

USE OF A COMPUTER-GUIDED GLUCOSE MANAGEMENT SYSTEM TO IMPROVE GLYCEMIC CONTROL AND ADDRESS NATIONAL QUALITY MEASURES: A 7-YEAR, RETROSPECTIVE OBSERVATIONAL STUDY AT A TERTIARY CARE TEACHING HOSPITAL

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ABSTRACT

Objective: Inpatient hyperglycemia, hypoglycemia, and glucose variability are associated with increased mortality. The use of an electronic glucose management system (eGMS) to guide intravenous (IV) insulin infusion has been found to significantly improve blood glucose (BG) control. This retrospective observational study evaluated the 7-year (January 2009–December 2015) impact of the EndoTool® eGMS in intensive and intermediate units at Vidant Medical Center, a 900-bed tertiary teaching hospital.

Methods: Patients assigned to eGMS had indications for IV insulin infusion, including uncontrolled diabetes, stress hyperglycemia, and/or postoperative BG levels >140 mg/dL. This study evaluated time required to achieve BG control (<180 mg/dL; <140 mg/dL for cardiovascular surgery patients); hypoglycemia incidence (<70 and <40 mg/dL); glucose variability (assessed by SD and coefficient of variation percentage [CV%]); excursions (BG levels >180 mg/dL after control attained); and the impact of eGMS on hospital-acquired condition (HAC)-8 rates.

Results: Data were available for all treated patients (492,078 BG readings from 16,850 patients). With eGMS, BG levels were brought to target within 1.5 to 2.3 hours (4.5 to 4.8 hours for cardiovascular patients). Minimal hypoglycemia was observed (BG values <70 mg/dL, 0.93%; <40 mg/dL, 0.03%), and analysis of variance of BG values <70 mg/dL showed significant reductions over time in hypoglycemia frequency, from 1.04% in 2009 to 0.46% in 2015 ($P<.0001$). The CV% per patient visit was 26.5 (± 12.9)%, and 4% of patients experienced glucose excursions (defined as BG levels >180 mg/dL once control was attained). HAC-8 rates were reduced from 0.083 per 1,000 patients (2008) to 0.032 per 1,000 patients (2011).

Conclusion: The use of eGMS resulted in rapid, effective control of inpatient BG levels, including significantly reduced hypoglycemia rates. (*Endocr Pract.* 2017;23:331–341)

Abbreviations:

BG = blood glucose; **CMS** = Centers for Medicare and Medicaid Services; **CV** = coefficient of variation; **CV%** = coefficient of variation percentage; **eGMS** = electronic glucose management system; **GV** = glycemic variability; **HAC** = Hospital-Acquired Condition; **ICU** = intensive care unit; **IU** = intermediate unit; **IV** = intravenous; **LOS** = length of stay; **VMC** = Vidant Medical Center

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INTRODUCTION

A disproportionate number of hospitalized patients experience hyperglycemia (1,2). Substantial risk is associated with inpatient hyper- and hypoglycemia due to diabetes and stress hyperglycemia. This has led to ongoing efforts to maintain glucose control in hospitalized patients (1,3). Three typical hyperglycemic patterns exist

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in hospitalized patients: diabetes that is known/previously diagnosed; undiagnosed diabetes identified during hospitalization; and hospital-related hyperglycemia (also known as stress hyperglycemia). Stress hyperglycemia presents during hospitalization but often reverts to normoglycemia following discharge (4). Hypoglycemia during hospitalization is also associated with increased mortality, longer length of stay (LOS), and an elevated risk of intensive care unit (ICU) admission in both insulin-treated and non-insulin-treated patients (5,6). Research indicates that approximately 8% of admitted patients will experience at least one hypoglycemic event (7). Additionally, inpatient glycemic variability (GV), defined as the overall distribution of glucose values around the mean, is an emergent risk factor that has been independently associated with increased mortality (8).

In-hospital hyperglycemia is an independent predictor of morbidity and mortality, and its appropriate management improves patient outcomes (2,9-11). In a 2002 study, Umpierrez and colleagues (2) found patients with hyperglycemia (on admission or in-hospital diagnosis) and no history of known diabetes were 29% more likely to be admitted to the ICU, and they experienced a 16% mortality rate. In 2001, Van Den Berghe and colleagues (9) found that critically ill patients treated to target blood glucose (BG) levels 80 to 110 mg/dL had a 32% mortality reduction compared to those with BG maintained at 180 to 200 mg/dL ($P < .04$). Subsequent to this initial research, our understanding of ideal in-hospital glucose targets has been further refined. The Normoglycemia in Intensive Care Evaluation and Survival Using Glucose Algorithm Regulation (NICE-SUGAR), a randomized controlled trial of more than 6,000 patients, found that lowering BG to <108 mg/dL in the ICU resulted in increased mortality (27.5%) over the control group, in which intermediate BG control (140 to 180 mg/dL) was maintained (24.9%; $P = .02$) (10,11). Likewise, during and after cardiac surgery, maintaining BG control <180 mg/dL reduces mortality, morbidity, and LOS and improves long-term survival (12). In a study of patients undergoing open-heart surgery, elevated BG levels were independent predictors of mortality ($P < .0001$), LOS ($P < .002$), and postoperative sternal infections ($P = .017$) (13). These data suggest that the association between BG and hospital mortality forms a J-curve, with euglycemia having the lowest mortality rate versus both hyperglycemia and hypoglycemia (10).

