By Joelle D. Hargraves, RN, DNP, APN, CCRN, CCNS

**Background** Acute hyperglycemia following cardiac surgery increases the risk of deep sternal wound infection, significant early morbidity, and mortality. Insulin infusion protocols that target tight glycemic control to treat hyperglycemia have been linked to hypoglycemia and increased mortality. Recently published studies examining glycemic control in critical illness and clinical practice guidelines from professional organizations support moderate glycemic control.

**Objectives** To measure critical care nurses’ knowledge of glycemic control in cardiac surgery before and after education. To evaluate the safety and effectiveness of an evidence-based insulin infusion protocol targeting moderate glycemic control in cardiac surgery patients.

**Methods** This evidence-based practice change was implemented in the cardiovascular unit in a community teaching hospital. Nurses completed a self-developed questionnaire to measure knowledge of glycemic control. Blood glucose data, collected (retrospectively) from anesthesia end time through 11:59 PM on postoperative day 2, were compared from 2 months before to 2 months after the practice change.

**Results** Nurses’ knowledge (test scores) increased significantly after education (pretest mean = 53.10, SD = 11.75; posttest mean = 79.10, SD = 12.02; \( t_{54} = -8.18, P < .001 \)). Mean blood glucose level after implementation was 148 mg/dL. The incidence of hypoglycemia, 2.09% before and 0.22% after the intervention, was significantly reduced (\( \chi^2 \) [n = 29] = 13.9, \( P < .001 \)). The percentage of blood glucose levels less than 180 mg/dL was 88.30%.

**Conclusions** Increasing nurses’ knowledge of glycemic control and implementing an insulin infusion protocol targeting moderate glycemic control were effective for treating acute hyperglycemia following cardiac surgery with decreased incidence of hypoglycemia. (American Journal of Critical Care. 2014;23:250-258)
Insulin infusion protocols (IIPs) targeting tight glycemic control (80-110 mg/dL), commonly used to treat acute hyperglycemia, have been linked to hypoglycemia (blood glucose level < 70 mg/dL), longer stays in the intensive care unit, and increased patient mortality. Inadequate glycemic control in cardiac surgery patients, whether it be hyperglycemia or hypoglycemia, is a significant issue in patients’ quality of care, linked to a knowledge deficit among health care providers, and with notable financial implications. To effectively and safely manage postoperative acute hyperglycemia, critical care nurses must be knowledgeable about the current evidence on moderate glycemic control in critically ill patients and cardiac surgery patients.

Background/Significance of the Problem

In 2001, researchers in the Leuven Study, a single-center randomized controlled trial (RCT), reported decreased mortality in surgical patients associated with tight control of blood glucose level. Following publication of the Leuven Study, on the basis of the strength of its findings, many critical care units implemented IIPs targeting tight control of blood glucose levels; however, reports of increased episodes of hypoglycemia and concern for the reliability and validity of a single-center study prompted additional clinical trials. Subsequent RCTs and cohort studies evaluated the risks and benefits of tight versus moderate glycemic control in critically ill patients.

In the NICE-SUGAR study (2009), the largest multicenter international RCT, researchers reported fewer incidences of hypoglycemia and lower mortality when an IIP targeting moderate glycemic control (blood glucose < 180 mg/dL) was used, compared with tight glycemic control (blood glucose 81-108 mg/dL) in both medical and surgical patients. In recent meta-analyses examining tight glycemic control in critically ill persons, researchers reported that IIPs targeting tight glycemic control were associated with a high incidence of hypoglycemia and increased risk of death and did not reduce the incidence of bloodstream infections or the need for dialysis.

Considering these findings, several professional organizations issued revised clinical practice guidelines (CPGs). The American Diabetes Association (ADA) currently recommends starting an insulin infusion in most critically ill diabetic and nondiabetic patients for persistent blood glucose levels greater than 180 mg/dL to maintain a blood glucose range of 140 to 180 mg/dL. The ADA also acknowledges that a more stringent goal of 110 to 140 mg/dL may be appropriate in select patients, while monitoring for hypoglycemia. In contrast, patients randomized to tight glycemic control in the NICE-SUGAR study had an insulin infusion initiated for a blood glucose level exceeding 109 mg/dL.

