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Multifaceted approach to reducing occurrence of severe hypoglycemia in a large healthcare system

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Purpose. Substantial reductions in inpatient episodes of severe hypoglycemia achieved by a large healthcare system through enhanced use of technology and sustained quality-improvement initiatives are described.

Summary. After internal data collection and analysis revealed that severe hypoglycemia accounted for 75% of all systematically monitored adverse drug events in its hospital network, St. Louis–based BJC HealthCare designed and executed a multifaceted approach to reducing hypoglycemia events. Initiated by a pharmacist-led task force, the project entailed (1) automated event detection and creation of dashboards for comparing hypoglycemia rates among at-risk patients at 11 BJC facilities, (2) implementation of evidence-based and internal best practices in use at BJC's top-performing hospitals, (3) development of an online "Hypoglycemic Event Analysis Tool" (HEAT) to support event investigation and collection of data on causative factors, and (4) the assembly of targeted interventions at a "Hypoglycemia Facility Strategy Tracking" (H-FaST) intranet site. As a result of the launch of the HEAT and H-FaST tools and associated provider education activities, the systemwide rate of hypoglycemia events in the specified at-risk patient population declined from 6.45 per 1000 patient-days during a preimplementation baseline period (July–December 2009) to 1.32 per 1000 patient-days during a designated postimplementation period (January–June 2014), an 80% overall reduction in hypoglycemia ($p < 0.01$); reductions in severe hypoglycemia events ranging from 70% to 100% were observed at all 11 hospitals.

Conclusion. A multifaceted, evidence-based, data-driven approach enabled a large healthcare system to markedly reduce the frequency of severe hypoglycemia events.

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Severe hypoglycemia is a common, recognized problem among hospitalized patients that can cause undesirable effects such as tremors, anxiety, sweating, cognitive impairment, and even death.[1] One study indicated that severe hypoglycemia was associated with increased hospital length of stay and greater odds of inpatient death and death within one year of discharge.[2] A large retrospective cohort study found that hypoglycemia was common in diabetic patients in the general ward of a large teaching hospital and found strong relationships between hypoglycemia and both inpatient length of stay and mortality.[3] There are other adverse consequences of hypoglycemia to consider, including a need for increased nursing resources during

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treatment as well as increased patient fear and treatment dissatisfaction, which have been found to be major causes of nonadherence to therapy.[4] Fortunately, when hospitals provide responsive and focused attention to risk factors for severe hypoglycemia, patient harm can be prevented.

While hypoglycemia can occur independently of drug administration, Braithwaite and colleagues[5] found that most hypoglycemia events among hospitalized patients are due to an adverse reaction to insulin or oral antidiabetic agents. In 2010 we found that severe hypoglycemia (defined as a blood glucose concentration of <40 mg/dL) in association with an order for a diabetes agent accounted for 75% of all systematically monitored adverse drug events (ADEs) within the BJC HealthCare system (BJC), which at the time comprised 11 hospitals, including 2 academic and 9 community hospitals. Under the leadership of a pharmacist and a physician champion, in 2010 BJC commenced a systemwide initiative to address severe hypoglycemia.

This report describes the implementation of a systematic process to reduce severe hypoglycemia events, as well as an evaluation of its impact on rates of severe hypoglycemia, in a large multicenter healthcare setting. Specifically, the initiative included formation of a multidisciplinary task force, creation of dashboard reports, implementation of evidence-based best practices, and continuous dissemination of knowledge.

Implementation of systematic process

BJC designed and executed a multifaceted and systematic approach to reducing severe hypoglycemia events. Initial methods included automating the event identification process, forming a multidisciplinary task force, raising institutional awareness, implementing evidence-based best practices, investigating events, and collecting information on causative factors. Subsequently, BJC developed practice-based and automated interventions (informed by prioritization of causative factors across the entire system) that were executed over several years, as depicted in Figure 1.

Automatic identification of events. BJC adapted a comprehensive trigger tool to identify ADEs,[6] including an automated method to identify severe hypoglycemia events. Using BJC's "pharmacy expert system" (PES), a clinical decision support application based on the Cerner Multum system (Cerner Corporation, Kansas City, MO) that has been described elsewhere,[7] all whole blood and capillary blood glucose concentration values were collected from each BJC hospital. For baseline and all subsequent event identification, severe hypoglycemia was defined as a glucose concentration of 15–39 mg/dL without a subsequent value of >39 mg/dL within 10 minutes and associated with an order for an antidiabetic agent in the previous 24 hours. Hypoglycemia trigger events within the next 12 hours were considered duplicate and not counted.