Substantial evidence indicates that BG management using protocol-driven insulin administration leads to improved patient outcomes (13-15). Typically, intravenous (IV) insulin infusion is the preferred management strategy, especially for critically ill patients (1,16), and several published protocols are available to guide IV insulin infusion administration (13,17,18). In a study comparing cardiac surgery patients with BG controlled via subcutaneous injection versus a protocol-based continuous infusion, use of

the IV protocol led to a 2.5-fold decrease in postoperative complications such as sternal infection ($P = .011$) (14). IV insulin protocol use has also been associated with substantial per-patient cost savings (19). In 2006, the American College of Endocrinology (ACE) and the American Diabetes Association (ADA) recommended that insulin protocols, algorithms, and/or order sets be used to manage hyperglycemia and hypoglycemia in the hospital setting (1).

Until recently, hospitals were limited to paper-based IV insulin infusion protocol management. In the last decade, however, a computerized approach, known as the electronic glycemic management system (eGMS), has become available. This has led to a growing literature base evaluating computerized insulin delivery mechanisms in the hospital setting. The past decade has seen substantial research to describe the performance of computer-programmed protocols (20,21), and a series of controlled studies found significantly improved BG control with eGMS versus paper-based protocols (22-29). This retrospective observational study was designed to evaluate the 7-year impact of an eGMS on patient hyperglycemia and hypoglycemia at Vidant Medical Center (VMC).

METHODS

Study Setting/Intervention

VMC (formerly Pitt County Memorial Hospital) is a 900-bed tertiary care teaching hospital affiliated with the Brody School at East Carolina University in Greenville, North Carolina. VMC provides acute, intermediate, rehabilitation, and outpatient health services to more than 1.4 million people in 29 counties, treating about 33,000 inpatients per year. In December 2008, to improve patient glucose control, VMC implemented the EndoTool® eGMS (now marketed by Monarch Medical Technologies) in select ICUs. Over subsequent years, eGMS use was expanded to include VMC's intermediate units (IUs).

EndoTool integrates with hospital information systems to manage IV insulin delivery. Using mathematical modeling and feedback controls, this eGMS analyzes BG reading trends to develop patient-specific physiologic insulin dosing curves based on patient weight, age, diabetes type, and glomerular filtration rate (Fig. 1). Clinician-inputted, patient-specific information is used to calculate the optimal timing of both fingerstick BG checks and appropriate IV insulin dosing, both of which are performed manually by nursing staff. Using patent-pending Model Predictive Control algorithms, the eGMS makes automatic, nonlinear adjustments to dose recommendations in order to minimize and help prevent episodes of hypoglycemia and hyperglycemia (26). Prior to implementing eGMS, VMC initiated a multistep assessment process that included: interdisciplinary review of failed cases; identification of a standardized IV continuous infusion protocol; selection of an appropriate computerized management tool; and action-step generation.