In December 2012, the Society of Critical Care Medicine (SCCM) published “Guidelines for the Management of Blood Glucose in Critical Illness” to address the controversy surrounding IIPs.

Acute hyperglycemia is associated with early morbidity and mortality.
Use of an Insulin Infusion for the Management of Hyperglycemia in Critically Ill Patients.24 Developed by an interprofessional task force of experts (intensivists, nurses, pharmacists, and outcome researchers) following analysis of key clinical trials, the guideline provides suggestions for glycemic control in critical illness, blood glucose monitoring, and quality improvement. The guideline recommends initiating an IIP for a blood glucose level of 150 mg/dL to maintain a blood glucose level less than 180 mg/dL with a goal range of 100 to 150 mg/dL.

Congruent with ADA recommendations, the SCCM advocates using an IIP that has demonstrated efficacy in achieving moderate glycemic control, is safe with a low incidence of hypoglycemia (blood glucose ≤ 70 mg/dL), and minimizes glucose variability. Chen7 in a literature review of intensive insulin therapy in critical illness, found no studies comparing the safety and effectiveness of different published IIPs. Although similarities existed between protocols, goals for blood glucose level varied. Therefore, critical care units should institute a quality improvement program that includes analysis of incidence of hypoglycemia and blood glucose values less than 150 and 180 mg/dL.

Glycemic Control in Cardiac Surgery

In 2009, the Society of Thoracic Surgeons published updated guidelines that recommended maintaining blood glucose levels at less than 180 mg/dL during surgery and immediately postoperatively to prevent complications, especially deep sternal wound infections.19 Following publication of the NICE-SUGAR Study and an updated ADA CPG, several researchers examined tight versus moderate glycemic control in cardiac surgery patients. Findings in cardiac surgery also support moderate glycemic control16-18 (Table 1).

Surgical Care Improvement Project

Initiated in 2002 by the Centers for Medicare and Medicaid Services and the Centers for Disease Control and Prevention, the Surgical Care Improvement Project (SCIP) was designed to improve the safety of care delivered to surgical patients in the United States by reducing the incidence of several postoperative complications, including surgical site infections.20 The SCIP-Inf-4 clinical indicator, aimed at reducing deep sternal wound infections, measures the percentage of cardiac surgery patients with blood glucose levels less than 200 mg/dL at 6 AM on postoperative days 1 and 2. As of January 1, 2014, The SCIP-Inf-4 measure was updated to percentage of cardiac surgery patients with controlled postoperative blood glucose (≤180 mg/dL) in the time frame of 18 to 24 hours after anesthesia end time.22 Besides affecting patients’ outcomes, the Centers for Medicare and Medicaid Services will reduce payments to hospitals that fail to perform on SCIP-Inf-4, a quality measure included in their value-based purchasing initiative.21

Knowledge Deficit Regarding Glycemic Control

The primary problems that guided the design of this evidence-based practice project were (1) an outdated IIP targeting tight glycemic control associated with hypoglycemia and (2) a knowledge deficit among health care providers. Several studies reported a knowledge deficit regarding glycemic management in attending physicians, resident physicians, advanced practice nurses, and registered nurses. In a study exploring attitudes and self-reported barriers to glucose management among midlevel providers, researchers reported that 39% were unsure of the best way to treat hyperglycemia and 22% were unsure when to start an insulin infusion.23 The need for ongoing education on glycemic control in critical illness was identified by the critical care clinical nurse specialist (CNS)/project lead on the basis of a review of the literature, requests for ongoing education on diabetes management from nurses on program evaluations, and compliance with SCIP-Inf-4.

