)		
Orthopedic	365 (9.6)	353 (9.3)		
Neurosurgery	350 (9.2)	325 (8.6)		
General surgery	316 (8.3)	331 (8.7)		
Orthopedic trauma	273 (7.2)	272 (7.2)		
General oncology surgery	205 (5.4)	208 (5.5)		
Vascular surgery	173 (4.6)	175 (4.6)		
Orthopedic sports/hand	142 (3.7)	141 (3.7)		
Head and neck surgery	134 (3.5)	143 (3.8)		

Data are presented as mean (± SD) unless noted otherwise. An independent sample Student's *t* test or Wilcoxon–Mann–Whitney test was used for continuous variables, depending on the distribution. Chi-square or Fisher exact test was used for categorical variables, depending on the expected frequency.
ASA = American Society of Anesthesiologists; BMI = body mass index; MAC = monitored anesthesia care.

perioperative process (in this instance, intraoperative glucose monitoring). The only costs and resources required to achieve this process change were the one-time programming costs, and no initial or ongoing educational efforts were required. Importantly, we committed to process evaluation both before and after project implementation in order to understand the impact of the system design changes. Had our system not achieved its goals (substantially improved glucose monitoring and a reduction in SSIs) we would have modified our approach or removed the clinical decision support prompts. This is a critically important step, as many decision support algorithms are developed, implemented, but then not fully assessed leading to inefficiencies and extraneous systems. Furthermore, the overall impact of a

Table 3. Outcome Characteristics

	Preintervention (January 1, 2010 to June 30, 2011)	Postintervention (July 1, 2011 to December 31, 2014)	Standardized Difference	*P* Value
Unadjusted analysis	n = 3,994	n = 11,901		
30-day readmission, n (%)	415 (10.4)	1,105 (9.3)	−0.04	0.04
SSI, n (%)	61 (1.5)	117 (1.0)	−0.05	0.01
Propensity-matched cohort	n = 3,802	n = 3,802		
30-day readmission, n (%)	397 (10.0)	348 (9.2)	−0.04	0.06
SSI, n (%)	59 (1.6)	37 (1.0)	−0.05	0.02

Our study uses the Centers for Medicare and Medicaid Services definition of unplanned hospital readmission. Data are presented as count (%) unless noted otherwise.
SSI = surgical site infections.