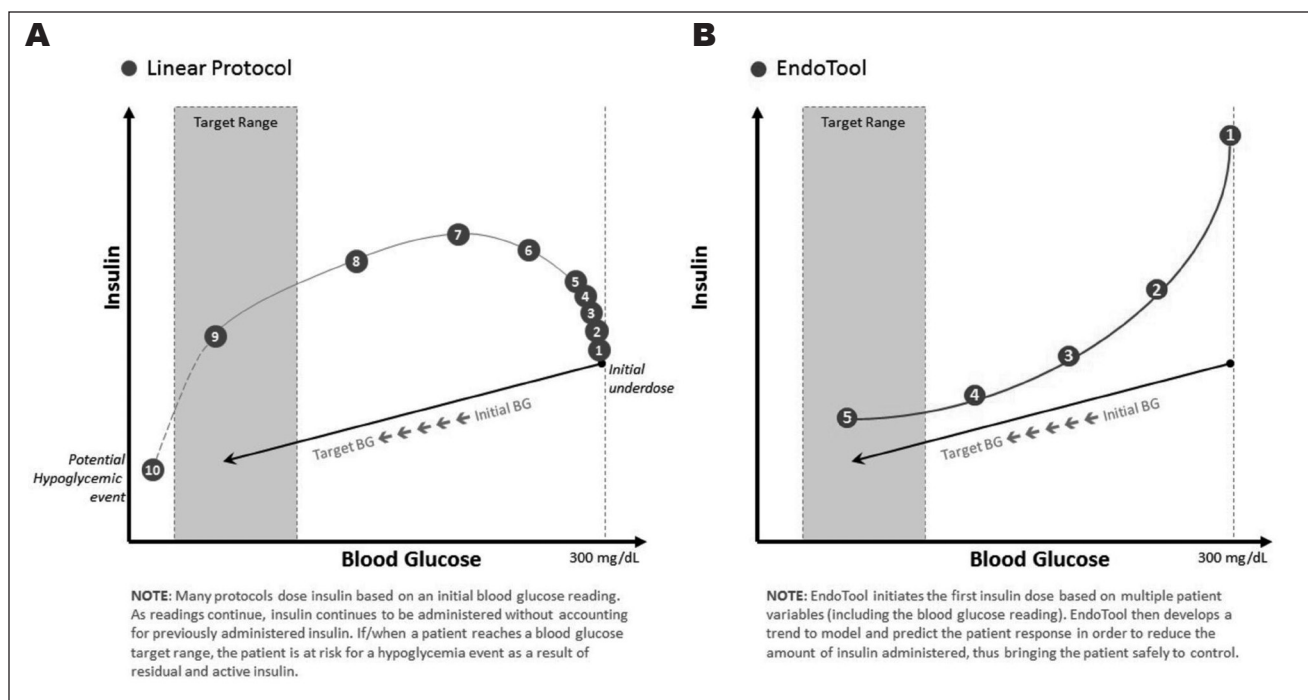


Fig. 1. Comparison of linear (paper) protocol and EndoTool's nonlinear physiologic dosing on insulin administration and blood glucose control. **A.** Linear (paper) protocol. Linear protocols dose insulin based on an initial blood glucose reading. As readings continue, insulin continues to be administered without accounting for previously administered insulin. If/when a patient reaches a blood glucose target range, the patient is at risk for a hypoglycemia event as a result of residual and active insulin. **B.** EndoTool. EndoTool initiates the first insulin dose based on multiple patient variables (including the blood glucose reading). EndoTool then develops a trend to model and predict the patient response in order to reduce the amount of insulin administered, thus bringing the patient safely to control. BG = blood glucose.

Patients and Outcomes Evaluated

This retrospective observational study evaluated the 7-year impact (January 2009 to December 2015) of the EndoTool eGMS in VMC's ICUs and IUs. During this period, VMC patients were assigned to BG management with eGMS if they had an indication for IV insulin infusion due to hyperglycemic emergency, severely uncontrolled diabetes, stress hyperglycemia, and/or postoperative glucose levels >140 mg/dL. Evaluated outcomes included: (a) average time to BG target following eGMS implementation, both overall (target <180 mg/dL) and for cardiovascular surgery patients (target <140 mg/dL); (b) overall incidence of hypoglycemia and severe hypoglycemia (BG <70 mg/dL and <40 mg/dL, respectively) and (c) rate of hypoglycemic events per patient visit; and (d) glucose variability and glucose excursions, with variability calculated as coefficient of variation (CV) and excursions defined as BG levels >180 mg/dL after prior glucose control was attained. Finally, the impact of eGMS on VMC's rates of Hospital-Acquired Condition (HAC)-8 was assessed.

The evaluated hyperglycemia targets of <180 and <140 mg/dL were based on threshold levels recommended by the ACE and ADA (1). The hypoglycemia cut-offs were based on recommendations from the International Hypoglycemia Study Group to treat BG levels ≤70 mg/dL to avoid progression to clinical iatrogenic hypoglycemia (30) and prior research which has set a threshold for severe hypo-

glycemia at <40 mg/dL (25,29,31). Glucose variability was assessed by calculating the percentage CV (CV%), defined as the ratio of the standard deviation to mean BG data for each patient visit (8). HACs were established in 2008 by the U.S. Centers for Medicare and Medicaid Services (CMS) and are defined as conditions that: (a) are high-cost, high-volume, or both; (b) result in the assignment of a case to a diagnosis-related group with a higher payment when present as a secondary diagnosis; and (c) could reasonably have been prevented through the application of evidence-based guidelines. This study's relevant measure is HAC-8, "manifestations of poor glycemic control," with criteria outlined in Table 1 (32). HAC-8 data were evaluated for all VMC patients and compared with national average data (2008 to 2011 only; as of 2012, CMS is no longer reporting national data for individual HAC outcomes) (33).