Hypoglycemia Task Force formation. With severe hypoglycemia accounting for the majority of ADEs at its facilities, BJC formed a systemwide Hypoglycemia Task Force to reduce harm from severe hypoglycemia. This pharmacist-led multidisciplinary team comprised certified diabetes educators, clinical nurse specialists, endocrinologists, dieticians, epidemiologists, pharmacists, informatics specialists, and a physician champion. Early on, the Hypoglycemia Task Force charged each community hospital with forming a similar institution-specific multidisciplinary diabetes management team. The formation of the hospital teams not only raised awareness of hypoglycemia risks and rates within the institution but also promoted sharing of best practices among nursing units. These teams used a variety of methods to keep healthcare providers focused on hypoglycemia risks, including generating and displaying monthly hypoglycemia dashboard reports specific to each nursing division, discussing hypoglycemia cases and process improvement strategies in staff meetings, providing diabetes management tips in staff newsletters and e-mails, and adopting a standard insulin order form.

Creation of dashboards. One of the first steps taken by the Hypoglycemia Task Force was to develop dashboards to display monthly progress, raise awareness, and garner leadership support. Data were displayed graphically as risk-adjusted rates and counts of severe hypoglycemia events at the system, hospital, and nursing unit levels. The dashboard reports were automatically distributed monthly to each hospital's diabetes management team members and hospital leaders. In addition, to bring this concern to the forefront, severe hypoglycemia events were added to BJC's systemwide quality scorecard beginning in 2011.

An essential component of dashboard development was the creation of a metric to adjust for differences in the patient populations of our hospitals. To do so, the Hypoglycemia Task Force developed a metric to calculate hypoglycemia rates to better reflect true exposure. This metric, the "hypoglycemia at-risk rate," was calculated by dividing the number of severe hypoglycemia events (as defined above) at each BJC hospital by the number of inpatient days for any patient with an antidiabetic agent order.

Development of this risk-adjusted metric accomplished several goals: The metric reduced measurement bias and allowed the task force to identify high-performing hospitals, prioritize hospitals for improvement, and secure a "buy-in" for the hypoglycemia reduction initiative among diabetes experts across the system. This standard metric was applied across the entire BJC system, which