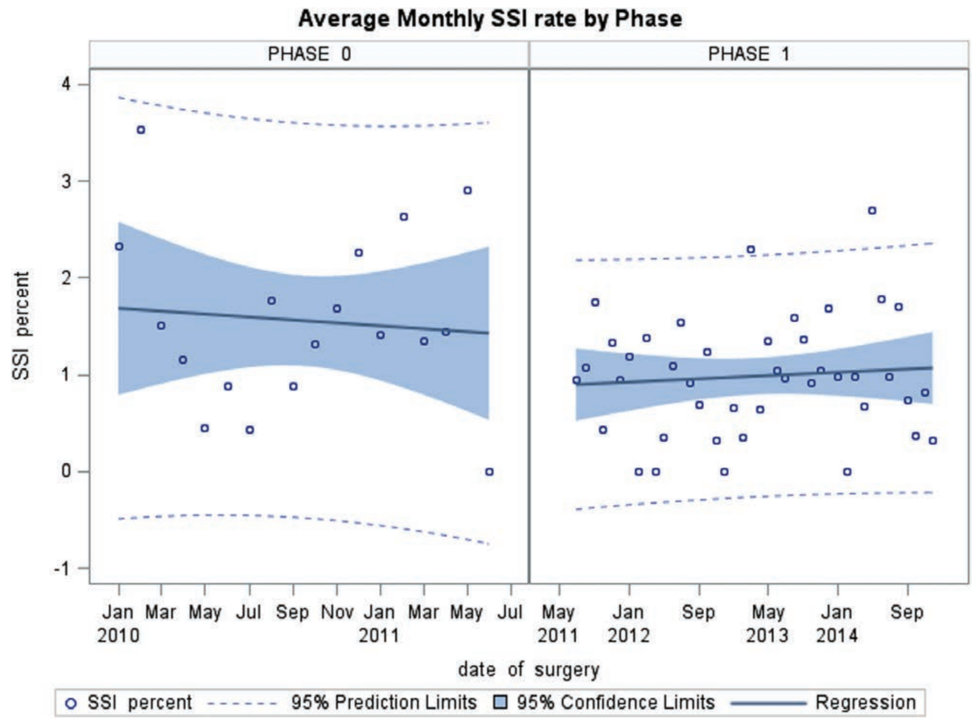

Fig. 6. Interrupted time series showing surgical site infection (SSI) rates. Interrupted time series analysis of the average monthly SSI rate. A negative change in level indicates a statistically significant drop in the SSI rate across phases (*P* = 0.04 in the segmented regression analysis, *P* = 0.016 in the autoregressive integrated moving average model).

given system is likely to be highly correlated with the degree to which notifications, alerts, and reminders are accepted or rejected by the end-users.

Our study has several limitations that must be considered. First, we only evaluated the impact of our system on patients with a diagnosis of diabetes or evidence of impaired glucose tolerance. We did not screen all patients for diabetes, nor did we achieve 100% capture of all diabetic patients. However, for patients where there was an indication, available to our system, of a need for glucose monitoring, we were able to provide appropriate care recommendations. Second, in our propensity score analysis, we selected factors known to impact the risk of SSI. However, our approach may be subject to the biases of confounders for which we did not adjust. We were unable to control for ascites and surgical site since those confounders were not available in our data. Nonetheless, we used previously published factors and believe our results have face validity. Glycosylated hemoglobin was only available for a subset of patients (20% preintervention, 26% postintervention) and was not included in the propensity score since matching on glycosylated hemoglobin resulted in a dramatic decrease in the number of matched pairs. Additionally, the current study has all the limitations of a retrospective study with the potential for residual confounding, which may explain the observed reduction in the outcome. Finally, not all patients evaluated in the study were seen in follow-up clinic visits. However, the vast majority did present for follow-up care (87%), and we expect that a patient who may have developed an SSI would have been more likely to seek additional care than a patient who did not.

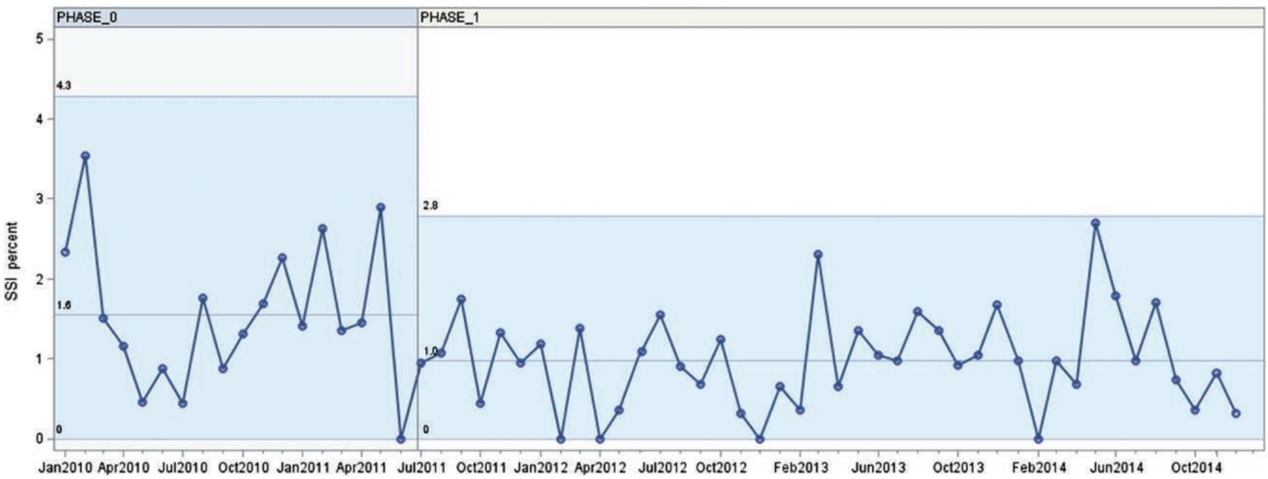

Fig. 7. Control chart showing surgical site infection rates. Control chart of surgical site infection rates as determined from patient follow-up data. Each point is the unadjusted surgical site infection rate (percentage of patients with postoperative infection) for all study patients (all patients who either were diabetic or received insulin during surgery) operated on in the indicated month. The *center lines* are the means of these monthly aggregates for the before- and after-implementation periods and differ slightly from the means reported in the text for this reason. The 3 SD control limits are shown for the before- and after-implementation periods. In the after-implementation data, there are eight consecutive points below the previous *center line* beginning in October 2011, indicating a likely special cause for this observation, detectable by May 2012.[21]