Implementation

As shown in Table 2, the eGMS was introduced in a staggered process starting with VMC's surgical, medical, and cardiothoracic ICUs in December 2008. The system was subsequently extended to all ICUs and multiple IUs and step-down units, for a total of 18 units. To be evaluable, patients were required to have: (a) at least six BG measurements obtained during their stay; (b) a first BG measurement >70 mg/dL; and, (c) a series of BG measurements with time gaps ≤4 hours (240 minutes). The >4-hour

Table 1 Hospital-Acquired Conditions-8 (HAC-8): Manifestation of Poor Glycemic Control (34)	
HAC-8: Manifestations of Poor Glycemic Control	ICD-9-CM codes
Diabetic ketoacidosis	250.10-250.13.9 (MCC)
Nonketotic hyperosmolar coma	250.20-250.23 (MCC)
Hypoglycemic coma	251.0 (CC)
Secondary diabetes with ketoacidosis	249.10-249.1 (MCC)
Secondary diabetes with hyperosmolarity	249.20-249.21 (MCC)
Abbreviations: CC = complicating or comorbid condition; ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification; MCC = major complicating or comorbid condition.	

time gap between BG measurements was imposed to identify patients with multiple hospital admissions as well as those taken off eGMS management for a substantial time period during a particular admission. Consequently, a given patient could have multiple visits, each representing a unique eGMS measurement series.

Patients' BG testing frequency was recommended by eGMS and occurred every 30, 60, or 120 minutes, depending on patient status and BG level. As shown in Figure 2, with EndoTool, nurses are alerted to: (a) review patient BG levels, select individual patients, and manually enter BG values that move patients towards their target range; and (b) confirm the data entered, as well as any recommended dosing changes. Following this, EndoTool makes appropriate insulin adjustments. EndoTool demonstrates optimal performance when BG readings are entered within 15 minutes of an alert. The alert comprises three consecutive rings per minute until the past-due BG is entered. Past-due alerts cannot be manually disabled from the bedside, a feature developed to promote compliance with patient BG management requirements. If a patient is being moved or transferred, users can temporarily discontinue a patient to avoid unintentional past-due alerts.

Analytics

Individual patient data were generated by the eGMS's analytic function. Year-by-year comparisons of patient data samples were analyzed using one-way analysis of variance (ANOVA). Glucose variability was assessed using mean BG data to identify the SD of BG measurements for each patient visit, followed by CV calculation, expressed as a percentage. Cumulative data were analyzed using descriptive statistics only. VMC HAC-8 data were compared with national data obtained from the CMS.

RESULTS

Data were available for 100% of treated patients. Over 7 years, 492,078 BG readings were obtained from 16,850 patients, for an average of 29 readings per patient. As shown

in Table 3, between 2009 and 2015, the eGMS was able to bring hyperglycemic patients to glucose levels <180 mg/dL within 1.5 to 2.3 hours. Among evaluable patient records, only 4% showed glucose excursions (>180 mg/dL) after prior glucose control was achieved; the average duration of a glucose excursion was 1.91 hours. In terms of GV, the mean BG $\pm$ SD was 143 $\pm$ 39.9 mg/dL on average per patient visit, with an average CV per patient visit of 26.5 ($\pm$ 12.9)%.

Data from VMC cardiovascular surgery units are shown in Table 4: approximately 4.5 to 4.8 hours were required for these patients to achieve a BG target of 140 mg/dL; ~98% of patients achieved this target. Likewise, the majority of cardiovascular ICU and IU patients reached an assigned BG target of 120 mg/dL (88.7 and 93.7%, respectively), while about one-half of patients with a lower target BG range (90 mg/dL) achieved this level. The average amount of time spent in glucose excursions per visit was 1.7 hours for the cardiovascular surgery intensive care unit and 1.5 hours for the cardiovascular surgery IU (data not shown).

Table 5 shows the number and percent of hypoglycemic values (<40 to <70 mg/dL) obtained between 2009 and 2015. Overall, minimal hypoglycemia was observed at VMC, with only 0.93% of BG values <70 mg/dL and 0.03% <40mg/dL. Over all medical units, on average only 1.01% of BG measurements per patient visit were <70 mg/dL and 0.03% were <40 mg/dL. Additionally, reductions in individual patient hypoglycemic BG levels showed a year-on-year decrease (Fig. 3). ANOVA of the percentage of glucose values <70 mg/dL obtained at VMC between 2009 to 2015 showed a statistically significant reduction in this measure of hypoglycemia frequency from 1.04% in 2009 to 0.46% in 2015 ($P<.0001$).

Last, overall improvements in glycemic control for all evaluated patients led to immediate and sustained reductions in HAC-8 measures, with rates showing consistent improvement over the evaluable period (Fig. 4), from 0.083 per 1,000 patients in 2008 to 0.032 per 1,000 patients in 2011, the last year national data were available for this measure (33). As of 2011, the national average for HAC-8 was 0.05 per 1,000 discharges (34,35).