### Table 1: Evidence supporting moderate glycemic control in cardiac surgery

<table>
<thead>
<tr>
<th>Reference and year</th>
<th>Level of evidence</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desai et al,18 2012</td>
<td>Randomized controlled trial</td>
<td>Liberal glycemic control (121-180 mg/dL) in coronary artery bypass graft patients was associated with less hypoglycemia and noninferior compared with strict glycemic control</td>
</tr>
<tr>
<td>Lazar et al,16 2011</td>
<td>Randomized controlled trial</td>
<td>Reported fewer episodes of hypoglycemia and no major differences in adverse events in diabetic cardiac surgery patients maintained on an insulin infusion protocol with a blood glucose goal of 120-180 mg/dL compared with 90-120 mg/dL</td>
</tr>
<tr>
<td>Bhamidipati et al,17 2011</td>
<td>Quasi-experimental study</td>
<td>Retrospective analysis of 4658 cardiac surgery patients found moderate glycemic control (127-179 mg/dL) superior to tight glycemic control (≤126 mg/dL) with lower morbidity and mortality and in patients with known diabetes or peroperative hyperglycemia</td>
</tr>
</tbody>
</table>
Purpose of Project

The purpose of the project to change to evidence-based practice was 2-fold. First, the plan was to revise the outdated IIP that targeted tight glycemic control to be an evidence-based IIP characterized by moderate glycemic control in critically ill patients. The newly revised IIP incorporated the Yale protocol with a blood glucose goal of 120 to 160 mg/dL. The second purpose of this project was to educate critical care nurses about glycemic control in cardiac surgery. Approval was received from the internal institutional review board before implementation of the evidence-based change in the clinical practice setting.

Methods

The Iowa Model of Evidence-based Practice to Promote Quality Care provided the framework for the project. Easily applied to work performed by interdisciplinary teams, the model incorporates problem-solving steps that promote a clinical environment where the most up-to-date clinical evidence and clinical expertise are fused to provide exceptional care for patients with beneficial outcomes for patients. Jean Watson’s Theory of Human Caring provides the framework for our professional nursing practice model. The model, based on the Ten Caritas Processes, focuses on caring, healing, and love (Caritas). Caritas 4 (developing and sustaining a helping-trusting caring relationship) and 6 (creative solution finding) are congruent with glycemic control in cardiac surgery patients.

Setting

The EBP change project was implemented at AtlantiCare Regional Medical Center, an integrated health care system located in southern New Jersey that includes a 567-bed teaching hospital with 2 campuses. Designed to help people achieve optimal health, the health system is home to many specialized health care services including a diabetes center and the Heart Institute—the region’s only full-service cardiac surgery program, where approximately 300 adults have cardiac surgery annually. The cardiovascular unit, a 10-bed critical care unit where the project was implemented, provides care to patients immediately following cardiac surgery.

Clinical Practice Guideline

Interprofessional collaboration is essential in successfully implementing a change to evidence-based practice. Led by the CNS, content experts specializing in nursing, endocrinology, pharmacology, critical care, and cardiac surgery collaborated in the development of the CPG targeting moderate glycemic control in critical illness. Approved by the critical care, diabetes, and pharmacy and therapeutics committees, the revised IIP is an adaptation of the Yale protocol with a blood glucose goal of 120 to 160 mg/dL.

The initial insulin bolus dose and starting infusion rate differ from the Yale protocol. In patients in the Yale medical intensive care unit (baseline blood glucose level, mean 306.1 mg/dL, SD 89.8 mg/dL), the mean time to achieve the target blood glucose level after initiation of the protocol was 8.3 hours. Our initial bolus dose is higher to provide enough insulin coverage to reduce blood glucose levels to the target range in a safe yet rapid manner to achieve compliance with the SCIP-Inf-4 clinical indicator. Before implementation of the outdated IIP that targeted tight control of blood glucose levels, the unit used a protocol with a low initial bolus dose that was initiated when the blood glucose level exceeded 200 mg/dL, which resulted in noncompliance with SCIP-Inf-4. Although compliance improved after implementation of tight control of blood glucose levels, so did the incidence of hypoglycemia associated with an insulin infusion.