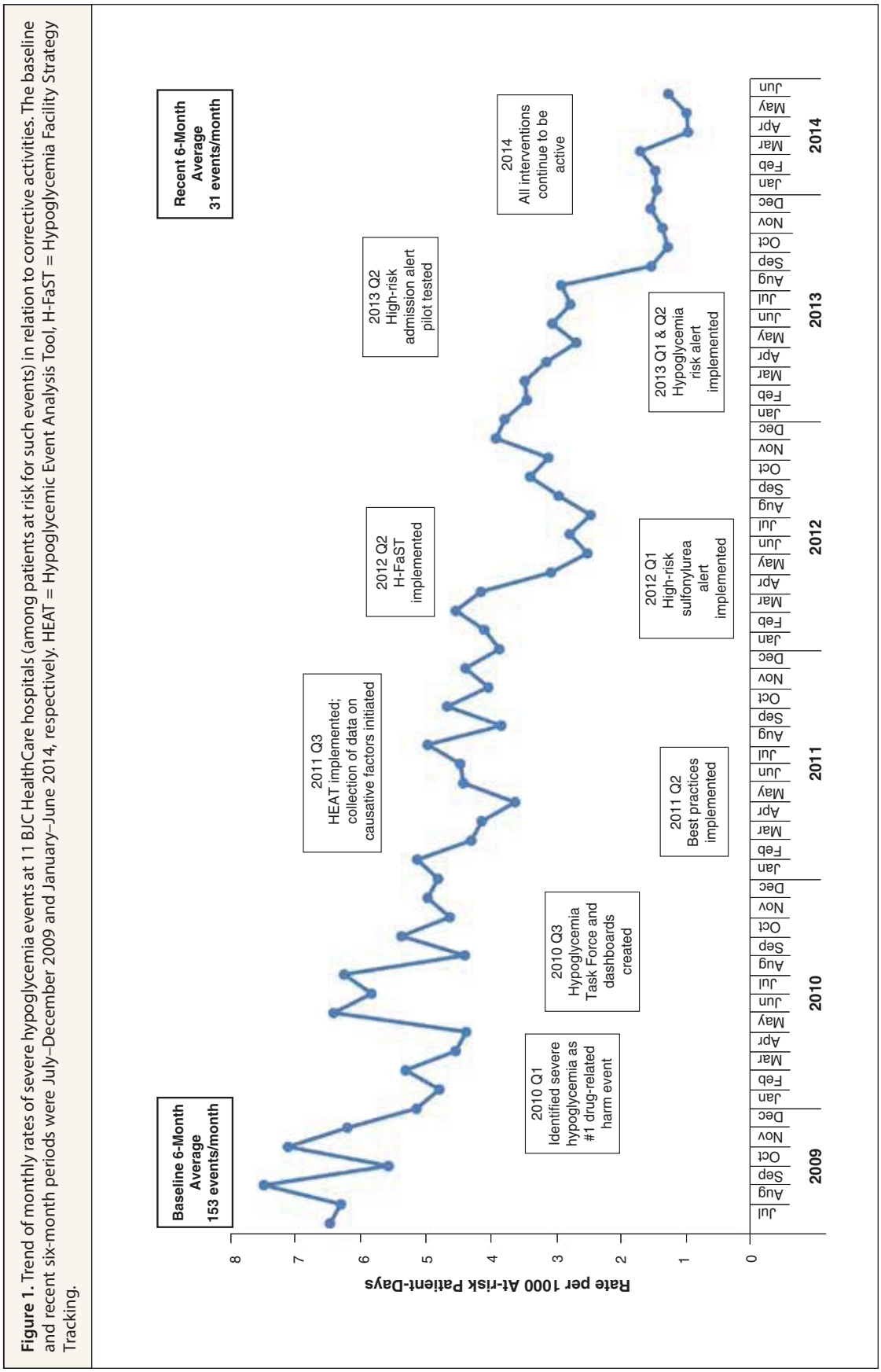


Figure 1. Trend of monthly rates of severe hypoglycemia events at 11 BJC HealthCare hospitals (among patients at risk for such events) in relation to corrective activities. The baseline and recent six-month periods were July–December 2009 and January–June 2014, respectively. HEAT = Hypoglycemic Event Analysis Tool, H-FaST = Hypoglycemia Facility Strategy Tracking.

comprises a heterogeneous mix of large and small, academic and community, and urban, suburban, and rural institutions with a wide range of rates of admission of patients with diabetes (2–40%; Table 1). We identified hospitals with the lowest event rates for site visits to guide the initial development of foundational best practices while targeting hospitals with the highest rates for early improvement initiatives.

Systemwide implementation of evidence-based best practices. Once standardized metrics were in place and the dashboards were drawing attention to the issue of severe hypoglycemia at each hospital, the Hypoglycemia Task Force sought evidence-based interventions to reduce severe hypoglycemia events. First, many of the recommendations of the 2009 joint American Association of Clinical Endocrinologists (AACE)–American Diabetes Association (ADA) consensus statement on inpatient glycemic control were adopted.[8] These recommendations were proposed as foundational practices to be readily implemented in each hospital. Then the team gathered input from local subject matter experts, including endocrinologists, nurse educators, diabetes educators, and pharmacists; conducted site visits at BJC's high-performing hospitals; and identified additional BJC best practices to be implemented immediately. These interventions included order form modifications, such as a stipulation that insulin be withheld only in response to a prescriber's order, a 30% reduction in the bedtime sliding-scale insulin dose relative to daytime doses, instructions to avoid routine use of correction insulin at 0200 and 0400 hours, and a requirement that the prescriber be notified in the event a patient had two measured blood glucose concentrations of <70 mg/dL or one glucose value of <50 mg/dL. Successful implementation of these improvements was tracked at the monthly Hypoglycemia Task Force meetings.

Development of an event analysis tool. The task force also developed a Hypoglycemic Event Analysis Tool (HEAT) to aid in systematically collecting information on causative factors discovered during event investigations. The HEAT was initially introduced as a paper data collection instrument to be completed by diabetes educators, nurses, or pharmacists from each hospital within 10 days of an event (Figure 2). During the investigation of an event, a trained clinician identified causative factors from a predefined list. Feedback from these clinicians and BJC leadership led to the incorporation of an electronic HEAT into the PES. The streamlined, partially prepopulated version of the tool reduced the burden of collecting information and increased adoption of the process.

Reports generated from HEAT data graphically display the frequency of the perceived causative factors associated with severe hypoglycemia events for each hospital and the entire system. During the original phase of data collection, in 2011–12, the three most frequently identified causative factors (as described on the predefined list) were "timing issues," "glucose trend not recognized," and "home regimen continued as inpatient." The list of causative factors continues to be reevaluated and updated to address newly identified concerns. HEAT data are shared with each hospital's chief nursing officer and quality-improvement leaders throughout the system and integrated into an interactive internal website that provides hospitals with customized suggestions for future hypoglycemia reduction strategies.