ENDOTOOL.IV General Hospital CCU Medical Director

A

Smith, James
Medical Record : 78787

GLUCOSE / EXTRA CALORIES PREVIOUS GLUCOSE: 155 mg/dL GOAL RANGE: 90-120 mg/dL

Glucose: 133 mg/dL

Sample Time: 07:01

Sample Date: 08-25-2015

Extra calories: Simple Calorie Meal Eaten Meal Timer

Calculate Cancel

B

Smith, James
Medical Record : 78787

DOSING RECOMMENDATION BLOOD GLUCOSE: 133 mg/dL GOAL RANGE: 90-120 mg/dL

Insulin-Regular Infusion

3 units / hour

Next Glucose Check

30 MIN

09:33

Fig. 2. EndoTool screen view: nurse management of patient blood glucose levels. *A*, The EndoTool dashboard shows a list of active patients and alerts the nurse when blood glucose (BG) checks are due. In this image, the nurse selects patient with a previous BG value of 155 mg/dL. The nurse enters a new BG level (133 mg/dL), which will be used by the system to adjust the patient's insulin drip and move the patient safely towards goal range (90 to 120 mg/dL). When appropriate, the nurse indicates if the patient has eaten a meal or snack (so the system may adjust for additional carbohydrates). *B*, The nurse confirms the recommended insulin drip rate that coincides with the BG entered. EndoTool will use the inputted BG value and patient's physiologic data to make a new insulin dosing recommendation and set the frequency for the next BG check.

DISCUSSION

The progressive roll-out of the EndoTool eGMS by VMC to administer IV insulin in its ICUs and IUs resulted in a marked improvement in patient quality of care. Over the 7-year study period, the appropriate use of eGMS led to only 0.03% of BG readings (157 of 492,078) consistent with severe hypoglycemia (<40 mg/dL), while the proportion of readings with hypoglycemic BG values <70 mg/dL was 0.93%. These results for successful hypoglycemia management are similar to or better than those reported in

prior retrospective studies evaluating other computerized glucose management systems (21,22,31). Other notable results included a significant reduction in year-upon-year hypoglycemia incidence (<70 mg/dL), from 1.04% in 2009 to 0.05% in 2015. This was the case even as patient volume more than doubled (from 1,280 patients treated with eGMS in 2009 to 2,890 in 2015).

VMC patients also experienced a relatively rapid time to BG control <180 mg/dL (1.5 to 2.3 hours) and a very low rate (0.4%) of glucose excursions (defined as BG levels >180 mg/dL once control was attained). Additionally, the

Table 2
Vidant Medical Center EndoTool Implementation and Blood Glucose Targets: 2008-2015

Dates	Units ^a	Target BG Range
December 2008	NSICU	110-150 mg/dL
January 2009	LD MICU	70-110 mg/dL 100-150 mg/dL
February 2009	CICU, CIU, CVICU, CVIU, SICU	90-140 mg/dL
May 2009	MICU	130-160 mg/dL
November 2009	SIU, SICU, NSU	100-150 mg/dL
December 2012	MIU	90-140 mg/dL
July 2013	1SO, BGSU, CICU, CIU, MICU, SICU ^b , SIU, MIU	140-180 mg/dL
August 2013	3EAS	140-180 mg/dL
September 2013	ORTHO	140-180 mg/dL
October 2013	1EAS, 3WEST	140-180 mg/dL
January 2014	HDU	140-180 mg/dL

Abbreviations: BG = blood glucose; BGSU = bariatric-general surgery unit (intermediate); CICU = cardiac care intensive unit; CIU = cardiac intermediate unit; CVICU = cardiovascular intensive care unit; CVIU = cardiovascular intermediate unit; HDU = hemodialysis unit; LD = labor & delivery; MICU = medical intensive care unit; MIU = medical intermediate unit; NSICU = neurosurgical intensive care unit; NSU = neurosurgical intermediate unit; ORTHO = orthopedics unit; SICU = surgical intensive care unit; SIU = surgical intermediate unit.
^a1EAS = east intermediate surgery unit; 1SO = south intermediate surgery unit; 3EAS = east intermediate medicine unit; 3WEST = west intermediate oncology unit.
^bAn optional SICU glucose target of 110 to 150 mg/dL was introduced December 2013 for brain surgery patients.

Table 3
**Time to Achieve Blood Glucose <180 mg/dL with EndoTool,
 All Vidant Medical Center Patients: 2009-2015**

Year	Evaluable patient visits	Average time to target (<180 mg/dL), hours
2009	1,275	1.5
2010	2,051	1.5
2011	1,993	1.5
2012	2,268	1.7
2013	2,995	1.9
2014	3,327	1.9
2015	2,862	2.3

overall rate of GV (calculated as CV%) was 26.5 (±12.9)%. To put this finding in context, in 2011, Rodbard (36) identified CV% levels <33.5% as “excellent.” Additionally, the CV% observed in this multisite study were substantially lower than hospital-level mean CV% analyzed in a similar fashion by two recent single-site epidemiologic analyses (31.9 [±13.4]% and 34.2 [±11.1]%) (8,37).