The newly revised IIP is initiated when the blood glucose level is 150 mg/dL or higher, as recommended by the Society of Thoracic Surgeons, rather than 180 mg/dL. Maintenance dosing is based on the current blood glucose level, the change in blood glucose level in the past hour, and the current insulin infusion rate (units/h) according to the titration parameters from the Yale protocol. To make it easier for the nurses to follow, the insulin infusion maintenance parameters were formatted into a titration table.

The protocol is initiated when the blood glucose level is ≥150 mg/dL.
A comparison of nurses’ knowledge after education indicated a significant increase.

Data were collected by retrospective review of electronic health records.

Nurses’ Knowledge
The CNS designed a pretest and a posttest to measure nurses’ knowledge of glycemic control in critical illness before and after the educational intervention. Test validity was established by content experts from the diabetes center. Approximately 30 nurses from the cardiovascular unit, regardless of sex, race, age, degree level, or years of experience, were asked to participate in the project. Education on the new CPG was mandatory. However, participation in the anonymous pretest and posttest was voluntary. Nurses from the unit were notified of the mandatory education with the option to participate through an e-mail that included a cover letter. Although the nurses had the option of completing the pretest and posttest electronically by clicking a link included in the e-mail, all but 2 nurses opted for a paper pretest and posttest. Completed pretests and posttests were placed in separate marked envelopes. Nurses participating in the professional nurse clinical ladder who completed the pretest and posttest received a verification form signed by the CNS for 1 ladder point under the innovation category, evidence-based practice subcategory. One nurse from the unit was on medical leave, and 1 nurse chose not to participate in the pretest and posttest.

To increase attendance, the educational offering on glycemic control in cardiac surgery and the newly revised IIP were presented by the CNS in the cardiovascular unit. Scenarios illustrating titration of an insulin infusion according to the new protocol and subsequent blood glucose monitoring were incorporated into a PowerPoint presentation. Each nurse received a copy of the PowerPoint presentation and the newly revised IIP.

Implementation
The CPG was implemented in September 2012. Blood glucose levels were monitored a minimum of every 4 hours immediately after cardiac surgery by bedside point-of-care (POC) testing with the Precision Xceed BG Testing System (Abbott Laboratories) and/or clinical laboratory testing. An insulin infusion was initiated if a blood glucose result was 150 mg/dL or greater.

To facilitate adoption of the new practice, the CNS was available during clinical rounds and by e-mail or phone to answer questions. Insulin infusion worksheets were reviewed to identify and provide concurrent feedback on protocol deviations and to monitor compliance with the SCIP-Inf-4 clinical indicator. Preliminary safety and effectiveness of the revised IIP were assessed by monitoring for hypoglycemia and severe hyperglycemia (blood glucose > 200 mg/dL). Three factors influenced successful implementation of the CPG: interprofessional collaboration during development of the IIP, nurse education before going live, and clinical rounding by the CNS after the intervention with the focus on performance and feedback.

Blood Glucose Data
Blood glucose data were collected by retrospective review of electronic health records by using a self-developed tool on 76 cardiac surgery patients 2 months before and after implementation of the newly revised IIP. Blood glucose data from anesthesia end time through 11:59 PM on postoperative day 2 were retrieved from the laboratory results and insulin view sections of the electronic health record. Data on patients’ age, sex, whether they were diabetic or non-diabetic, and surgical procedure also were collected.

Data Analysis
Test scores and blood glucose data were transferred to an Excel spreadsheet for statistical analysis. Descriptive and inferential statistics were used to compare nurses’ test scores before and after the education and blood glucose levels in cardiac surgery patients before and after the intervention. The intended outcomes of the project included (1) an increase in critical care nurses’ knowledge about glycemic control in cardiac surgery, (2) a reduction in potentially dangerous hypoglycemic episodes in cardiac surgery patients after adoption of a CPG targeting moderate glycemic control, and (3) effective management of acute hyperglycemia with 80% of blood glucose levels at 180 mg/dL or less. The final measure was selected on the basis of the Yale findings that after the target level for blood glucose was reached, 42% of subsequent measurements remained in the target range and 76% were less than 180 mg/dL.