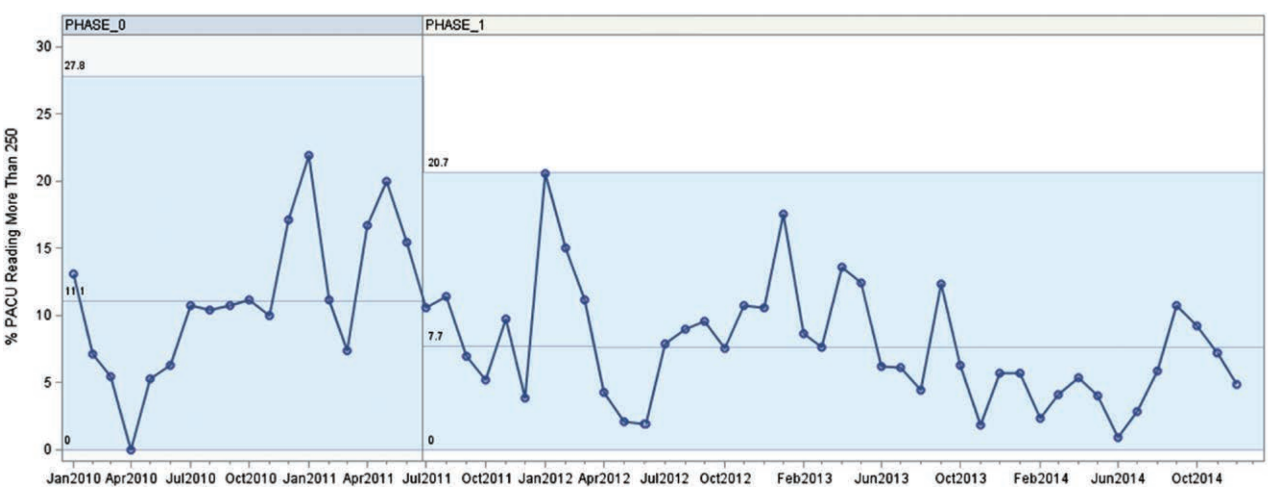

Fig. 8. Control chart of hyperglycemia in the postanesthesia care unit (PACU). Control chart of hyperglycemia rates (blood glucose greater than 250 mg/dl) upon entry to PACU. Each point is the hyperglycemia rate (percentage of patients with postoperative hyperglycemia) for all study patients (all patients who either were diabetic or received insulin during surgery) operated on in the indicated month. The *center lines* are the means of these monthly aggregates for the before- and after-implementation periods and differ slightly from the means reported in the text for this reason. The 3 SD control limits are shown for the before- and after-implementation periods. In the after-implementation data, there are eight consecutive points below the previous *center line* beginning in October 2013, indicating a likely special cause for this observation.[21] The observed reduction in hyperglycemia rates was not pronounced.

In conclusion, anesthesiologists continue to improve value in health care by permanently fixing problems in perioperative systems. As adoption of perioperative information management systems rise,[29,30] understanding the optimal way to leverage these systems to improve process reliability, demonstrate outcomes, and provide feedback[31,32] will become increasingly important. In the future, we hope to study and refine ways in which these types of systems can be developed to continuously evaluate themselves, enabling the development of new tools for managers and system designers to know when further system changes are warranted.

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Competing Interests

The authors declare no competing interests.

Correspondence

Address correspondence to Dr. Ehrenfeld: Departments of Anesthesiology, Surgery, Biomedical Informatics, Health Policy, Vanderbilt University School of Medicine, Department of Surgery, Uniformed Services University of the Health Sciences, 4648 Vanderbilt University Hospital, Nashville, Tennessee 37232. Jesse.ehrenfeld@vanderbilt.edu. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.

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