Postsurgical cardiovascular patients, who had more stringent BG targets, were able to achieve goal within 4.5 to 5.0 hours (patients with BG target <140 mg/dL) or 6.1 to

8.2 hours (target <120 mg/dL). Thus, EndoTool is effective at achieving and maintaining cardiovascular patients at the higher end of the 90 to 140 mg/dL target range. Last, 2011 HAC-8 glycemic outcomes for VMC were 0.032 per 1,000 patients, compared to a national average of 0.050 per 1,000 patients (34). These results placed VMC in the top 10% of all U.S. hospitals for HAC-8 compliance (38).

Research has documented the improved performance of eGMS compared with paper algorithms (23-25,27-29,31,39). However, it has been difficult to determine what

Table 4 Vidant Medical Center, Cumulative Blood Glucose (BG) Data (2009-2015) for Cardiovascular Postoperative Patients			
BG target (mg/dL)	Number of evaluable patient visits	Percent of patient visits that achieved BG control	Average time (hours) to BG target
CVICU			
90	1,011	56.2	20.0
120	1,687	93.7	8.2
140	1,762	97.9	4.8
CVIU			
90	218	48.3	11.2
120	400	88.7	6.1
140	440	97.6	4.5
Abbreviations: CVICU = cardiovascular intensive care unit; CVIU = cardiovascular intermediate unit.			

Table 5 Vidant Medical Center Hypoglycemia Summary Data for all Patients (2009-2015 and Overall) and Per-Patient Visit (Overall)										
Summary data, all patients										
Year	# Patient visits	# BG records	# BG values (mg/dL)				Percent of BG values (mg/dL, %)			
			<40	<50	<60	<70	<40	<50	<60	<70
2009	1,280	41,666	16	50	145	433	0.04	0.12	0.35	1.04
2010	2,055	61,507	24	71	274	796	0.04	0.12	0.45	1.29
2011	1,998	58,354	22	55	184	646	0.04	0.09	0.32	1.11
2012	2,274	64,906	15	63	234	715	0.02	0.10	0.36	1.10
2013	3,004	84,163	35	114	319	898	0.04	0.14	0.38	1.07
2014	3,349	94,550	26	89	262	665	0.03	0.09	0.28	0.70
2015	2,890	86,932	19	51	157	403	0.02	0.06	0.18	0.46
Overall	16,850	492,078	157	493	1,575	4,556	0.03 ^a	0.10 ^a	0.32 ^a	0.93 ^a
Per-patient visit data, all patients										
# Patient visits		Average # BG records per patient visit <40	Average # BG records per patient visit (mg/dL)				Average hypoglycemia rate per patient visit (mg/dL, %)			
			<50	<60	<70	<40	<50	<60	<70	
Overall	16,850	29.21	0.01	0.03	0.09	0.27	0.04	0.12	0.37	1.02
Abbreviation: BG = blood glucose.										
^a Mean: 2009 to 2015 data.										

factors are responsible for this superiority. Recent evidence indicates that, compared with paper-based protocols, software-driven IV insulin administration more effectively manages the three pivotal domains of glucose control (hyperglycemia, hypoglycemia, and GV) (23,27,39). These three BG parameters are all independently associated with higher in-hospital mortality rates and LOS (2,7,8) and have all been shown to improve with eGMS

compared with paper-based protocols, both in previous studies (23,25,26,28,39) and the current analysis.

VMC's success mirrors other sites' experience with the EndoTool eGMS. Two prior randomized studies and a retrospective analysis have found that, in eGMS-managed surgical ICU patients, the number of BG measurements falling within target range significantly improved and BG excursions significantly decreased compared with paper