Utilization of HEAT data. With causative-factor data showing that

Table 1.
Characteristics of BJC HealthCare Facilities 2014

Facility	Setting	No. Licensed Beds	No. Annual Inpatient Discharges	% Admissions With Diabetes
A	Urban academic (adult)	1,342	57,405	26
B	Urban academic (pediatric)	264	10,414	2
C	Suburban community	497	24,805	22
D	Suburban community	485	13,962	40
E	Suburban community	397	16,892	22
F	Suburban community	206	7,527	30
G	Suburban community	127	5,229	30
H	Suburban community	113	2,849	19
I	Suburban community	72	3,798	17
J	Rural	133	3,371	31
K	Rural critical access	35	2,269	23

[a]HMO = health maintenance organization, PPO = preferred provider organization.

timing issues related to the insulin administration process around mealtime were a major contributing factor in severe hypoglycemia at several hospitals, one of the community hospitals conducted a kaizen blitz.[9] The hospital's multidisciplinary diabetes management team took action on the AACE–ADA best-practice recommendations to ensure that the timing of insulin administration coincided with food intake.[8] The team held a week-long onsite event that included brainstorming and rapid testing of solutions. The safety goal was to improve the percentage of insulin doses administered within 30 minutes of a glucose test and thereby reduce severe hypoglycemia events. This process resulted in a new workable solution: A member of the hospital's dietary staff alerted a nurse when meals arrived on a patient care unit, prompting the nurse to perform a glucose test and administer insulin at the appropriate time. At this community hospital, the percentage of insulin doses given within 30 minutes of a glucose test was increased from 47% to 80%. After the hospital's successful implementation of the solution and demonstration of sustained process improvements, the solution was customized and adopted by all other hospitals within the system.

Continuous dissemination of knowledge. Across the system, communication of successes and challenges was vital for hospitals to learn from each other and standardize work. To manage all the efforts of the Hypoglycemia Task Force, an interactive internal website—the "Hypoglycemia Facility Strategy Tracking" (H-FaST) site—was created. The H-FaST site was used to collect and track the interventions, dashboards, causative factors, and best-practice recommendations (Figure 3). The site provides a monthly updated prioritization of causative factors for each hospital, with links to factor-specific task force recommendations. Updates to the best practices, discussion boards, and forms were automatically e-mailed to the Hypoglycemia Task Force members. Local hospitals were able to identify which other hospitals had implemented the recommendations and easily request information regarding successes and challenges. The H-FaST website continues to support a process of ongoing quality improvement because the site is continuously updated with current and changing causative factors.

Development of targeted risk alerts. For the primary causative factors identified using the HEAT tool, the lead clinical pharmacist for the BJC system worked with a system informatics pharmacist, academic partners, and an application developer to create, operationalize, and broadly distribute several system-wide electronic rules. These included customized clinical decision support alerts addressing sulfonylurea use in high-risk patients, hypoglycemia risk alerts generated through predictive modeling, and risk alerts to help identify patients with a history of hypoglycemia events on admission to any BJC emergency department.

Sulfonylurea alert for high-risk patients. The "high-risk sulfonylurea alert" notified pharmacists when the use of a sulfonylurea was contraindicated due to an increased risk of hypoglycemia.[8,10,11] These alerts were sent when a patient receiving sulfonylurea had a blood glucose concentration of <70 mg/dL if he or she was 75 years of age or older or had a creatinine clearance value of <30 mL/min (<50 mL/min for patients receiving glyburide) or a body weight of <75 kg. The sulfonylurea alert was implemented across BJC, and a process measure was added to

Race (%)			Payer (%)			
Black	White	Other	Commercial/ HMO/PPO[a]	Medicare	Medicaid	Self-Pay/ Other
34	62	4	26	40	23	11
28	64	8	49	0	48	3
10	75	15	46	43	6	4
62	36	2	15	55	17	13
4	86	10	37	51	8	4
10	89	2	19	56	20	5
4	92	3	28	60	5	7
3	29	67	50	40	4	6
3	82	15	47	36	12	6
1	95	5	17	53	22	8
1	82	18	14	44	35	8

Figure 2. Paper version of BJC HealthCare's Hypoglycemic Event Analysis Tool.

HYPOGLYCEMIC EVENT ANALYSIS TOOL *(HEAT)*

Not Part of Medical Record

Event Date and Time_____ BG Level_____ Investigating RN_____

Calorie Intake at Time of Event: ☐ NPO ☐ PO ☐ Tube Feeding ☐ IV ☐ TPN with Insulin

- ☐ Patient's dietary status changed within 24 hours of event
- ☐ Status change was discussed with the provider
- ☐ Patient ate since last meal

Amount of meal, prior to event, that was consumed ____% ☐ Unknown

Comments for Reviewer:

Drug Administration

- ☐ Insulin order changed within 24 hours of event

Time between insulin administration and the meal nearest to event:

_____ minutes before meal or _____ minutes after meal

Place Patient Label Here
Name
DOB
ID#
Room #

RECOMMENDATION for an intervention to prevent a similar future event:

Prescriber Notification (Complete Shaded Section at Time of Event)