Results
Nurses’ Knowledge of Glycemic Control
Twenty-nine nurses, with a mean of 13.7 years (range, 2-37 years) in nursing and 11.7 years (range, 2 months-30 years) in critical care, completed the pretest with a mean score of 53%. Twenty-seven nurses completed the posttest with a mean score of 79% (Figure 1). A 1-tailed t test, conducted to compare nurses’ knowledge (test scores) before and after education, indicated a significant increase in

4 hours immediately after cardiac surgery by bedside point-of-care (POC) testing with the Precision Xceed BG Testing System (Abbott Laboratories) and/or clinical laboratory testing. An insulin infusion was initiated if a blood glucose result was 150 mg/dL or greater.

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nurses’ knowledge after education (pretest score: mean = 53.10%, SD = 11.75%; posttest score: mean = 79.11%, SD = 12.02%; t_{54} = -8.18, P < .001).

Two questions that measured nurses’ knowledge of hypoglycemia and current ADA guidelines for glycemic control were analyzed independently. The definition of hypoglycemia (correct answer: blood glucose < 70 mg/dL) was selected correctly by 83% of nurses before and 89% after education. Clinically, this finding is important as both the outdated and newly revised CPG instructed nurses to treat hypoglycemia by administering carbohydrates or glucose.

Before the education, no nurse correctly answered the question about the range within which the ADA recommends blood glucose levels in critical illness be maintained (correct answers: 140-180 mg/dL and 110-140 mg/dL in select populations while monitoring for hypoglycemia). Six nurses (21%) selected 1 correct answer before education. After the education, 15% of nurses selected both correct answers, 52% selected 1 correct answer; and 33% answered incorrectly. Although nurses’ knowledge increased significantly, a mean score of 79.1% after the education and analysis of individual questions support ongoing education on moderate glycemic control in critical illness.

**Blood Glucose Levels**

The characteristics of the patients in the group assessed 2 months before the implementation of the CPG targeting moderate glycemic control and the group assessed 2 months after implementation of the CPG are summarized in Table 2. Forty-two patients (88%) were treated with the outdated IIP to control postoperative acute hyperglycemia. The mean number of blood glucose levels per patient from anesthesia end time through 11:59 PM on postoperative day 2 was 34.9.

Two months after implementation of the CPG, 27 patients (96%) were treated with an insulin infusion to control postoperative acute hyperglycemia (Figure 2). In that group, the mean number of blood glucose levels per patient from anesthesia end time through 11:59 PM on postoperative day 2 was 40.0.

A 2-tailed t test was conducted to compare patients’ age in each group. Patients in the preintervention group were significantly younger (mean = 63.29 years, SD = 11.80 years) than patients in the postintervention group (mean = 69.21 years, SD = 10.6 years; t_{42} = -2.18, P = .03). A χ² test was conducted to compare history of diabetes in each group. The percentage of patients with a history of diabetes did not differ between groups (χ² [n = 76] = 0.51, P = .47).

Before implementation of the revised IIP, the mean blood glucose level during insulin infusion therapy was 122 mg/dL; after implementation, it was 148 mg/dL. Table 3 compares blood glucose levels before and after implementation of the CPG.