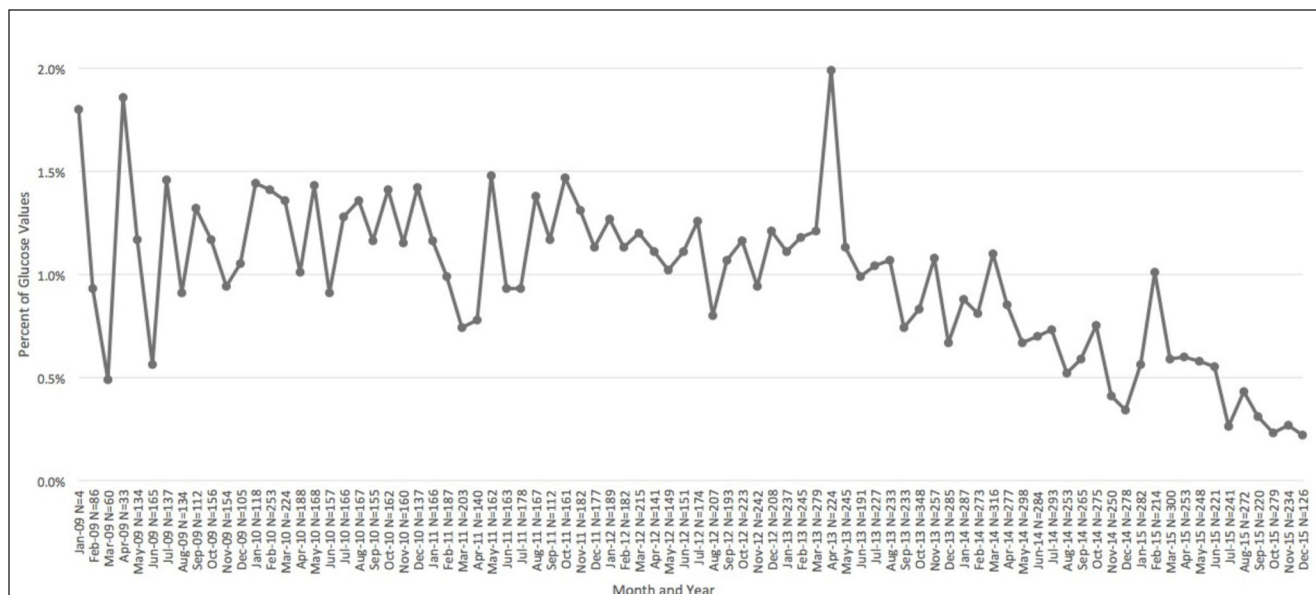


Fig. 3. Percentage of Vidant Medical Center (VMC) patient glucose values <70 mg/dL with EndoTool: 2009 to 2015. *N* = number of patient visits. *EndoTool was rolled out progressively at VMC sites as follows: 2008/2009: CICU, CIU, CVICU, CVIU, LD, MICU, NSICU, SICU; 2010: NSU, SIU; 2012: MIU; 2013: 1EAS, ISO, 3EAS, 3WEST, BGSU, ORTHO; 2014: HDU.

1EAS = east intermediate surgery unit; ISO = south intermediate surgery unit; 3EAS = east intermediate medicine unit; 3WEST = west intermediate oncology unit; BG = blood glucose; BGSU = bariatric-general surgery unit (intermediate); CICU = cardiac care intensive unit; CIU = cardiac intermediate unit; CVICU = cardiovascular intensive care unit; CVIU = cardiovascular intermediate unit; HDU = hemodialysis unit; LD = labor and delivery; MICU = medical intensive care unit; MIU = medical intermediate unit; NSICU = neurosurgical intensive care unit; NSU = neurosurgical intermediate unit; ORTHO = orthopedics unit; SICU = surgical intensive care unit; SIU = surgical intermediate unit.

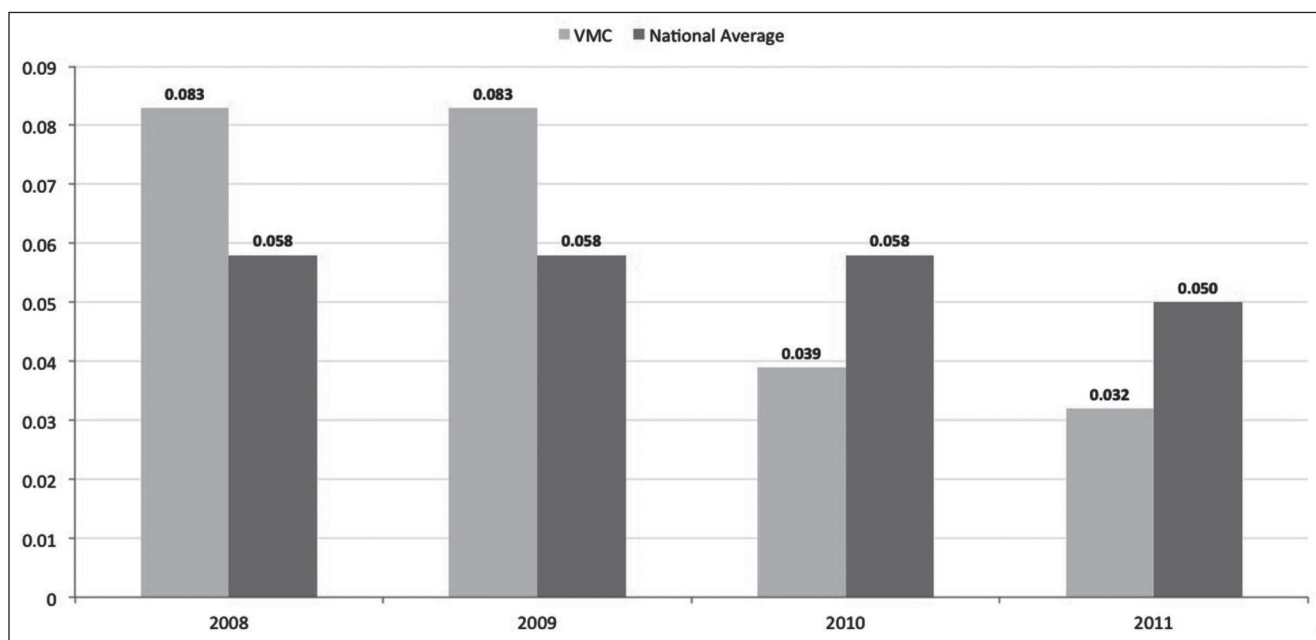


Fig. 4. Hospital Acquired Conditions-8 (HAC-8) rate per 1,000 patients: 2008-2011, Vidant Medical Center versus U.S. national average: 2008 to 2011* (38,40).