- ☐ Documentation of prescriber notification of glucose trend before event (severe hypoglycemia)
- ☐ Documentation of prescriber notification of severe hypoglycemia (blood glucose < 40) at time of event

Causative Factors - choose a maximum of 3 of the most important factors (definitions on back)

Prescribing Related (Dosing not in alignment with patient's medical condition prior to event)

- ☐ Home regimen continued as inpatient
- ☐ Event while treating elevated potassium
- ☐ Basal heavy regimen
- ☐ High dose sliding scale insulin
- ☐ Sulfonylurea-related hypoglycemia
- ☐ Inpatient regimen not adjusted due to:
  - ☐ Glucose trend not recognized
  - ☐ Significant reduction in steroid dose
  - ☐ Decreased nutritional intake
- ☐ Event related to outpatient or emergency department drug administration

Process Related

- ☐ Insulin administration and food intake not synchronized
- ☐ POC glucose reading not linked to insulin administration
- ☐ POC glucose reading not synchronized with food intake

Administration Related

- ☐ Wrong drug, dose, route, patient, or time
- ☐ Insulin stacking

Monitoring Related

- ☐ Insufficient glucose monitoring

Invalid Alert

- ☐ Erroneous lab value

Contributing and Other Factors

- ☐ Diabetic agents received prior to admission

Diabetes Type:

- ☐ Type I
- ☐ Type II
- ☐ Gestational

Home Diabetic Regimen

- ☐ Insulin
- ☐ Oral agent

Was the MD notified of the findings?

- ☐ Yes
- ☐ Not available for discussion

Was the RN notified of the findings?

- ☐ Yes
- ☐ Not available for discussion

Definition for Causative Factors:

1. **Basal Heavy Regimen** – Greater than 0.5 Units/KG of basal insulin without any or minimal mealtime insulin OR > 0.3 Units/Kg basal insulin without any or minimal mealtime insulin in patients with renal impairment (CrCl<30 mL/min).
2. **High Dose SSI** –Event due to "high" dose SSI being ordered.
3. **Insulin Stacking** – Rapid acting insulin administered and repeated within 3 hours (or less) OR Regular insulin administered and repeated within 4 hours (or less) resulting in hypoglycemia.
4. **Sulfonylurea-related hypoglycemia** – Sulfonylurea primary cause of or contributed to the event. *Mark especially if sulfonylurea alert fired.*
5. **Event Related to Outpatient or Emergency Department drug administration-** Medication given in ED or prior to admission and is the proximate cause of inpatient hypoglycemia.
6. **Insufficient glucose monitoring-** Improper time gap of ordering or drawing of glucose levels.
7. **Glucose Trend not recognized**- BG level <90 and/or significant change in BG levels where current insulin regimen poses a patient safety risk.
8. **Significant change reduction in steroid dose**- Steroid tapered or discontinued without change in insulin requirements.
9. **Decreased nutritional intake**- Event secondary to lack of insulin adjustment in patient with poor food intake, other enteral nutrition, or NPO.

TIMELINE: Start with event and complete for up to 24 hrs. prior to event

Date/time	POC /Venous	Scheduled Time	Admin Time	Agent	Dose ordered	Dose Admin	Correctional?	Notes
	(Event)						Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	
							Yes / No	

Optional Narrative:

BJC HealthCare 2014
St. Louis, Missouri

the systemwide quality scorecard to capture the rate at which pharmacists responded to the alerts. Additionally, a letter was sent to prescribers stating that a pharmacist alert had been created to facilitate identification of at-risk patients in real time and that pharmacists would contact prescribers to alert them to this risk and suggest (at a minimum) temporary discontinuation of orders for oral antidiabetic agents. Internal BJC data indicated that prior to the initiative described here, one in seven patients identified by this alert suffered a severe hypoglycemia event if no prescribing change was made. These pharmacy-mediated alerts resulted in therapy changes one third of the time. In addition, as of June 2014, the systemwide use of oral sulfonylureas in patients with diabetes had been decreased to 7%, as compared with a rate of sulfonylurea use of 15% in 2009 (the year before the initiative was launched).