A 2-tailed t test was conducted to compare blood glucose levels before and after the interventions. Blood glucose levels differed significantly (t_{2191} = -17.70, P < .001) from before (mean = 122.53 mg/dL, SD = 34.40 mg/dL) to after (mean = 148.18 mg/dL, SD = 32.06 mg/dL) implementation of the revised IIP. The mean time to achieve the target range for blood glucose level (120-160 mg/dL)
The incidence of hypoglycemia (blood glucose < 70 mg/dL) associated with the outdated IIP was 2.09% (27/1291). Eighteen of 48 patients (37.5%) experienced at least 1 hypoglycemic episode, and several patients experienced multiple episodes of hypoglycemia. Eleven additional patients had at least 1 blood glucose level between 70 and 79 mg/dL (Table 3). The incidence of hypoglycemia associated with the revised IIP was 0.22% (2/902). The incidence of hypoglycemia after the intervention was significantly lower than the incidence before implementation of the evidence-based IIP ($\chi^2 \ [n = 29] = 13.9$, $P < .001$).

The new CPG instructed nurses to use POC testing to measure blood glucose levels at the bedside at the same time as the morning blood samples were collected. This instruction was added to the CPG to avoid noncompliance with the SCIP-Inf-4 clinical indicator. Nurses performed a POC measurement of blood glucose level when the morning blood samples were collected 70% of the time (39/56 instances). Nurses were notified via e-mail of the 70% compliance. The e-mail explained the importance of the measure, as a POC blood glucose measurement of 199 mg/dL prompted a nurse to increase the insulin infusion rather than waiting approximately 1 hour for the morning blood work results, preventing a failure to comply with the SCIP-Inf-4 clinical indicator. To evaluate the accuracy of POC blood glucose measurements compared with serum levels of blood glucose, a paired $t$ test was conducted. Results indicate no significant difference ($t_{76} = -0.01$, $P = .09$ between POC (mean = 138.4 mg/dL, SD = 33.8 mg/dL) and serum (mean = 136.5 mg/dL, SD = 31.8 mg/dL) measurements of blood glucose level.

**Limitations**

The evidence-based change in practice was implemented at a single center. Although the CNS indicated in writing on the pretest that some questions may have more than 1 answer and verbally told nurses the same instructions, some nurses may have had difficulty with multiple select questions on the pretest and posttest. Two nurses did not complete or return the posttest after the education because they were called away to receive a patient from the operating room.

Although blood glucose data were collected on all cardiac surgery patients 2 months before ($n = 48$) and 2 months after the intervention ($n = 28$), the preintervention group was larger. The greater number of participants before the intervention was most likely related to an increase in the general population.
Discussion

This evidence-based practice change project was effective because critical care nurses’ knowledge of glycemic control in critical illness increased. Ongoing education is needed to continually improve critical care nurses’ knowledge of glycemic control in critically ill patients, including cardiac surgery patients. A learning curve associated with how to follow the insulin infusion titration table was noted. Several protocol deviations were identified when the insulin infusion was not decreased for a blood glucose level of 100 to 119 mg/dL, which affected the percentage of blood glucose measurements between 120 and 160 mg/dL. Red education was provided to correct the practice, emphasizing the importance of preventing hypoglycemia.

To effectively and safely manage postoperative acute hyperglycemia in cardiac surgery patients, interprofessional health care providers must develop CPGs based on the latest evidence, educate colleagues, use patient care technologies for blood glucose monitoring, and information technology for communication along the continuum of care. Continuous subcutaneous or intravascular blood glucose monitoring, currently under investigation in humans and animal models, respectively, may potentially benefit patients by reducing variability in blood glucose levels (also associated with poor patient outcomes), hypoglycemia, and decreasing painful finger sticks due to POC testing of blood glucose levels, while optimizing control of blood glucose levels. 

The change to evidence-based practice was successful because of interprofessional collaboration during all phases of the project. Nurses, cardiac surgery patients, and the institution benefited from this change. Critical care nurses’ knowledge of glycemic control in cardiac surgery was significantly increased. Cardiac surgery patients benefited because the evidence-based IIP was safe (the incidence of hypoglycemia was significantly reduced) and effective (mean blood glucose level was 148 mg/dL). No failures to comply with SCIP-Inf-4 occurred during the 7 months immediately following implementation of the newly revised CPG (Figure 3).

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