VMC = Vidant Medical Center.

*Data reported only through 2011; after this year, individual mean HAC measures were no longer reported by the Centers for Medicare and Medicaid Services.

protocol management (23,28,39). Likewise, the use of this eGMS to manage BG levels in critically ill surgical ICU patients has been associated with a decreased frequency of serious hypo- and hyperglycemia (26). Another study reported that the mean time free from severe hypoglycemia following cardiovascular ICU discharge was 7.0 days for patients treated with eGMS and 1.1 days for paper protocol-treated patients (25).

The EndoTool eGMS uses an algorithm comprising clinician-inputted, patient-specific information to calculate the optimal timing of both fingerstick BG checks and appropriate insulin infusion dosing. Each BG reading and insulin dose is entered into the system, allowing the algorithm to recalculate as needed. The resulting individualized insulin dosage curve helps to minimize hyperglycemia, hypoglycemia, and glucose excursions. Furthermore, this system can typically be integrated into electronic health record systems and/or order entry menus, eliminating the need for paper or printed protocols. EndoTool is a U.S. Food and Drug Administration–approved eGMS that uses patented modeling with individualized feedback to maintain glycemic control (40). To evaluate performance, the system provides patient- and unit-specific reporting capabilities and postuse analytics (39).

Limitations

This study is one of the largest and longest retrospective analyses of eGMS data conducted to date; it also reflects a range of patients with varying characteristics on admission. The primary limitation of this study is that it was a retrospective, single-center analysis. Based on this, it is difficult to know whether other variables or heterogeneity between the multiple units analyzed influenced outcomes. Ideally, future studies will evaluate patient outcomes both prior to and following eGMS implementation. However, the observed improved glucose outcomes, and the similarity of these results with prior research findings, argue in favor of a positive relationship between eGMS use and improved BG control.

It is also feasible that other factors contributed to the year-upon-year improvements observed in this study. For example, increased staff familiarity with eGMS technology procedures and subsequent improved response could drive ongoing performance efficiency. It should also be noted that, in late 2015, VMC upgraded to a web-based version of EndoTool that included several upgrades (staged goals for diabetic ketoacidosis and hyperglycemic hyperosmolar syndrome, as well improved dextrose supplementation recommendations at certain BG thresholds).

Last, some paradoxical year-on-year data were observed in terms of time required for VMC patients to achieve glucose control <180 mg/dL. Between 2009 and 2011, patients achieved BG control in 1.5 hours; however, this increased to 1.9 hours by 2014 and 2.3 hours by 2015.

This change may be explained in part by a VMC procedural adjustment made in May 2014. In an effort to reduce hypoglycemia and to prevent rapid drops in fasting BG, all eGMS patients were assigned to receive a maximum insulin bolus of 10 units (instead of 20 or 50 units as previously established). This likely affected patient time to target.

With the passage of the Health Information Technology for Economic and Clinical Health Act and other incentives, in-hospital use of eGMS is on the rise (41). Therefore, it is worth noting that the results of this study suggest potential future research directions. To date, very few randomized controlled trials (RCTs) of eGMS have been published (29). A RCT evaluating clinical outcomes associated with eGMS-managed moderate versus strict BG control would provide hospitals and clinicians with valuable, practicable information. Similarly, controlled research examining the relationship between time to BG target and patient outcomes will help clinicians to even further refine in-hospital hyperglycemia management. Last, the impact of BG management with eGMS in specific high-risk patient groups should be evaluated (for example, following coronary artery bypass grafting or in patients with diabetic ketoacidosis).

CONCLUSION

The use of an eGMS to manage glucose levels in hospitalized patients with diabetes may lead to improved glycemic control, and therefore, better patient outcomes. VMC's use of the eGMS to administer IV insulin in the ICUs and IUs in the setting of a large tertiary care hospital resulted in significant improvements in overall glucose control, assessed as hyperglycemia, hypoglycemia, and glucose excursions. It is likely that other facilities could achieve similar improvements in BG control and patient outcomes using the EndoTool eGMS.

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DISCLOSURE

Robert J. Tanenberg is on the Advisory Board of Monarch Medical Technologies, which markets the EndoTool system. The other authors have no multiplicity of interest to disclose. All authors (Drs. Tanenberg, Hardee, and Drake, and Ms. Rothermel) collaborated to draft and revise this paper.

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