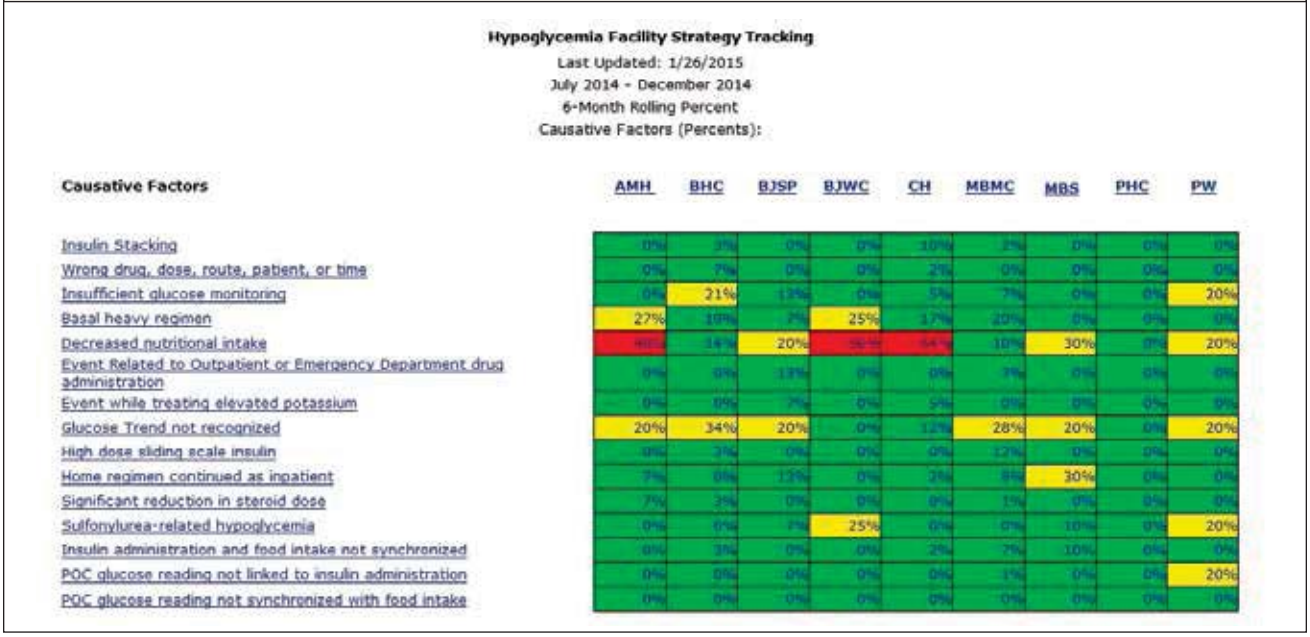
Hypoglycemia risk alert. The "hypoglycemia risk alert" was developed by colleagues in the endocrinology division of the department of medicine at Washington University School of Medicine.[12] This alerting tool was designed to employ predictive analytics in identifying patients with diabetes at risk for hypoglycemia due to low body weight, low creatinine clearance, high basal insulin doses, the use of sulfonylurea therapy, and mealtime sliding-scale insulin therapy. Once the alert was implemented, responders used a systematic tool to identify appropriate changes to therapy and communicate those recommendations to the prescriber. The alert was pilot tested at select nursing stations at BJC's adult academic hospital in 2011, with a subsequent 68% reduction of severe hypoglycemia in high-risk patients that year.[13] A further reduction of 19% was seen in 2012, when the alert system was implemented on all acute and progressive-care nursing units.[14] With the approval of medical and administrative leaders at each BJC hospital, diabetes educators, nurses, and pharmacists were trained to respond to this alert at all remaining BJC hospitals.

High-risk admission alert. Recently, a "high-risk admission alert" was developed to identify patients admitted to the emergency department who experienced a hypoglycemia event at a BJC facility within the prior two years. This electronic alert includes patient demographics and details of the prior hypoglycemia event, causative factors, laboratory test values, and past and current drug orders. High-risk admission alerts are sent to various personnel at the hospital. This alert also includes the HEAT form regarding the previous event to facilitate early action, as 27% of hypoglycemia events at BJC facilities occur within 24 hours of patient arrival. This alert is currently being pilot tested at several BJC hospitals.

Evaluation methods

The hypoglycemia reduction initiative was evaluated with a pre–post

Figure 3. Screenshot of BJC HealthCare's Hypoglycemia Facility Strategy Tracking intranet site showing causative factors for severe hypoglycemia events identified during the period July–December 2014. The abbreviations above the grid represent various BJC HealthCare hospitals. For any particular hospital, yellow indicates factors that accounted for 20–39% of events, and red indicates factors that accounted for at least 40% of events.



study design using PES data collected for the purpose of ongoing surveillance of ADEs. Severe cases of hypoglycemia were defined as described previously. System-level and hospital-specific changes in rates of hypoglycemia over the study period (July 2009–June 2014) were evaluated for the at-risk hypoglycemia population (defined as days of a patient's stay when a diabetes agent was ordered), as well as the entire inpatient population. All patients meeting these broad criteria were included in rate calculations.

A chi-square test was used to compare hypoglycemia rates (expressed as events per patient-day and events per "at-risk patient-day"; see Table 2 footnotes for definitions) in the first six months of the study period (July–December 2009, the preimplementation period) and the last six months of the study period (January–June 2014, the postimplementation period). In addition, linear regression was used to assess the magnitude of the change in the hypoglycemia rate for at-risk patients, by month, throughout the five-year study period. All statistical analyses were carried out using SAS, version 9.2 (SAS Institute, Cary, NC).

Monthly data for the baseline year of 2009 were unavailable for two BJC community hospitals; therefore, for these hospitals the mean numbers of events and patient-days from January through June 2010 were used as baseline data. This imputation was considered reasonable and conservative given that intervention activities in the first six months of 2010 were mostly planning activities and that the two hospitals represented only 7% of BJC's total admissions during the baseline year. Sensitivity analyses were performed to compare results derived using the imputed data and results derived using data only from the nine hospitals with complete data.

Evaluation findings

BJC experienced a sharp decline in the number of severe hypoglycemia events from the preimplementation to the postimplementation period (913 and 185 cases, respectively) (Table 2). For all evaluated BJC facilities combined, the rate of severe hypoglycemia events in the patient population at risk for hypoglycemia declined from 6.45 per 1000 at-risk patient-days in the preimplementation period to 1.32 per 1000 at-risk patient-days in the postimplementation period—an 80% reduction ($p < 0.01$); reductions in severe hypoglycemia events were observed at all hospitals and ranged from 70% to 100%.

A similar trend of reduced severe hypoglycemia events was observed in the BJC patient population overall (not just at-risk patients), in which there were 2.35 and 0.49 events per 1000 patient days in the preimplementation and postimplementation periods, respectively (data not shown in Table 2); both systemwide and at individual hospitals, the degree of decline was similar to that observed in the at-risk patient population (a system-level rate reduction of 79%, $p < 0.01$), with rate reductions at in-

Table 2.
Rates of Hypoglycemia Before and After Implementation of Corrective Measures at BJC HealthCare Facilities

	Preimplementation (Jul–Dec 2009)			Postimplementation (Jan–Jun 2014)				
Facility	No. Cases[a]	No. At-risk Patient-Days[b]	Rate[c]	No. Cases[a]	No. At-risk Patient-Days[b]	Rate[c]	% Reduction in Rate	*p*
A	262	66,007	3.97	71	69,715	1.02	74	<0.01
B	0	1,947	0	0	3,210	0	. . .[d]	. . .
C	162	25,179	6.43	36	19,451	1.85	71	<0.01
D	248	17,965	13.80	30	20,356	1.47	89	<0.01
E	71	13,018	5.45	14	12,384	1.13	79	<0.01
F[e]	84	4,116	20.41	20	4,915	4.07	80	<0.01
G	44	6,073	7.25	7	4,144	1.69	77	<0.01
H	7	1,672	4.19	0	1,250	0	100	. . .
I[e]	6	1,560	3.85	1	1,823	0.55	86	0.07
J	17	2,642	6.43	4	2,045	1.96	70	0.03
K	12	1,411	8.50	2	1,144	1.75	79	0.04
Total	913	141,590	6.45	185	140,437	1.32	80	<0.01

[a]Instances of severe hypoglycemia.
[b]Days during a patient stay on which an antidiabetic agent was ordered.
[c]Cases per 1,000 at-risk patient-days.
[d]Not applicable or not calculated.
[e]Monthly data for the baseline year of 2009 were unavailable for this facility, so preimplementation data were for January–June 2010.

dividual facilities ranging from 66% to 100%.

Figure 1 clearly shows an overall pattern of decline in the occurrence of severe hypoglycemia events among at-risk patients at BJC facilities; the slope of the fitted regression line indicated that the rates of hypoglycemia declined, on average, by 0.08 (95% confidence interval, 0.09–0.07) event per 1000 at-risk patient days per month ($p < 0.01$, $r^2 = 0.85$). The calculated rate reduction and slope estimates were unchanged when the two community hospitals with imputed baseline values were excluded from the analysis.

Discussion

By identifying all severe hypoglycemia events, collecting causative factors for each event, and implementing customized, evidence-based interventions, BJC reduced severe hypoglycemia events by 80% in five years. Across BJC's 2000-bed hospital system, nearly five severe hypoglycemia events per day were identified during a six-month baseline period prior to the hypoglycemia initiative; by comparison, with similar patient-days, the count during the first six months of 2014 was one event per day. The automated surveillance program identified a hidden epidemic of severe hypoglycemia at our hospitals. By establishing a multidisciplinary task force, gaining leadership support at all levels, and leveraging a wide array of system resources, BJC improved patient outcomes while aligning processes to sustain improved hypoglycemia event reduction in all of its 11 hospitals. Notably, our approach made efficient use of current hospital resources while leveraging a very diverse group of employees, including pharmacists, certified diabetes educators, clinical nurse specialists, endocrinologists, dieticians, epidemiologists, and informatics specialists.

This developed and implemented process is consistent with other published initiatives as well as clinical practice recommendations. The creation of our Hypoglycemia Task Force is in line with current recommendations, including an ASHP Foundation expert consensus panel's recommendation that all hospitals develop "protocol-driven and evidence-based order sets that permit prescribing of complex insulin regimens."[15] The early steps taken by the BJC task force included modifying the antidiabetic medication order sets within each hospital based on current evidence.[16] Pasala and colleagues[17] recently reported developing a similar inpatient hypoglycemia committee that investigated all severe hypoglycemia events, developed a treatment protocol, revised insulin order sets, and educated physicians; results of that initiative were not enumerated. Cobaugh and colleagues[15] recognized the importance of retrospective analyses of hospitalwide data to identify the root causes of severe hypoglycemia and enhance insulin-use safety in hospitals. Our process included many recommended strategies, such as nurse-driven hypoglycemia protocols for correction of blood glucose concentrations of <70 mg/dL to prevent mild events from deteriorating into severe events and creating multidisciplinary committees to evaluate and improve current hospital procedures.[18]

Two factors were perceived to be crucial to the successful implementation of this process at multiple sites. First, a valid method of event identification was required in order to garner extensive buy-in from senior leadership. This support led to increased awareness at all levels of leadership and was crucial throughout the effort to sustain resources for the hypoglycemia reduction project. Second, the systematic collection of data on causative factors led to each hospital making local and system-level changes that decreased severe hypoglycemia events. In fact, all of the interventions implemented after the foundational interventions were informed by the systematic collection of those data. This step provided many benefits, including greatly reducing the pool of candidate interventions, thereby allowing prioritization of the projects selected for implementation. Enumerating the causes helped to foster acceptance of the initiative by local staff and managers, as well as the BJC executive leadership. Also, continuously tracking causative factors enabled us to see the effect of our interventions on specific problems, further increasing leadership and staff buy-in.

While our process changes resulted in consistent improvements over time, there are some important limitations to their application in other hospital settings. First, it is possible that severe hypoglycemia events were undercounted, as the task force determined that the event identification criteria should exclude measured blood glucose concentrations of <15 mg/dL; this decision was made because an internal audit found that in most cases such values indicated a "false-positive" result that was typically followed by a much higher glucose value, suggesting an error with the first reading. Second, we could not estimate either the costs of or the cost savings attributable to the implementation; however, only existing staff and resources were used in the initiative. Lastly, some of the intervention components may not be replicable in hospitals without the capacity to customize and use extensive automation. However, implementing these interventions manually may be an option for such hospitals given that initially we were successful in manually collecting data on causative factors and creating dashboards using widely available spreadsheet software. Also, while the use of custom automated tools streamlined our interventions, the logic for these tools is available and can likely be adapted to various hospital clinical decision support platforms.

While the BJC hypoglycemia reduction effort was coordinated at a system level, one of the great strengths of the approach was its generalizability to diverse hospital settings. First, individual hospitals used self-identified causative-factor data to prioritize mitigation efforts, even among individual nursing units. Second, our interventions were based on foundational best practices found in the literature or stemmed from successful strategies within our hospital system. Third, the processes described were successfully implemented and shown to be effective in reducing severe hypoglycemia in a variety of hospital types with diverse patient populations, from large urban academic hospitals to small, rural critical access hospitals.

Most importantly, the same processes and tools applied in the BJC initiative to reduce severe hypoglycemia events can be used to reduce other ADEs. At BJC, the lessons learned are now being applied to reduce other prevalent ADEs in BJC facilities: severe hyperglycemia and diabetic ketoacidosis. The same process is being followed, including the formation of a multidisciplinary task force composed of frontline clinicians, creation of dashboard reports, collection of data on causative factors, implementation of informed interventions, and continuous dissemination of knowledge through an internal website.

Our BJC Hypoglycemia Task Force reduced severe hypoglycemia events markedly by adopting an innovative approach to identify harm, create dashboards, and identify causative factors, followed by implementation of systemwide and local interventions informed by those data. We encourage other hospitals and health systems to adopt and implement the HEAT and begin systematically collecting and sharing information on causative factors; this step will allow them to effectively identify interventions likely to have the greatest impact on their patients. Furthermore, we recommend that hospitals adopt the metric used by BJC (or another simple method) to identify severe hypoglycemia events, as this was critical both to gaining support and tracking improvements. Adopting this approach of continuously monitoring both events and causative factors and creating a multidisciplinary task force will provide a sustainable method of efficiently directing future interventions to improve patient care and safety.

Conclusion

A multifaceted, evidence-based, data-driven approach enabled a large healthcare system to markedly reduce the frequency of severe hypoglycemia events.

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